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Refractory Experience in Circulating Fluidized Bed Combustors, Task 7

Final Report

R.Q. Vincent

November 1989

Work Performed Under Contract No.: DE-AC21-85MC22012

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Fluidized Bed Technologies, Inc.
Chattanooga, Tennessee

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November 1989

ABSTRACT

This report describes the results of an investigation into the status of the design and selection of refractory materials for coal-fueled circulating fluidized-bed combustors. The survey concentrated on operating units in the United States manufactured by six different boiler vendors: Babcock and Wilcox, Combustion Engineering, Foster Wheeler, Keeler Dorr-Oliver, Pyropower, and Riley Stoker. Information was obtained from the boiler vendors, refractory suppliers and installers, and the owners/operators of over forty units. This work is in support of DOE's Clean Coal Technology program, which includes circulating fluidized-bed technology as one of the selected concepts being evaluated.

ACKNOWLEDGEMENTS

The contents of this report would not be possible without the cooperation and input received from the various boiler vendors, refractory suppliers and installers, and owner/operators. The time taken out by these individuals to answer questions, provide reports, and allow site visits is appreciated. The author wishes to thank Mr. Joseph E. Macko, DOE Program Manager, for his guidance and technical review of the report.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is actively involved in the implementation of a Clean Coal Technology (CCT) program. Two rounds of solicitation and selection have occurred with the third solicitation currently out for proposals. One of the key technologies that has already been identified and selected under this program is fluidized-bed combustion and, in particular, atmospheric circulating fluidized-bed (CFB) combustion.

The DOE has selected proposals from three CFB facilities. The Colorado-Ute Electric Association (CUEA) CFB at Nucla, Colorado was selected under the first round CCT solicitation. The CUEA project involves the replacement of three stoker fired units with a Pyropower CFB. In addition, the plant was upgraded from 36-Mw to 110-Mw with the addition of a new 74-Mw turbine generator. Southwestern Public Service Company (SPS) was selected from the second round CCT solicitation. The SPS project involves the repowering of an existing 250 MW (nominal) steam turbine-generator at the SPS Nichols Station Unit 3 in Amarillo, Texas with a Combustion Engineering (CE) CFB. The project represents about a 2 to 1 scaleup of the Texas-New Mexico Power (TNP) 150 MW CE CFB plant currently under construction. The TNP design represents about a 2 to 1 scaleup of the CE CFB at the Scott Paper Company in Chester, Pennsylvania. A third CFB project has recently been added to the list of selected projects under the DOE CCT program. The city of Tallahassee was chosen, as an alternate under Round 1, for repowering their Arvah B. Hopkins Station Unit 2 with a CFB. The boiler vendor had not been identified at the time this report was written.

A major concern of these projects is the performance of the refractory. Many refractory designs, products, and installation methods are currently being used in the industry. This is symptomatic of the uncertainty in the design requirements for this system. CUEA has already experienced refractory problems which have resulted in forced outage time. Several other units are rumored to be experiencing refractory problems and requiring significant outage time to make repairs and modifications.

2.0 OBJECTIVE

The objective of this task was to develop a benchmark as to where the design and selection of refractory materials for use in CFB systems exists today. There are close to 40 operating CFB units in the United States with varying amounts of operating time and experience. Most of these units are small in comparison to the Colorado Ute, SPS, and Tallahassee projects; nevertheless, they operate with similar temperatures and most operate with coal and limestone. The objective of this task was carried out by:

- identifying and summarizing refractory problems experienced with operating domestic CFB's,
- identifying CFB's that did not experience problems and explaining reasons why as compared to those that did (e.g. design, installation, operating differences, process upsets, etc.),
- providing causes for the problems and recommendations/fixes made to eliminate the refractory problems identified,
- and determining for each CFB the brand and type of refractory, the installer, method of installation, curing process, and whether the refractory was field or factory installed.

Based on the information gained from this task, general recommendations have been made for the design, installation and operating requirements for future CFB refractory systems.

3.0 SCOPE

To maximize the usefulness of this task in supporting DOE and the Clean Coal Technology program, the survey concentrated on CFB plants which, (1) have an appreciable amount of operating experience and (2) operate on coal (bituminous, subbituminous, anthracite, and coal waste products such as anthracite culm, and gob). Six major vendors were identified: Babcock and Wilcox, Combustion Engineering (Lurgi), Foster Wheeler, Keeler Dorr-Oliver, Pyropower, and Riley Stoker. Tables 1 through 6 list the units which these vendors have operating, under construction, or planned. A total of 31 CFB units was researched. The information contained in this report is based on discussions and information provided by the owners/operators of these units, the boiler vendors, and the refractory vendors. Table 7 is a listing of the type of information that was solicited from these sources.

TABLE 1

BABCOCK & WILCOX DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	STEAM CONDITIONS °F	DATE	FUEL
ENERGY FACTORS FEATHER RIVER PROJECT	MARYSVILLE, CA	164	1450	955	1986	WOOD
ULTRAPOWER MAINE POWER SERVICES	W. ENFIELD, ME	220	1450	955	1/87	WOOD
ULTRAPOWER MAINE POWER SERVICES	JONESBORO, ME	220	1450	955	1987	WOOD
LA COUNTY SANITATION DISTRICT	CARSON, CA	3 X 48	1125	830	1988	SEW
LAUHOFF GRAIN	DANVILLE, IL	226	1750	960	8/89	COAL
EBENSBURG, POWER	EBENSBURG, PA	465	1550	955	1990	COAL

TABLE 2

COMBUSTION ENGINEERING/LURGI DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	°F	DATE	FUEL
SCOTT PAPER	CHESTER, PA	650	1450	950	5/86	CULM
NEW BRUNSWICK POWER	CHATHAM, CN	210	900	900	7/86	COAL
AMERICAN LIGNITE PROD.	IONE, CA	146	1250	950	4/87	LIGN
WESTWOOD ENERGY	JOLIETT, PA	271	925	900	6/87	CULM
ULTRASYSTEMS	FRESNO, CA	220	1250	950	7/88	WOOD
ULTRASYSTEMS	ROCKLIN, CA	220	1755	955	5/89	WOOD
NORTHEASTERN POWER CO.	KLINE TOWNSHIP, PA	425	1800	1000	5/89	CULM
SCHUYLKILL ENERGY	MAHONOY, PA	825	1500	955	6/89	CULM
AES THAMES	MONTVILLE, CT	2 X 679	1972	1005	8/89	COAL
TEXAS-NEW MEXICO POWER COMPANY	ROBERTSON CITY, TX	1025 1025	1990 1990	1005 1005	1/90 1/91	LIGN LIGN
ULTRASYSTEMS	POSO, CA JASMINE, CA	290 290	1650 1650	950 950	[illegible]/89 7/89	COAL COAL
AES SHADY POINT	PANAMA, OK	4 X 570	1970	1005	3/90	COAL
SOUTHWESTERN PUBLIC SERVICE CO.	AMARILLO, TX	1656	1300	1000	1993	COAL
COLMAC ASSOCIATES	MECA, CA	2 X 220	1250	950	1992	WOOD

TABLE 3

FOSTER WHEELER DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS		DATE	FUEL
			PSI	°F		
FORT HOWARD PAPER	RINCON, GA	320	1500	950	4/88	COAL
MT. CARMEL COGENERATION	MT. CARMEL, PA	2 X 192	925	910	11/89	CULM
PURDUE UNIVERSITY	PURDUE, IN	200	650	825	7/90	COAL
CITY OF MANITOWOC	MANITOWOC, WI	200	975	905	4/91	COAL

TABLE 4

KEELER DORR-OLIVER DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	°F	DATE	FUEL
ARCHER DANIEL MIDLAND	DECATUR, IL	5 X 425	1310	900	2-12/87	COAL
ARCHER DANIEL MIDLAND	CEDAR RAPIDS, IA	3 X 477	1310	900	11/88	COAL
FRACKVILLE COGENERATION	FRACKVILLE, PA	410	1310	955	10/88	CULM
MONTANA ONE	COLSTRIP, MT	355	1300	955	1989	GOB
TENNESSEE EASTMAN	KINGSPORT, TN					COAL

TABLE 5

PYROPOWER DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	°F	DATE	FUEL
GULF OIL	BAKERSFIELD, CA	50	2500	670	1983	COAL
CENTRAL SOYA	CHATTANOOGA, TN	88	190	384	4/85	COAL
CALMAT-CALIFORNIA	COLTON, CA	190	650	825	4/85	COAL
B. F. GOODRICH	HENRY, IL	125	500	470	10/85	COAL
GENERAL MOTORS (ARGONAUT)	PONTIAC, MI	300	1460	955	1986	COAL
COLORAD-UTE	NUCLA, CO	910	1510	1005	1987	COAL
IOWA STATE UNIVERSITY	AMES, IA	2 X 170	410	750	9/88	COAL
AIR PRODUCTS	STOCKTON, CA	500	1550	955	2/88	COAL
GILBERTON POWER CO.	WEST MAHONEY, PA	2 X 355	1500	955	3/88	CULM
UNIV. OF NORTHERN IOWA	CEDAR FALLS, IA	105	675	750	1990	COAL
MT. POSO	BAKERSFIELD, CA	500	1550	955	4/89	COAL
FORT DRUM	FORT DRUM, NY	3 X 175	1525	950	6/89	COAL
P. H. GLATFELTER	SPRING GROVE, PA	400	1500	950	7/89	COAL
SOUTHEAST PAPER	DUBLIN, GA	400	1300	950	1989	COAL
UNIV. OF NORTH CAROLINA	CHAPEL HILL, NC	2 X 250	1300	900	1989	COAL
RUMFORD	RUMFORD, ME	2 X 415	1300	955	1990	COAL
KERR-MCGHEE	TRONA, CA	910	1525	1005	1990	COAL

TABLE 5

PYROPOWER DOMESTIC CFB UNITS (CONT.)

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	°F	DATE	FUEL
NORTH BRANCH	GRANT CO., WV	2 X 395	1500	955	1991	BIT WASTE
UDG	NIAGRA FALLS, NY	468	1500	955	1991	COAL/TIRES
CAMBRIA	EBENSBURG, PA	2 X 395	1550	955	1990	GOB
MORGANTOWN	MORGANTOWN, WV	2 X 280	1500	955	1991	GOB
GRANTTOWN	GRANTTOWN, WV	2 X 400	1365	955	1991	GOB
AES-BARBERSPOINT	BARBERSPOINT, HW	2 X 664	1972	1005	1991	COAL
NOVA SCOTIA POWER CORP.	NOVA SCOTIA, CN	1043	1854	1005	1993	COAL

TABLE 6

RILEY STOKER DOMESTIC CFB UNITS

PLANT	LOCATION	KPPH	STEAM CONDITIONS PSI	°F	DATE	FUEL
GENERAL MOTORS	FORT WAYNE, IN	2 X 150	700	755	3/87	COAL
UNIV. OF MISSOURI	COLUMBIA, MO	200	950	850	2/88	COAL
UNIV. OF IOWA	IOWA CITY, IA	170	475	760	9/88	COAL
A. E. STALEY	DECATUR, IL	2 X 375	1265	955	10/88	COAL
ARCHBALD POWER CORP.	SCRANTON, PA	200	1335	955	1989	COAL
CITY OF WYANDOTTE	WYANDOTTE, MI	250	875	900	4/90	COAL

TABLE 7
SURVEY INFORMATION

PLANT INFORMATION

- SIZE (MW, KPPH, DIMENSIONS)
- FUEL, SORBENT/BED MATERIAL
- BOILER VENDOR
- HOURS OF OPERATION
- OPERATING CONDITIONS (VELOCITY, TEMPERATURE, CYCLING, BASE LOAD, ...)

REFRACTORY INFORMATION

- BRAND/TYPE
- INSTALLATION METHOD (GUNITE, CAST, RAM, BRICK)
- ANCHOR REQUIREMENTS (TEMPERATURE, TIME)
- PROPERTIES (SHRINKAGE, THERMAL CONDUCTIVITY, ABRASION LOSS, STRENGTH, DENSITY)
- Q.C. PROGRAM
- COST/SCHEDULE
- THICKNESS

EXPERIENCE

- WHAT WORKED/WHAT DIDN'T
- PROCESS UPSETS
- RESULTING PROBLEMS
- REPAIRS/FIXES
- SERVICE LIFE
- RECOMMENDATIONS
- ANNUAL MAINTENANCE COST

4.0 CFB DESCRIPTION AND REFRACTORY REQUIREMENTS

Fluidized-bed combustion of coal in the United States has seen a shift from bubbling bed units to circulating bed units with the potential for better combustion efficiency and lower pollution (SO_2 and NO_x) emissions. Bubbling beds, by design, operate with relatively low velocities (4-12 ft/sec) and low recycle ratios (0-5 lbs recycle/lb coal). At these conditions, the need for refractories is minimal. CFB units, on the other hand, are dependent on reliable refractory service for three primary reasons: (1) combustion and emission performance are dependent on high recycle ratios (typically 40 - 50 lbs of solids recycled per lb of coal fed) which increases the solids loading in the system and thus the erosion/abrasion potential, (2) performance is dependent on higher velocities (15-30 ft/sec) to entrain and "circulate" the larger amounts of solids which also increases the erosion/abrasion potential, and (3) CFB's are operated with staged combustion air to improve emissions (primarily NO_x) which requires that a portion of the unit be operated at substoichiometric conditions. To operate in this manner, CFB's must have refractory designs which protect uncooled surfaces from overheating while minimizing heat loss in the uncooled areas. CFB refractory designs must also protect the components from the high velocity, high dust loading abrasive/erosive environment, and, in addition, the refractory design must also protect metallic components that are located in substoichiometric, reducing environments.

Figures 1 through 6 are typical of the CFB configurations that are provided by the six boiler vendors. CFB components which require refractory include: combustor, cyclone, dip leg or downcomer, loop seal or seal valve, bottom ash cooler (optional), external heat exchanger (optional), and windbox.

Combustors require refractory in the lower section, just above the distributor plate, to protect the combustor walls from the turbulent mixing of fuel, sorbent, and recycle material. One vendor's (Riley Stoker) design also maintains a dense bed of large inert material. The lower region in all CFB's is run substoichiometric and refractories are required to shield the metallic components from this potentially corrosive environment. Depending on the design, the floor of the unit may have a refractory layer. The upper section of the combustors are waterwall lined with refractory used at

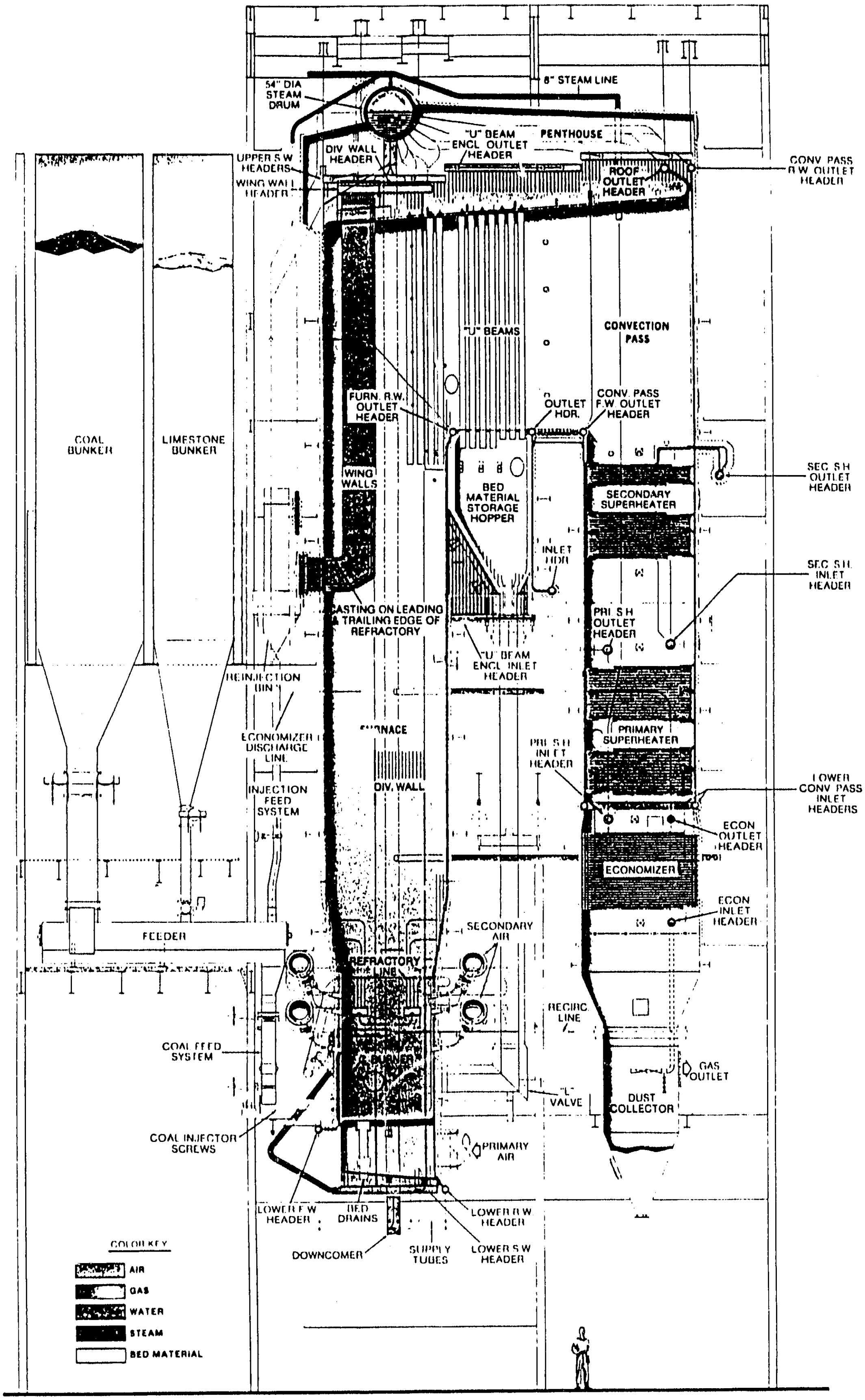
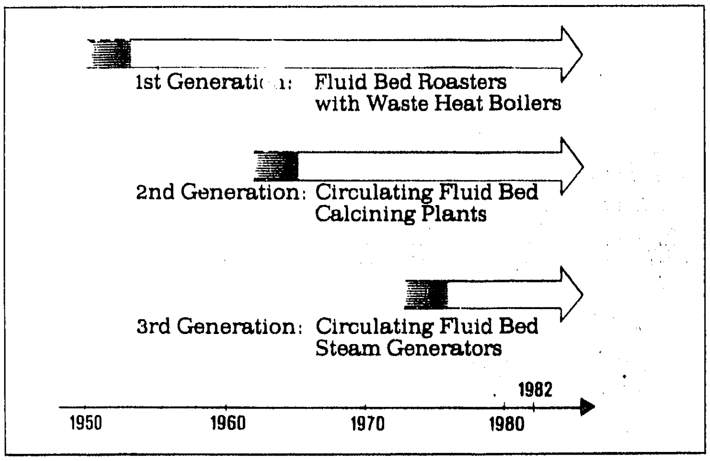
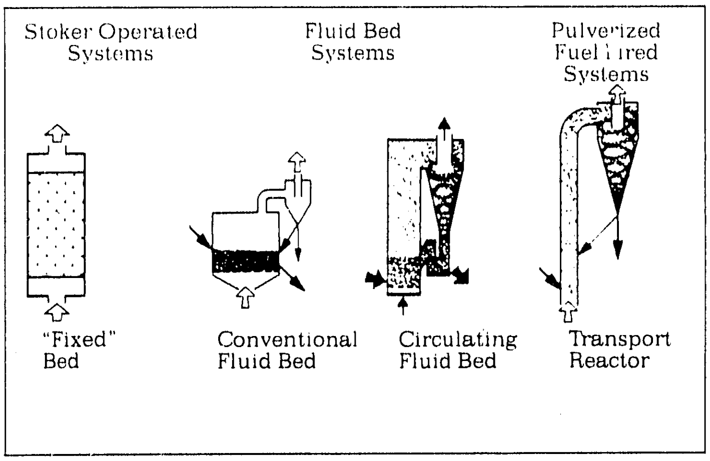


FIGURE 1 - BABCOCK & WILCOX CONFIGURATION





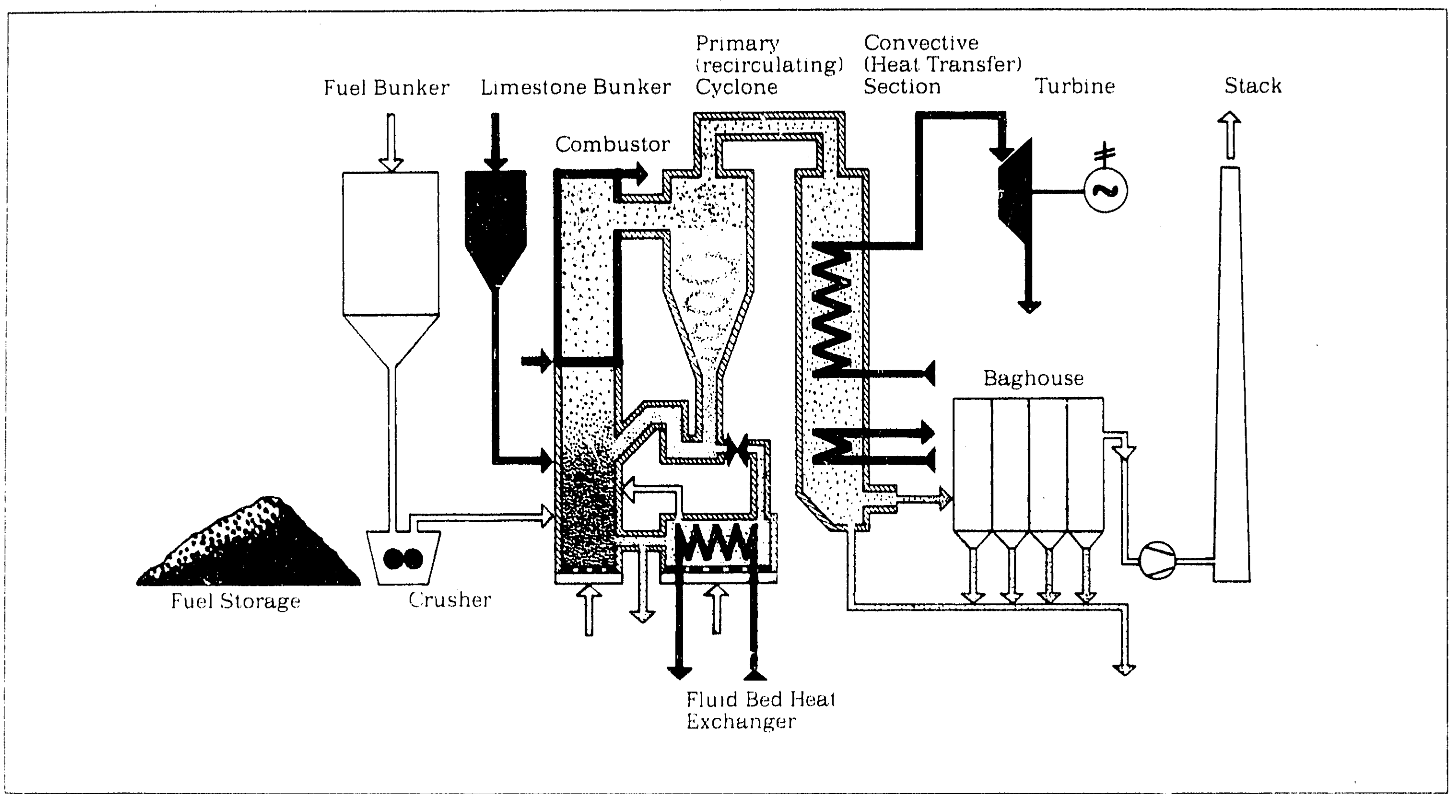


FIGURE 2 - COMBUSTION ENGINEERING CONFIGURATION

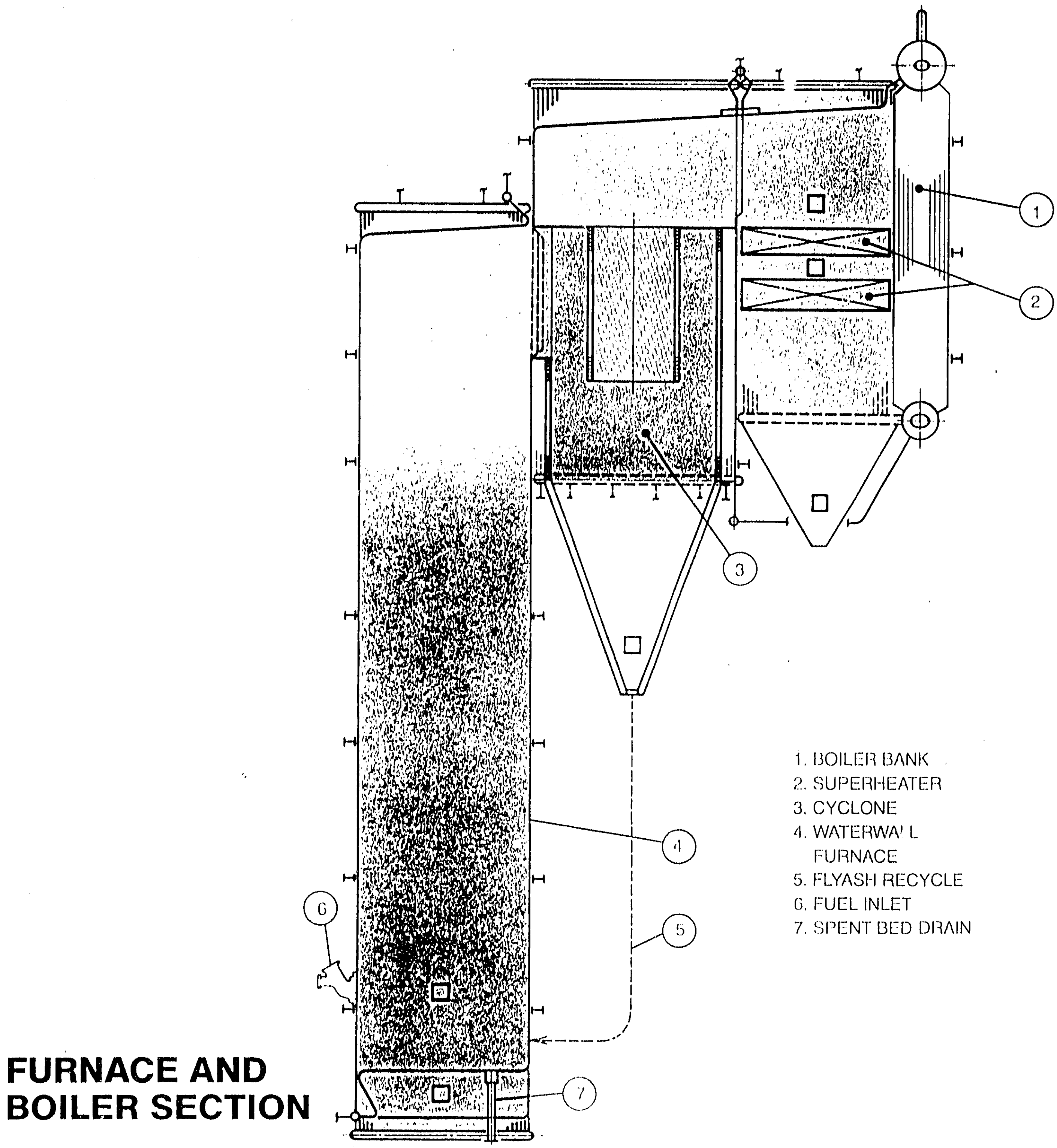
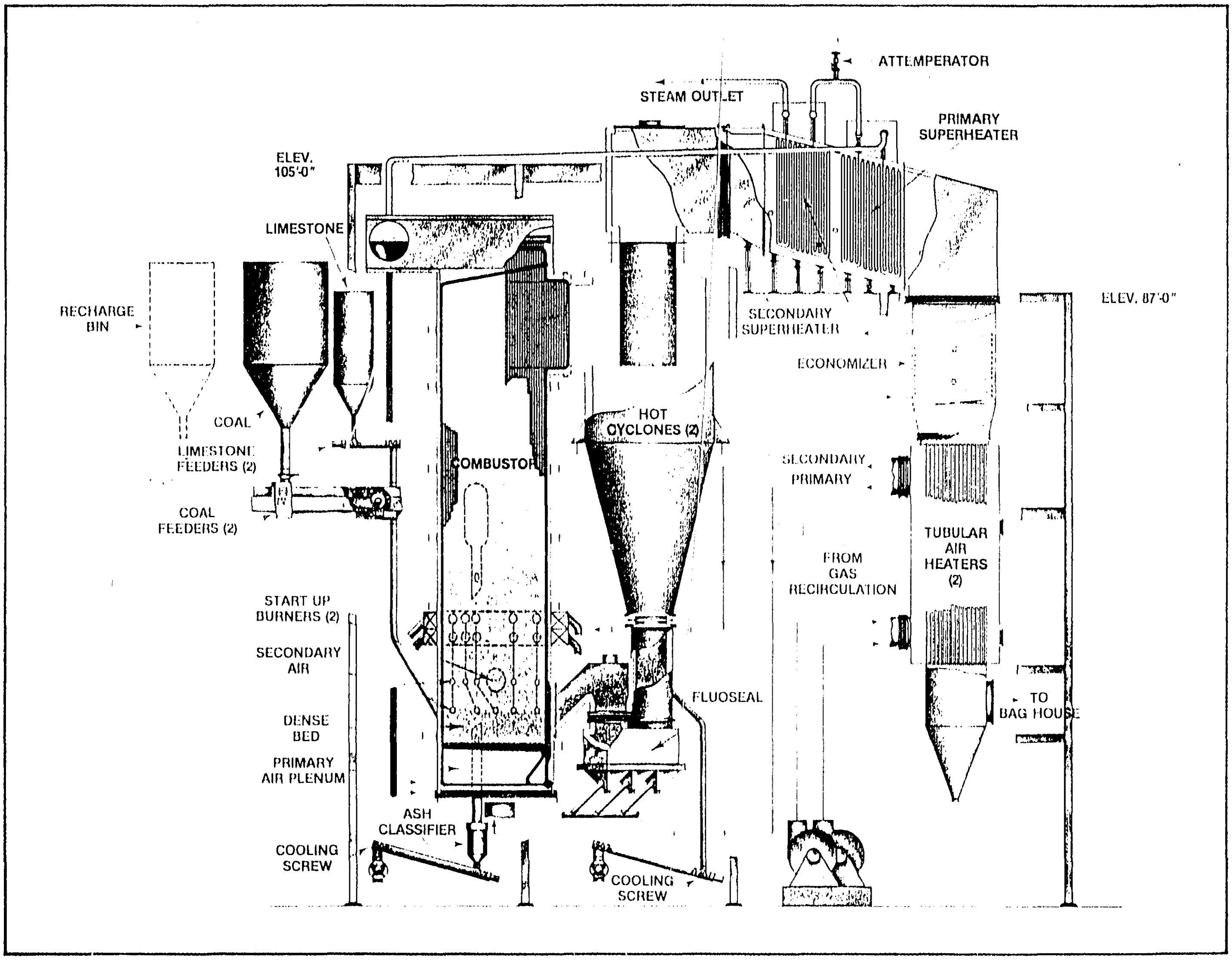


FIGURE 3 - FOSTER WHEELER CONFIGURATION

Keeler/Dorr-Oliver Model HCFS



Configuration for high pressure, high-temperature generation

FIGURE 4 - KEELER/DORR-OLIVER CONFIGURATION

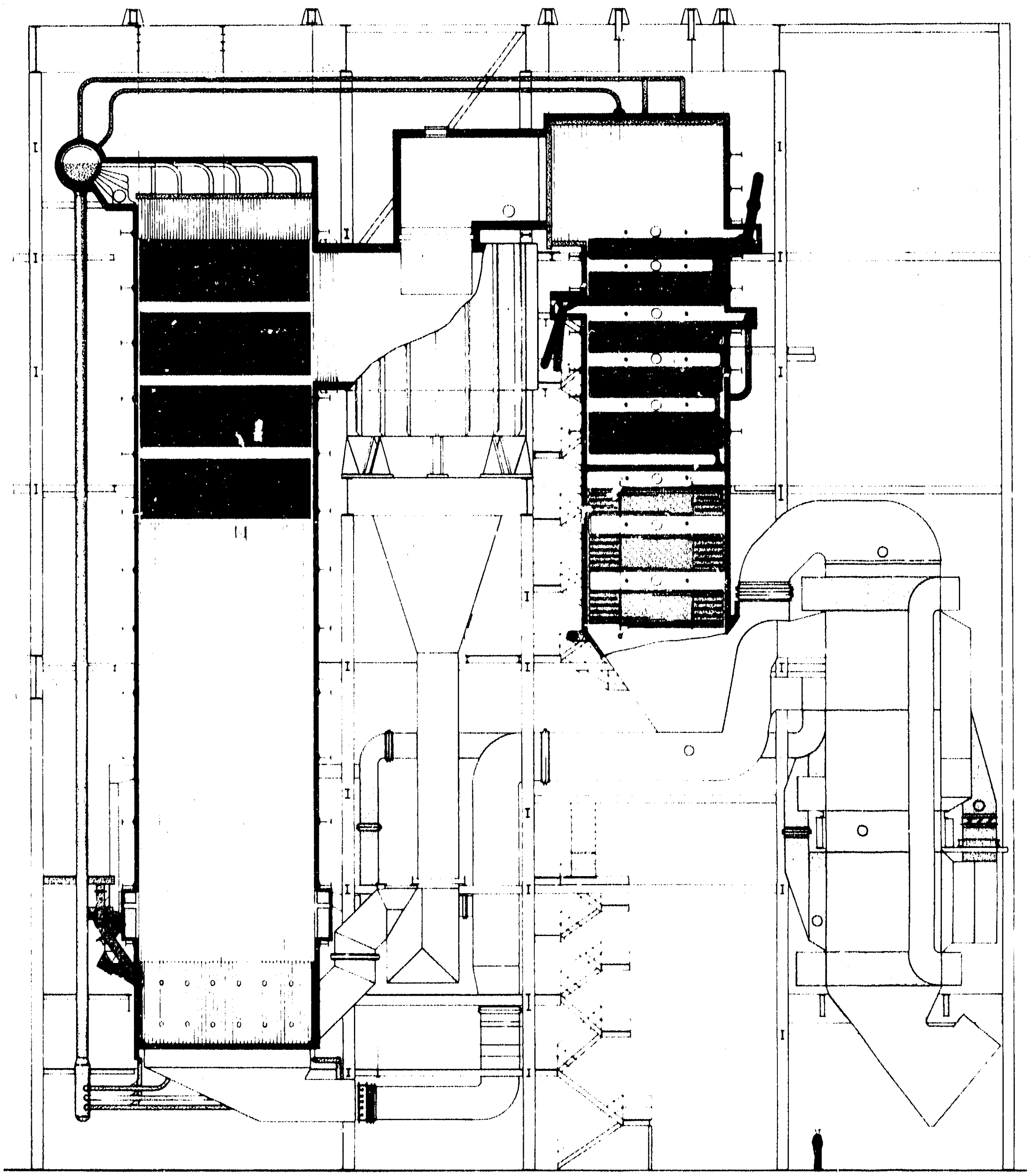


FIGURE 5 - PYROPOWER CONFIGURATION

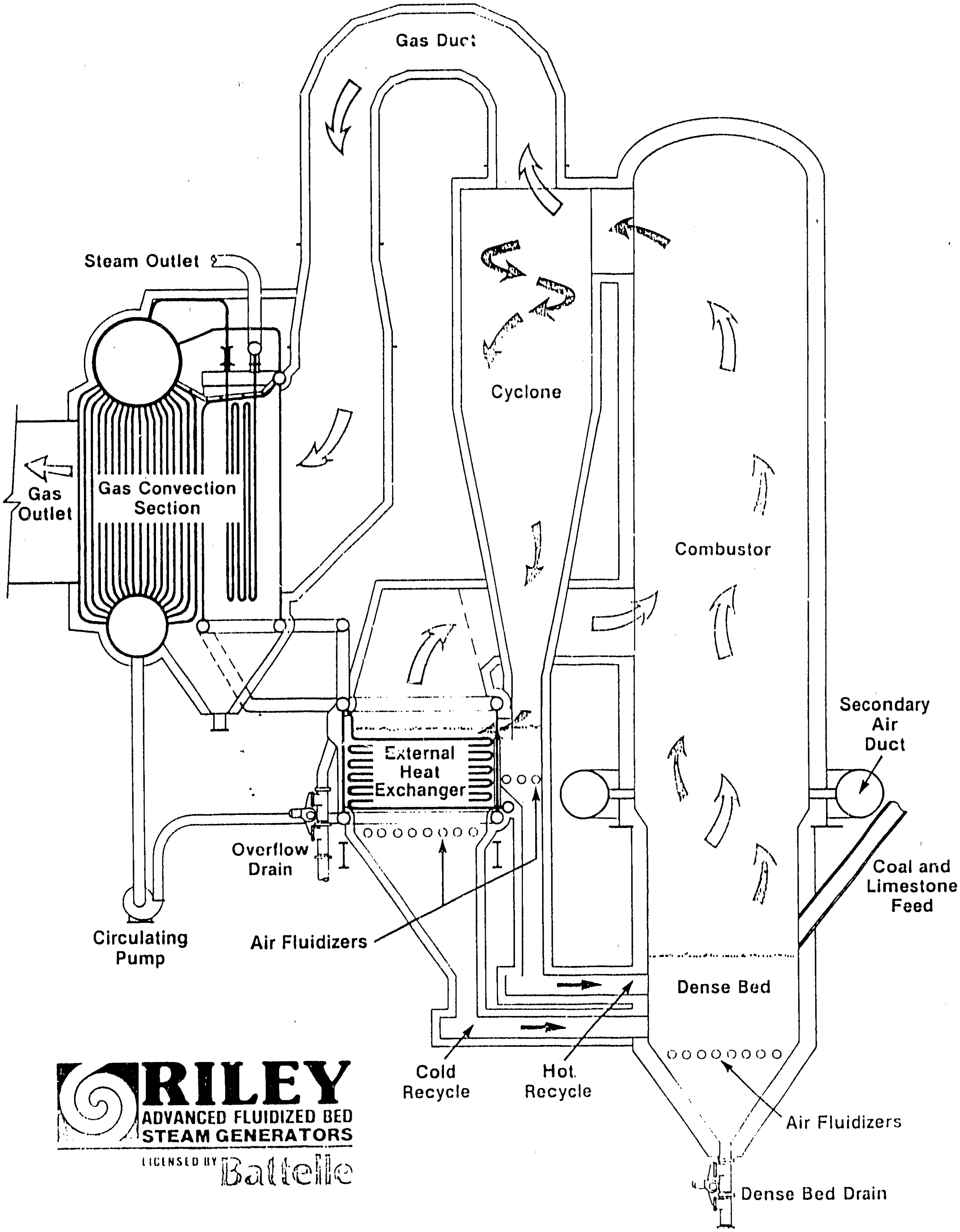


FIGURE 6 - RILEY STOKER CONFIGURATION

the combustor exit to the cyclone and in some cases the combustor roof as well.

The cyclones operate at high velocities to produce the high collection efficiencies required to maintain high recycle ratios (solids loading). Babcock and Wilcox does not utilize cyclones but rather uses a U-Beam separator, which does not require refractory protection except for the casing around the separator and the collection hopper. The discussion on cyclone refractory experience is divided into the following sections: gas/solids inlet, cyclone barrel and roof, cyclone cone (solids outlet), and cyclone outlet (gas outlet). Refractories must withstand high velocities, high dust loadings, and high temperatures. The cyclones provide the severest test for refractories and hence have experienced more problems.

From the solids outlet of the collection device solids travel to the pressure seal device through a dip leg or downcomer. This head of material also assists in providing a pressure seal and the driving force for recycle of solids back to the combustor. Refractory requirements in this region are primarily for insulation purposes. Hard facing is required but velocities are relatively low.

The pressure seal/control device acts as the pressure seal between the positive pressure in the lower combustor and the negative pressure in the cyclones. Solids are collected from the downcomers and reinjected into the lower combustor. Various types of devices, called by different names, are used including loop seals, J-valves, L-valves, seal pots, and Fluoseals, to name a few. All serve a similar function. These devices are second only to the cyclones for experiencing refractory problems. The redirection of the solids requires an acceleration of the material and subjects the seal device to thermal expansion. Several of the seal devices have had failures to the metal casing due to these thermal stresses.

Two of the vendors (Combustion Engineering and Riley Stoker) utilize a separate vessel, referred to as an external heat exchanger (EHE), to perform additional heat duty. The EHE collects solids from the cyclones and flows a portion of this material over evaporator, superheat, and/or reheat surfacing in a 'benign' low velocity bubbling bed. Both vendors also have provisions for directly reinjecting hot solids back to the combustor. Refractory needs in this area are primarily for insulating purposes; however, both vendors use refractory weirs or dam walls in the EHE to separate the EHE into different temperature zones.

To maintain proper solids loading and size distribution, bottom ash is periodically removed from the bottom of the combustor. Many of the vendors utilize a refractory lined vessel to fluidize this drained material. The smaller material is elutriated and carried back into the combustor while the large material is selectively removed and disposed. A portion of the sensible heat is removed from the large material by the fluidizing air and retained in the system. Refractory needs in this device are primarily insulating requirements with the ability to handle the fluidized material. Because of the intermittent nature of draining bottom ash, the coolers are subjected to cyclic operation over a wide temperature range.

The primary air to the combustor is brought into a plenum or windbox except for Riley Stoker which uses air sparger pipes. The windbox provides uniform fluidization air, typically from the outlet of an airheater, during normal operation and hot air from an induct burner during unit startups. Refractory in this region serves as an insulation barrier and, in general, has not been an area of major concern.

As can be seen, refractories play a vital role in the successful operation of CFB's. Failure of the refractories to perform properly can result in operation and maintenance problems such as plugged drains, hot spots, defluidization, erosion, abrasion; any of which can bring a unit off-line.

5.0 SURVEY RESULTS

Based on technical discussions with boiler vendors, refractory suppliers, and owner/operators of CFB's, and review of available technical reports, a summary of refractory system design development for CFB's has been collected. The CFB technology has experienced rapid growth and acceptance over the past five years. With this growth, lessons have been learned and products have been developed to improve the design of refractory systems for CFB's. The following sections summarize the findings from discussions with boiler vendors and owner/operators of CFB's. Appendix A contains information obtained from refractory suppliers on products which have been used in CFB's and where they were applied.

5.1 BOILER VENDORS

Attempts were made to discuss refractory experience and design development with all six boiler vendors. As can be seen below, some were more willing to share information than others. This topic is sensitive as some vendors feel they have a commercial edge over their competitors and are unwilling to discuss the subject. Others are hesitant to discuss details, as they have units which are still under warranty and in some cases are in arbitration with refractory suppliers and installers. Summarized on the following pages are comments received from boiler vendors, verbally or through written reports.

5.1.1 BABCOCK & WILCOX

Babcock & Wilcox (B&W) has CFB units at six sites. Three of these are wood fired and one is fired with sewage. The other two units are coal fired, neither of which have started operating yet. Table 1 gives a listing of these units along with their location, steam conditions, and date of commercial operation. The following information was obtained from discussions with B&W personnel and reference 1.

The B&W units use a thin layer (approximately 1-inch) of high thermal conductivity refractory on the lower walls of the combustor for erosion and corrosion protection. The refractory height was initially 6-1/2-feet from the floor. Later, overfire air ports were installed higher in the combustor with the refractory raised accordingly. The West Enfield refractory was raised to a height of 18 feet, while Jonesboro was raised to 15 feet. Biasing of the overfire air with more being injected through the front wall resulted in wear in the furnace refractory. Where waterwall tubes are bent out of plane to allow for ports, wear also occurs. These areas have been protected with refractory. The lower combustor is covered with a 82% silicon carbide refractory with a calcium aluminate hydraulic bond. This material is gunned onto a dense array of 7/8-inch long pin studs. Undulations in the refractory surface, which did not meet flatness or thickness specifications, resulted in uneven wear of the surface. Sheets of refractory 1/16 to 1/8 inch thick spalled off (beyond the ends of the pin studs). It is believed that the gunning material set up too quickly (15-20 minutes) and prevented the surface from being straight-edged smooth. Later refractory installation used a modification of the above gun mix which had a longer set time (45-60 minutes) and resulted in better conformance to the specification for flatness. Later repairs and extensions used a 77% silicon carbide material supplied by another vendor (Harbison-Walker Harbide 80). This material has held up extremely well.

In addition to the lower combustor waterwalls, the combustor roof is coated with 2-inches of gunned 47% alumina refractory (Kaocrete HSRFT) which contains 2-3% stainless steel needles. The needles are added to improve the thermal shock, spalling, and abrasion resistance of the refractory. No problems have been noted after 2-1/2-years of operation. Refractory is held in place with V-anchors placed on a staggered pitch.

The B&W CFB units do not use cyclones, but instead, collect solids via a U-Beam mechanical collector. The outer walls, roof, and collection hopper of the U-Beam are refractory lined with an abrasion resistant high-density gunned 56% alumina refractory which incorporates stainless steel needles. This material is a higher grade refractory than the material used for the combustor roof. It was chosen since these areas are somewhat inaccessible. The roof and wall areas have 2 inches of refractory attached with V-anchors. No refractory problems have been experienced on these surfaces in 2-1/2 years of operation. The collection hopper abrasion resistant refractory has a thick layer of insulating refractory between it and the hopper shell to retain heat. Both layers are held in place with Y-anchors. The abrasion resistant refractory disintegrated in six months, exposing the insulating refractory to the abrasive fly ash.

The hoppers were repaired by casting three inches of the same abrasion resistant refractory. This repair looks good at the Jonesboro site, but some cracking due to thermal cycling has occurred at West Enfield. B&W has made design changes to their CFB for future units by using waterwall membrane panels to form the hoppers. This eliminates the need for dual layer refractory in this area. The hoppers are now designed for 4-inches of abrasion resistant refractory anchored directly to the panels. This design is used at the Lauhoff Grain CFB. V. J. Mattson installed the refractory at this plant.

5.1.2 COMBUSTION ENGINEERING

Combustion Engineering has five CFB units which have appreciable operating time and thirteen additional units which have either recently started up or will be in operation within the next year or so. Fuels used in these units include bituminous, anthracite culm, lignite, and wood. Combustion Engineering classifies these units into three designs. The first generation units have straight combustor walls which consist of upper sections of waterwall membranes and lower walls of refractory lined plate. The Scott Paper and New Brunswick units have this design. The second generation units are characterized by combustors with straight walls which are made entirely of waterwall membrane construction. Units with this configuration are the Ione and Westwood plants. The third and current design configuration has tapered lower walls and use waterwall membrane construction for all the walls, floor, and plenum. The Fresno and following units have this design. As these design changes were made, refractory changes were being made as well. The following is based on discussions with Combustion Engineering personnel and reference 2.

The early first generation units with the lower portion of the combustor uncooled required two layers of refractory, 16-20 inches thick. The high density, abrasion resistant, hot face refractory was gunned onto anchors with expansion gaps approximately every two feet. These gaps filled with bed ash during operation which caused pinch spalling during heatup. This situation was made worse by numerous startups and shutdowns. Cracking and loss of refractory around large combustor ports occurred even on second generation units. Spalled refractory caused problems by plugging bed drains and bottom ash conveyors. Spalled areas were repaired using phosphate bonded plastic refractory.

The later second and third generation units which have fusion welded waterwalls require only a thin abrasion resistant refractory lining. Thin linings minimize thermal spalling by having only small temperature gradients through the material. Pre-fired silicon carbide tiles, 6 inches x 6 inches which are formed to the waterwall contour, are currently being used and are showing good strength and abrasion resistance characteristics. These tile are attached to the walls by pins and mortar. Silicon carbide possesses a high heat transfer coefficient (100-120 Btu-in./hr. ft^2 F) which allows lower waterwalls to be heat transfer effective and at the same time minimize thermal spalling of the refractory due to large temperature gradients. Silicon carbide also has excellent erosion/abrasion resistance. The Fresno unit has seen excellent service from silicon carbide tile in the lower combustor.

The cyclones used with the early combustor designs were equipped with the same refractory construction as the lower section of the combustors. The cyclones saw the same type of problems with pinch spalling occurring, especially in the lower cone area. The cyclone barrel section saw refractory loss due to erosion in the target zone (area where particles impact from the high velocity tangential cyclone entry). Patching was required. The solution to these problems has been the replacement of the gunned abrasion resistant refractory with brick. Brick was installed in the cone section of two units and the barrel section of another unit. After over a year of service, the brick in these units looks excellent. Combustion Engineering's current cyclone refractory design calls for abrasion resistant brick in the cyclone barrel and cone sections. Multiple layers of insulating blocks of calcium silicate are used to provide the required skin temperature. Work is continuing on identifying materials which possess better wear resistance for use in the target zone.

Original loop seal and downcomer refractory designs were similar to the gunned installation used in the original lower combustors and cyclones. As to be expected, they saw the same type of problems as mentioned above. The design of the refractory for these components has evolved into the use of plastic and fused silica castable refractories. These materials have been in use for over a year with excellent results.

5.1.3 FOSTER WHEELER

Foster Wheeler has one CFB in operation and two units under construction. The Foster Wheeler design differs from other CFB's in that it uses a water/steam cooled cyclone. This allows a much simpler, thinner refractory lining. Cooled cyclones are covered with only 2-4 inches of refractory compared to 12-16 inches of dual layer refractory for uncooled cyclones. Skin temperatures are much lower for the cooled cyclones as well. The refractory, typically 2 inches of Blue Ram plastic with stainless steel needles, is shop installed on closely spaced steel studs. This refractory covers the entire surface except for the seams where the different sections of the cyclone are welded together in the field. These joints are then covered with the same material. If the client requests it, abrasion-resistant tiles of Blue Ram can be placed as an inner protective liner. Refractory dryout and heat curing of the shop applied material is done during a furnace stress relieving cycle at 1250-1275 F. Dryout and heat curing in the field are performed by filling the water circuit and firing the in-duct burner normally.

Wear in the cyclones is low angle abrasion except for erosion which may be occurring on the target zone. The standard test for evaluating abrasion (ASTM C704) does not do a good job at duplicating cyclone service conditions: velocities are uncertain, tests use high velocities at high angles, conventional erodent is suspect, and loadings are typically low. Foster Wheeler has developed a low-angle impingement test rig which better evaluates the relative abrasion characteristics of refractory materials and CFB particulates. Results from this rig show that some castables and plastics benefit from being heated, with significantly better abrasion resistance developed at temperature. Of the materials tested, a phosphate bonded 90% alumina trowel mix and a 60% alumina plastic gave the best high temperature abrasion performance. Gunited materials are not erosion resistant and should not be used for this application. Test results showed that cool startup particulate can be considerably more abrasive than hot recycle material. This may be a result of wearing bare metal versus a metal oxide and/or a softening of the particulate matter with temperature. Less refractory is required at the cyclone gas outlet due to the lower abrasion severity brought about by the reduced dust loading and reduced particle size.

5.1.4 KEELER DORR-OLIVER

Keeler Dorr-Oliver has 9 CFB units in operation with two more planned. These units are listed in Table 4. The lower combustor membrane walls are refractory lined to protect them from the turbulent, substoichiometric bed environment. Silicon carbide cast and tile blocks are now used in the combustors. The elevation of this refractory has been raised with time as wear was experienced on the waterwall at this interface. The roof of the combustors was originally unlined and began to suffer tube failures in a matter of a few hundred hours. This area was repaired by adding a thin layer of silicon carbide refractory. The cyclones and loop seals (Fluoseal) are brick lined in the newer units. The loop seals in earlier units caused problems primarily due to improper expansion joints. Brick linings are more expensive to use but they provide allowance for expansion. Because of the thick refractory requirements for the cyclones and loop seals, cold startups require approximately 15 hours with heatup rates of 100 F/hr. Cyclones should not be gunited due to the severe service, i.e., high particle loadings and high velocities. This service requires brick. If the coal ash is highly alkaline, the use of silicon carbide based materials will result in chemical attack of porous surfaces, characteristic of gunited acid based refractories. The formation of glass phase reaction products in these pores can build up stresses, eventually leading to peeling of the refractory. A successful refractory design is dependent on using proper materials with the proper technique for installation.

5.1.5 PYROPOWER

Pyropower has 25 CFB units which are either in operation or will be by 1990. These units are all coal fired with one burning anthracite culm and another gob. Table 5 is a listing of these units, describing plant, location, steam conditions, fuel, and date of commercial operation.

Pyropower has formed their own refractory subsidiary, Pyropower Energy Services Company (PESCO). Pyropower feels they have developed, over the past 14 months, a refractory system that gives them a competitive advantage. Pyropower declined to discuss their refractory experience or philosophy. PESCO is not interested in performing refractory work for any non-Pyropower jobs. PESCO did state that future Pyropower units would use brick in the cyclones and loop seals.

5.1.6 RILEY STOKER

Riley Stoker has seven CFB units in operation and one under construction as shown in Table 6. These units, which all burn coal, use the Multisolids-Fluidized-Bed-Combustion (MSFBC) concept licensed by Battelle. The design uses larger feed stocks and rocks to form a dense bed in the lower section of the combustor. The early concept involved completely refractory lined combustors which decoupled combustion and heat transfer and provided fuel flexibility. There wasn't a large demand for fuel flexibility and the use of fully refractory lined combustors was not cost competitive, primarily due to the additional material and installation costs. For these reasons, Riley Stoker switched to a combustor with the lower section refractory lined and the upper section having waterwall heat transfer surface.

Riley Stoker does not have a refractory division which required them to go outside for a refractory supplier and installer. The initial position was to have the refractory supplier be responsible for the installation as well. This limited the number of responses for Riley's early units to a few suppliers (Plibrico, CE, and A. P. Green). However, this did provide for a tighter designed refractory system with better warranty provisions. The only warranty available from the refractory manufacturers today is "our materials are what we say they are." Riley Stoker is currently in arbitration with one refractory supplier and is involved in discussions over technical differences with another. Riley currently splits the contract for refractory materials and installation.

Initial information on refractories (primarily from the petroleum industry) was very limited. What was known was that shell temperatures should be kept below 350 F. Higher temperatures would cause differential expansion between the shell and refractory and would break the anchors. Riley Stoker feels that development work needs to be performed to allow shell temperatures to be increased to 650 - 700 F. This would result in lower capital and maintenance costs as hundreds of tons of refractory could be eliminated. Foundation loads would be decreased and structural steel costs would be lowered. Today, however, no suppliers are comfortable at designing anchor systems for these higher temperatures. Offsetting this would be the requirement for additional external insulation to minimize heat losses. Reliable methods would be needed to detect hidden hotspots. The other specification that was given was the refractory should have an abrasion loss of around 10 cc (ASTM C704 test). What resulted from these specifications was a two or three layer system. Riley Stoker opted for the two layer system which consisted of a six to nine inch layer of gunned insulating refractory next to the wall with a four to six inch layer of hard facing. Y-anchors on six to twelve inch centers, depending on refractory thickness, was the preferred anchor design. Early experience with thick hot cyclone refractory showed that two inch x two inch screen ("road mesh") caused refractory to fail in shear at the screen. All suppliers recommended Y-anchors.

One Riley Stoker site has suffered a very large number of refractory failures in the lower combustor. Large pieces of refractory have broken loose and interfered with the local fluidization. Sections have become defluidized, causing clinkers to form which in turn took the unit offline. Large cracks formed in the upper combustor caused overheating of the combustor casing. Six to eight months of operation at this site saw one-third of the hard facing worn off at the cyclone inlet. The cone section experienced major cracking with large pieces falling out. Sections of the walls of the external heat exchanger (EHE) fell off. Recycle lift lines (lines for recycle back to the upper section of the combustor) saw no cracking but within two months of operation, the refractory was worn to the bare carbon steel. Riley Stoker is in arbitration with this supplier (Plibrico) regarding use of improper materials and poor installation. Over half of the original refractory (6000 ft^3 of hard facing) has been replaced at this site.

Riley switched to a different refractory material supplier and installer (A. P. Green) for the next unit. Cracks were noted on this unit, but much less than seen at the site described above. Problems were experienced with EHE bricked dam walls. This design was replaced with a monolithic casting with proper expansion joints. Over vibrating can cause the aggregate and binder to separate. Cracks are more prone to start near combustor penetrations which do not have proper anchors. Riley Stoker has not reported any corrosion on any of their units, but they have noticed some discoloration of the refractory.

Another Riley Stoker unit suffered a major failure in the lower combustor when one wall of the combustor suffered anchor failures. The failures occurred between the insulating and hard face refractories causing the wall to crack and pull away from the side of the combustor. The refractory didn't fall in but had to be chipped out and replaced. The original hard face refractory, Ultra-Green 45 (an ultra-low cement vibrating castable) was replaced with Greengun 83P (a gunned phosphate bonded high alumina plastic). George P. Reintjes, the original installer, made the repairs. Repair patches at other Riley Stoker units show that phosphate bonded plastics are performing better than low cement castables. Rammed plastic is labor intensive to install but with the development of gunned plastics this would be Riley Stokers recommended refractory today.

Results from early units showed that modifications were needed to improve combustion efficiency. These modifications were implemented where possible on units that were already under construction. One change that was made was to go to smaller reducing zones and larger oxidizing zones. To implement this on units under construction required reducing refractory thicknesses. These changes raised shell temperatures up from 140 F to 240 F, still well below the 350 F maximum limit.

The dam walls in the Riley Stoker EHE have suffered failures with monolithic and brick designs. These problems have been resolved by the use of monolithic cast walls with proper expansion joints. Lift lines have seen some high local wear due to local flow disturbances. Design changes should eliminate these problems.

5.2 CFB OWNER/OPERATOR

CFB sites supplied by the six boiler vendors were identified and contacts were made with 31 of these units. The survey concentrated on units which had operated for a sufficient amount of time to be able to gather meaningful results. The survey also was directed toward coal fired units as this task is in support of the DOE Clean Coal Technology program. Experience varied from "no problem" to "refractories have a major impact on availability." Operating time for these units ranged from 0 to 25,000 hours.

Many of the people interviewed were quite knowledgeable about the refractory design and experience for their units; however there was also a lack of refractory knowledge by some of the operators. Refractory systems typically have been a low priority issue to the customer during the plant design review and construction phase. The level of knowledge is somewhat indicative of the amount of refractory problems experienced. Material types, brand names (original and replacement), and installer names are given for many of the units. In those instances where this information is not given, it is usually due to the lack of refractory knowledge by the plant personnel quizzed and not due to a refusal on their part to share information. However, some owner/operators were reluctant to discuss their refractory experience because of warranty issues that were still pending or a desire to retain a commercial advantage over their competitors who might use this technology. Comments received from the owner/operators and information obtained on these units from written reports are summarized on the following pages.

5.2.1 NEW BRUNSWICK POWER

New Brunswick Power operates a 210 kpph Combustion Engineering CFB in Chatham, Canada. The unit began operation in June of 1986 and has accumulated approximately 4500 hours of operation. Steam conditions for the unit are 850 psi and 900 F.

Combustor

The combustor cross section is roughly 12-feet x 12-feet with approximately the first 20 feet of the combustor walls refractory lined. Since this portion of the walls is not constructed of waterwalls, the refractory is composed of a dual layer of eight inches of insulating and eight inches of abrasion resistant refractory. Velocity in this region is on the order of 11-12 ft/sec. Castable material used in this area had problems essentially immediately. Since startup, there have been five or six occasions where major repairs were required. On these occasions, one or more walls of the combustor have been stripped back to the walls and studs. Minor repairs have been made with some success using a rammable material which was used at Georgetown and Summerside (Combustion Engineering (now Premier) "Red Ram"). Spalled pieces of refractory tended to cause operating problems by plugging drains. The unit has experienced some slagging, but corrosion does not appear to be a problem. Cyclic operation may have been partly to blame for the spalling experienced. Some problems, such as ash getting behind the refractory around ports, were due to improper installation. Bricks were installed above the fuel chute arch and have worked well. They have only seen minor damage in 3000 hours of exposure.

The remainder of the refractory in the unit (cyclones, downcomer, loop seals) has performed with essentially no problems. The external heat exchanger which has refractory lined floor, roof, walls, and weirs, experienced minor problems with a section of the roof refractory collapsing. This most likely was due to poor installation. All the refractory in the unit was installed in the field except for some piping that was delivered lined.

5.2.2 AMERICAN LIGNITE PRODUCTS

The American Lignite Products plant in Ione, California has a Combustion Engineering CFB that produces 146 kpph of steam from lignite and lignite waste. The lignite has high silica ash with a lot of rocks. The CFB began operation in February of 1987 and, except for the first few months, has been operated at 75% availability. Steam conditions from the CFB are 1250 psi and 950 F.

Combustor

The combustor utilizes waterwalls the full length of the unit with the lower portion of the walls covered with an abrasion resistant refractory. This material was installed 6 inches thick originally. It began to crack and suffer some spalling, but was still considered serviceable. North American Refractories Guncrete, a low iron abrasion resistant gun mix, was used. Initially there was too much refractory on the walls and some of it had to be removed to get the proper amount of heat transfer. In April of 1989, the combustor refractory was replaced with silicon carbide tile, except around the burner throat.

Cyclone

The cyclone began operation with 8 inches of insulating refractory next to the shell with 6 inches of abrasion resistant refractory (North American Refractory 'Guncrete') between the insulating refractory and gas stream. Rapid erosion was experienced in the cyclone at the target zone (direct impingement point of dust laden gas stream in the barrel of the cyclone). Repairs were made in this area by patching with NIKE 50AR. Later, brick material was tried in the cyclone, but was found to be sensitive to "calcium attack". Corrosion products permeated the surface with a resulting change in color of the bricks noted. The cyclone ended up with corrosion/erosion wear. Currently, the bricks have been replaced with a phosphate bonded chrome alumina material (North American Alchrome 85P). This material has been installed for about 18 months with site staff estimating a two-year service life. Chrome bearing refractories pose a disposal problem since they are classified as a hazardous waste.

Although there has been some cracking of the refractory in the downcomer and recycle loop, these materials have not had to be touched. The ash cooler refractory was cast and has seen some spalling, especially on the line to the cooler. Because of the intermittent use of the ash cooler, it is subjected to a lot of cyclic operation between 1500 F and 200 F.

The unit was designed to handle and remove large material, but still gets plugs due to 4-5 inch pieces of refractory which spall occasionally. The installation of screens over the drain points has helped.

The owner stated that because of the significant number of repairs that are required, refractories could be a major cost item.

5.2.3 WESTWOOD ENERGY

Westwood Energy operates a 271 kpph Combustion Engineering CFB at Joliett, Pennsylvania. Steam conditions are 925 psi and 900 F. Operation of the unit began in June of 1987 and has approximately 17 months of service. The unit does not have a fluid bed external heat exchanger but does have a fluid bed ash cooler. Operating temperature for the combustor is approximately 1800 F, using anthracite refuse with limestone addition.

Combustor

The combustor is composed of a waterwall designed enclosure with a cross sectional area of approximately 14 feet x 14 feet. The first 25 feet or so of the waterwall from the distributor plate up is refractory lined. This area is covered with approximately a 3-inch thick layer of high density abrasion resistant material for corrosion and erosion protection. The combustor has seen localized spalling of the refractory but no major repairs have been required. A test panel of silicon carbide refractory material has been installed in the wall for evaluation.

Cyclone

All the uncooled system components (cyclone, seal pot, fluid bed ash cooler) use a dual layer of refractory, a low-density insulating refractory next to the metal casing and a high-density abrasion resistant refractory on the gas side. The original material was a field installed gunited castable. Spalling and erosion problems were experienced in the cyclones. The original material was replaced with brick which has been performing well for the last year and a half. The inlet to the cyclone has had to be repaired, with Combustion Engineering (now Premier) "Blue Ram" rammable plastic utilized. Only minor repairs have been required in the bed material ash cooler.

5.2.4 SCOTT PAPER

Scott Paper operates a Combustion Engineering CFB at its Chester, Pennsylvania plant. The unit produces 650 kpph of steam at 1450 psi and 950 F. The fuel burned at the plant is an anthracite culm. Operation of the Scott Paper CFB began in June of 1986.

The staff at Scott Paper declined sharing their operating experience with refractories. The reason stated was that Combustion Engineering is still involved in resolving refractory concerns. Scott Paper is representative of Combustion Engineering's first generation CFB. Generic comments on this design are discussed under Combustion Engineering's writeup.

5.2.5 FORT HOWARD PAPER

Fort Howard Paper Company operates a Foster Wheeler CFB at its plant in Rincon, Georgia. The CFB produces 320 kpph of steam at 1500 psi and 950 F. The unit began operation in February of 1988 and reached full load in April 1988, and has been at full load the past six months. The unit has burned coal and petroleum coke.

The staff at Fort Howard Paper stated that the unit has not had any refractory problems. The combustor lower waterwalls were coated with air setting A. P. Green AA22 refractory applied to 3/4 inch stud anchors. In May of 1988 a portion of this refractory was removed to increase the heat absorption to the waterwalls with the studs left exposed. The upper portion of the combustor consists of a radiant superheater which is incorporated into the front wall and roof. These are coated with a 1/2-inch thick high conductivity abrasion resistant refractory (AA22). This same material was used to coat the cyclone inlet area. To improve cyclone collection efficiency, the inlet width was reduced by two feet with the addition of a refractory plug made from Combustion Engineering (now Premier) Blue Ram material. The cyclone is constructed of waterwall panels and therefore only requires a thin coat of abrasion resistant refractory. The cyclone barrel has approximately two inches of Blue Ram plastic refractory which is covered by Blue Ram tile with a 1/4-inch gap between tiles. The cone section has a vibration cast fused silica refractory lining. The loop seal/downcomer region has a dual layer of refractory made up of 5 inches of insulating refractory and 4 inches of vibration cast fused silica. The loop seal roof was gunited and has seen some wear. J. T. Thorpe Company was the refractory installer.

5.2.6 FRACKVILLE COGENERATION

The Signal Energy's Frackville Cogeneration plant in Frackville, Pennsylvania operates a Keeler-Dorr Oliver CFB rated at 410 kpph. Steam conditions for this plant are 1310 psi and 955 F. The plant started up in October of 1988 and uses anthracite culm as the fuel.

Problems with turbine trips have resulted in numerous thermal cycles. Erosion has been noted in the cyclones, but the main refractory problem has been in the loop seal ("Fluoseal") which was gunited. The combustor uses a single refractory layer of abrasion resistant material. The outlet and cone sections of the cyclone are brick (super duty and high duty brick on gas side and light weight insulating refractory next to the shell). The spalling of refractory has caused some pluggage problems.

5.2.7 ARCHER DANIEL MIDLAND

Archer Daniel Midland operates eight Keeler-Dorr Oliver CFB units at two plants. The Decatur, Illinois plant has five units, each of which produces 425 kpph of steam at 1310 psi and 900 F. The first of these units began operation in February of 1987 and the last one in December of 1987. Average availability of these units has been around 85%. The other three units are at the Cedar Rapids, Iowa plant. These units each produce 477 kpph of steam at 1310 psi and 900 F. They began operation in November of 1988 and have approximately 5000 hours of service.

The Archer Daniel Midland staff at the Decatur facility stated that their company had invested heavily in the development and advancement of their CFB units. Because of this vested interest, they declined discussing their experience with refractories. They did, however, have one of their refractory suppliers (Norton) provide some information (see Appendix A). The Decatur facility uses Norton LC904, a calcium aluminate bonded silicon carbide castable.

The Cedar Rapids units use Norton LC904 and CN183, a silicon nitride bonded silicon carbide. The CN183 refractory is used in tube block shapes. The Cedar Rapids units benefited from the refractory lessons learned at the Decatur units. There have been some refractory problems in the loop seal (Fluoseal) region. The cyclones are brick lined and have not been a problem. The cast silicon carbide refractory was added to higher elevations in the combustor to combat abrasion.

5.2.8 COLORADO-UTE

Colorado-Ute Electric Association operates a 910 kpph Pyropower CFB at Nucla, Colorado. The unit produces 110 MW with steam conditions of 1510 psi and 1005 F. Operations began during the summer of 1987. Total operating time through January 1989 was approximately 5500 hours. Refractory experience for this unit was obtained from discussions with site personnel and abstracted from reference 3 and 4. The majority of the discussion centers around a major refractory outage that occurred in January-February 1989.

Periodic problems with refractory failures have plagued the Nucla CFB. Several factors are thought to have led to this experience. Low refractory mix temperatures are believed to have resulted in poor workability of the original refractory. This led to increased water usage which reduced refractory properties and resulted in high shrinkage. Poorly cleaned surfaces may also have contributed to the refractory performance reported. The use of a "top-down" guniting application resulted in rebound and other debris collecting on the walls which can lead to poor bond strength. One other factor that caused spalling problems was improperly prepared construction joints. These joints should have been 90° to the refractory surface. Shallow angles allowed material to collect in the construction joints which in turn caused triangular pieces of refractory to break off and cause operating problems such as pluggage and nozzle erosion. Improper curing (dehydration) of the refractory at the joints may also have been a contributing factor to failures. Finally, the numerous startups and shutdowns over this time period (24 cold starts in 1988 alone), no doubt, played a part in the performance of the refractory.

Combustor

The lower combustor refractory shows signs of widespread cracking. The majority of these cracks propagate from the combustor openings (feed ports, air ports, bottom ash cooler ports, startup burners) with crack widths varying from 1/4-inch to 1-inch. Spalled refractory and bed material build up was noted in the larger cracks. This material was "layered and hard-packed" indicating that it had been deposited in the cracks over time and been under compressive loads. Periodic inspections, including visual observations and photographs, indicate that some of the cracks are growing in width with time. It is believed that this crack growth is due to the thermal cycling of the combustor. During startup, the unit is fluidized causing bed material to be deposited in the cracks which are at their widest openings in the cold condition. As the unit and refractory come up in temperature, the refractory expands and causes the cracks to close. Any material which was deposited in the cracks in the cold condition is compacted as the cracks close. This scenario is repeated each time the unit is brought up to temperature and later cooled back down. As mentioned above, the materials deposited in the cracks build up and take a layered, compressed form.

Compressed bed materials can exert tremendous forces during thermal cycling. Bubbling fluidized bed combustors have experienced failure of in-bed tube supports due to compaction of bed material in crevices between tube supports and tubes. Cyclic operation of the combustors can cause a ratcheting of the tube supports to the point where welds which hold the supports together are broken. Similarly, the material in a CFB can be deposited in refractory cracks to the point where cracks are expanded and finally result in pinch spalling of the refractory.

Areas of refractory spalling in the combustor were somewhat random. Larger areas where spalling has been noted include: lower sections of walls, below manway in one combustor, to left of loop seal return in both combustors, and at the top of the refractory interface with the waterwall in one combustor. Spalled areas were repaired in both combustors using Thermal Ceramics Mix 228G reinforced with stainless steel fibers. Some areas were repaired by hand troweling and others by a gunned application.

Erosion of the refractory in the combustor has been minor with most of it occurring in the region near the corner primary air lower injection nozzles. The discharge from these nozzles, due to their orientation, impinges directly onto the adjacent refractory. Some erosion was also found below the coal and limestone feed ports which has reached a steady state condition. By proper care in designing the discharge from these nozzles and ports, erosion can be reduced so that it is not a concern at this unit.

Cyclone

The cyclones have a dual layer refractory lining, initially consisting of 7-inches of insulating material (NARCO Litecrete 20) with 5-inches of abrasion resistant material (NARCO Guncrete). The performance of the refractory varied with location. Results are discussed for each section of the cyclones (inlet, barrel, cone, and outlet).

The inlet and barrel roof around the vortex finder was in good shape with little erosion and essentially no cracking. More wear and cracking was noticed on the vertical walls of the barrel section. The refractory in this area was originally installed in four separate sections above the cone, with horizontal cold joints between each section. These joints with time filled with dense-layered bed material, similar to that described for the combustor. The widths of these joints were enlarged due to pinch spalling and erosion.

Refractory at the upper section of the bullnose in one cyclone had cracked completely through, causing the outer steel shell to discolor due to overheating. The bullnose is the interface area between the cyclone inlet duct and the trailing edge of the cyclone barrel. Thermal expansion forced the free end of the refractory toward the inlet expansion joint and away from the bullnose. To provide lateral restraint to this movement, expansion stops have been added. These stops are a series of steel plates (3/4-inch thick x 30-inches long x 8-inches wide) with three gusset plates welded to them and the steel cyclone shell. They extend from the ledge of the inlet to the roof of the cyclone barrel. Two stops were installed in each cyclone barrel; one stop is located in the barrel ten feet downstream of the inlet expansion joint and the other stop is located in the barrel, one foot from the bullnose. Testing will confirm whether these stops restrain the lateral movement and increase refractory life.

The floor of the cyclone inlet extends into the barrel of the cyclone, forming a ledge which tapers to blend in with the barrel approximately 180° around the cyclone. The abrasion resistant refractory on the outer corner of the ledge had several loose or broken pieces. These were replaced during the January 1989 refractory repair outage. Both layers of refractory were removed as required and a new anchor design was installed. Seven inches of Thermal Ceramics Kaolite 1800 insulating refractory and five inches of Thermal Ceramics 228G with approximately 1-inch long 304 ss needles were gunned on in this area.

Refractory anchors were removed and replaced with a new design during the January 1989 outage. The original anchors were the "long-horn" or "V" design made from 3/8-inch diameter stainless steel rod material configured to be 8-inches long x 1-inch wide at the base x 9-inches wide at the tip. The anchors were attached with 1/2-inch threaded stainless steel studs welded to the fireside of the steel shell. The new anchors are made in two pieces: (1) a stainless steel rod stud extension which attaches to the existing studs on the shell at one end and provides a 3/8-inch male thread on the other end, and (2) a V assembly which attaches to the rod extension. The V piece is made from 1/4-inch diameter stainless steel rod material, measuring 4-inches long x 1-inch wide at the base x 4-1/2-inches at the tip. The insulating refractory is applied up to the base of the V assembly. The V assembly is then encased in the abrasion resistant refractory.

The growth of cracks in the refractory was noticed in the cyclone barrel and cone also. As discussed above, this growth is believed to be due to the thermal cycling and ingress of bed/recycle material. The cyclones, by design, introduce large quantities of solids to the walls (and cracks). As this material packs into crevices, the refractory weakens locally and is easily eroded/abraded by the high velocity dust laden gas stream. Some of the cracks in the cone section approached 4-inches in width. Three large vertical cracks were noted in each cyclone, extending from the base of the cone up to the horizontal refractory support ring at the base of the cyclone barrel section. The cracks were evenly spaced around the circumference of the cones. Several cracks had been repaired in the April 1988 time period with a plastic ram refractory material. It also was noted to have suffered cracking and spalling. The insulating refractory was exposed in some areas as was a number of the refractory anchors. During numerous outages, large sections of refractory have been found lodged in the loop seals. The cone section appears to be more prone to packing of recycle material in the refractory cracks than the vertical walls of the barrel due to the gravitational forces that are at work. The new abrasion resistant layer of refractory was installed with special care to minimize the number of cold joints.

The cyclone gas outlet section were found to be in good condition. The general cracking, erosion, and spalling problems seen in the combustor and other areas of the cyclone were not present in the outlets. The dust that did collect in the cold joint of the refractory was not hard packed but could be easily removed with finger pressure. With collection efficiencies in the high 90's, the outlet section is subjected to much lower solids loading.

Downcomers/Loop Seals

During a boiler walkdown on January 5, 1989, a hot spot was noticed on the loop seal casing due to the failure of the loop seal refractory. An orderly shutdown was immediately begun to minimize damage. Once down, the loop seals were opened and the cast arches of both loop seals were found to have failed. Cracking and erosion were widespread with sections of broken refractory laying in the bottom of the loop seals along with broken anchors. Approximately one wheelbarrow full of loose refractory was removed from each loop seal. A heavy concentration of stainless needles were noted at one failure area. The loop seal discharge leg to the combustor showed signs of cracking; however, the refractory was sound and has not been a problem.

After removal of the loop seal refractory in January 1989, several cracks were found in the steel shells. The area near where the hot spot had been noticed was discolored (dark red oxide) and was experiencing scaling. A detailed inspection of the fireside of the downcomers was not possible due to limited access. However, widespread cracking could be seen.

Prior to the hot spot failure which occurred in early January 1989, the boiler vendor (Pyropower) had already decided that the loop seal arch should be replaced and was part of the planned workscope for the 1989 refractory repair outage. Work planned included replacing refractory in the loop seal arches, lower 8 feet of the downcomers, and in the loop seal up-leg (bottom of loop seal to top of discharge leg to combustor).

The originally installed loop seal refractory was a combination of cast and gunned material. Because of the continued failures in this area, this material was replaced with a combination cast, gunned, and firebrick refractories. Figure 7 shows the locations where the new materials were placed. The cast and abrasion resistant gunned material used was Thermal Ceramics Mix 228G. The firebrick used were National Refractories Jay Bee S fireclay brick.

The downcomer region between the cyclone cone outlet and the top of the new loop seal firebricks was examined by the boiler vendor and loose sections of refractory were removed and abrasion resistant gunned material applied to make these areas flush with the original refractory (approximately 40% rework).

Site personnel feel the refractory repairs are superior (materials and workmanship) to those originally installed.

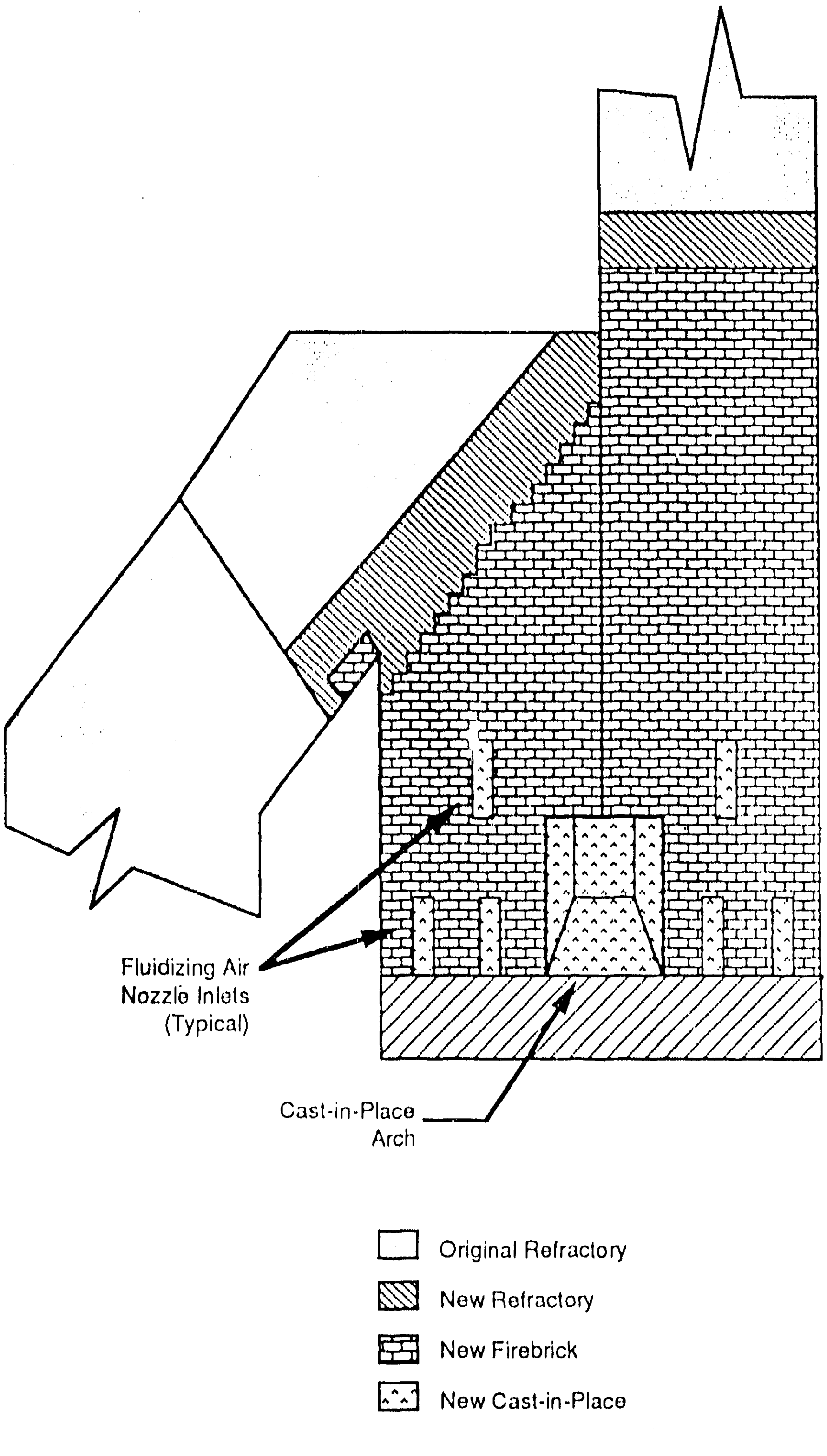


FIGURE 7 - LOOP SEAL REFRACTORY REPAIR

These repairs will be monitored periodically to determine if these changes improved performance.

Miscellaneous

Refractory and firebrick performance in the bottom ash coolers has not been a problem. Refractory in the windbox is normally designed for insulating purposes; however, with the occurrence of any backsifting of bottom ash or dust carryover from regenerative air preheaters it may be prudent to install a thin layer of abrasion resistant refractory over the insulating refractory.

5.2.9 CENTRAL SOYA

Central Soya operates a 88 kpph Pyropower CFB in Chattanooga, Tennessee. The unit began operation in December of 1985 and has run approximately 70% of the time. Steam conditions for the unit are 190 psi and 384 F, produced from burning a medium sulfur (<2%) coal.

Combustor

The waterwall combustor, measuring approximately 9 feet square, has the lower seven feet protected with a gunited Plibrico refractory on the studded walls. The refractory in this area has experienced some cracking and spalling, but has not required any major repairs. Tips of the studs are showing in several areas on the walls. The top one foot of this refractory has been redone.

Cyclone

Major repairs were required in the cyclone and downcomer in April of 1987. The original refractory (Plibrico) consisted of 8-inches of insulating refractory covered with 4-inches of abrasion resistant refractory. Repairs were made using Combustion Engineering (now Premier) Blue Ram H.S. and Hot Top Moldit. Y-anchors are studded directly to the cyclone metal shell on approximately a one-foot x one-foot pitch. The cyclone and downcomer required a second major repair during the summer of 1989. The insulating refractory is being replaced with A. P. Green Kast-Set 2700 F castable, with A.P. Green Lo-Abrade being used in the downcomer. The cyclone barrel is being redone with brick using a high alumina T-36 cement. In the boiler outlet/cyclone inlet section, Harbison-Walker Coral Plastic is being used. This material is a 85% alumina phosphate bonded, heat setting plastic refractory. Summit City Boiler Service made these repairs. They recommended against using stainless steel needles in this application, citing a tendency for the needles to settle out at the lower portion of pours. Needles can burnout up to 2 to 4-inches into the refractory which can leave the refractory weakened.

Operating problems have been primarily pluggage of the ash cooler due to spalled pieces of refractory. The largest pieces of refractory found have been six to eight inches in diameter. The ash cooler was initially lined with a cast refractory, but spalling problems resulted in this material being removed and the cooler lined with brick. Bricks are also used in the loop seal return line to the combustor.

5.2.10 B. F. GOODRICH

The B. F. Goodrich plant located in Henry, Illinois has a Pyropower CFB that began operation in October of 1985. The unit produces 125 kpph of steam at 500 psi and 470 F. To date, the unit has operated for approximately 25,000 hours.

A general comment on the B. F. Goodrich plant is that refractories have not been a problem. All the refractory was installed in the field and was gunned on except from the cyclone outlet to the combustor which was poured. Harbison-Walker refractories were installed by V. J. Mattson Company.

Combustor

The combustor, which is approximately 11-foot square, is constructed of waterwalls with approximately the lower eight feet of elevation protected with a nominal 3-1/2-inches of Hargun ER abrasion resistant refractory. The unit is equipped with five gas lances that are used during loss of coal or for load cycling. Some spalling has been experienced around these ports due to expansion problems. Bed material got behind the refractory in one instance and caused a waterwall tube leak. This leak in turn soaked the refractory in the windbox causing it to have to be replaced. The unit was down for a summer inspection this year and minor patch work was being done around the gas lance ports. Castolast 'G' with 3% by weight of stainless steel needles was used to make these repairs. The floor of the combustor has six inches of Light Weight Cast 22.

The poured refractory (cyclone outlet to combustor) has seen some cracking and wear. This was noticed after the first year of operation, but has stabilized since then with no repairs required. The two coolers are lined with 5-inches of Harcast ES which have not required any repairs. The cyclone, downcomer, and loop seal are lined with 12 inches of Harvibe Light Weight Gun Mix 22 and Hargun ER. No major repairs have been required in these areas.

The unit is cooled down by cutting the fans off and opening the access doors and allowing natural draft to cool the unit (approximately 200 F/HR).

5.2.11 CALIFORNIA PORTLAND CEMENT

California Portland Cement operates a 190 kpph Pyropower CFB, referred to as "Calmat", at Colton, California. Steam conditions for the unit are 650 psi and 825 F. The unit cogenerates approximately 25 MWe. The unit began operation in April of 1985 and has had a 90% availability for the last four years. The unit burns a 50/50 mix of coal and coke and uses ground bottom ash as a supplement to limestone.

Combustor

The combustor is approximately 60 feet tall and has waterwalls the full length. The lower 9-10 feet of waterwall surface has 3-4 inches of abrasion resistant refractory. The unit still has the original refractory and has seen only minor spalling. Refractory at the combustor exit to the cyclones has experienced significant wear and has been replaced with a more wear resistant material.

Cyclone

The majority of refractory problems at Calmat have been in the cyclone. The cyclones, as well as other uncooled structures have 5-inches of insulating refractory and 7 inches of hard wear resistant refractory. Severe erosion has occurred in the roof and sidewall of the cyclone barrel section. The original gunned material spalled off in some areas near the inlet due to poor installation. Expansion joints produced uneven surfaces which aggravated the erosion potential.

Each year, this section of the cyclones is patched with a rammable plastic which sets at 900 F. The rammable plastic has been used with and without the addition of stainless steel needles with no significant difference in performance noted. Pieces of refractories, which spalled after repairs were made, have caused plugged cyclones.

The cone section of the cyclones has experienced spalling and cracking which is believed to be primarily due to not enough expansion allowance. Minor repairs have been made but they are not considered to be a long term solution. Current plans are to replace this material in the cone section with brick in the spring of 1990.

Downcomers/Loop Seals

Excessive erosion is the primary refractory problem in the loop seal (roof) and loop seal return. The loop seal return has been replaced with high grade refractory brick which are performing acceptably.

Miscellaneous

Only minor repairs have been required to the original cast refractory used in the bottom ash cooler.

5.2.12 GENERAL MOTORS-ARGONAUT

The General Motors-Argonaut plant in Pontiac, Michigan has a 300 kpph Pyropower CFB which cogenerates (27 MW and 150 kpph). Steam conditions are 1460 psi and 955 F. The unit came on line in January of 1987 and has operated the last twelve months with a 98% availability.

Refractories have not been a major problem. The lower combustor refractory has seen some considerable wear in the dense bed. Wear is to the point where hangers can be seen. Areas of refractory have been patched and cut out and replaced. The cyclones were gunited and are experiencing some cracking, but haven't seen any spalling. The loop seals where they feed back into the boiler have been replaced with insulating and abrasion resistant bricks.

5.2.13 IOWA STATE UNIVERSITY

Iowa State University has two 170 kpph Pyropower CFB's at the Ames, Iowa campus. One unit began operation on coal in September of 1988 and the second unit in December of 1988. Steam conditions at both units are 410 psi and 750 F. High sulfur bituminous coal is burned in both units. Harbison-Walker refractories were applied to the combustors, cyclones, and loop seals over a period of six weeks.

The lower 12-15 feet of combustor waterwalls are covered with 8 inches of insulating and 2-inches of abrasion resistant (with stainless steel needles) gunned refractory. This section has seen normal cracking in all areas due to thermal expansion. No appreciable erosion or spalling has occurred. The refractory was cured over a period of three days with temperature hold points of 500, 1000, and 1500 F. A 1-ft x 1-ft section of wall refractory at the ash cooler inlet did try to pop out. This failure appeared to be due to a poor initial bond and is the only repair made.

The cyclones also have 8 inches of insulating and 2 inches of abrasion resistant refractory lining. Cast sections in the loop seals experienced localized erosion due to direct impingement of limestone in this area. Cast material was replaced in the target area (24-inch x 30-inch long section) with brick in January 1989.

Pyropower conducted a quality control program on the refractory installation with Iowa State personnel monitoring. Core samples were taken from various locations and examined for strength. Loop seal samples failed strength tests twice before finally passing.

5.2.14 PYROPOWER UNIT

One plant was willing to share refractory experience, but preferred not to be identified by name. This facility has a Pyropower CFB which operates at average steam capacity and high pressure and temperature firing coal.

Combustor

The lower combustor was initially equipped with a dual layer of Kaolite 1600/2300 refractory installed by Turnaround Maintenance. Because of design changes, the velocity in the lower combustor was increased by adding additional refractory thickness. This modification was made without changing the original anchors and resulted in delamination between the layers. Early in 1989 all the combustor refractory was replaced with Norton Refractory LC904, a gunned silicon carbide material. Exception to this was the use of Harbison-Walker Ruby Chrome rammable plastic which was used around tube bends and combustor penetrations. Approximately 70% of the lower combustor is coated with the gunned refractory and 30% with the plastic refractory. Studs, 1-1/2 inches long, are used to anchor the refractory to the walls. Examination of this refractory was conducted in May and looked good.

Cyclone

The cyclones were lined with Kaolite 1600 and 2300 which were gunned on in the field. Erosion of this material in the target zone of the cyclone barrel resulted in local overheating of the cyclone shell. Thermax ES was cast in the cyclone target zone and a diametrically opposite area of the cyclone barrel where erosion was pronounced during an early 1989 outage. This material, installed by J. T. Thorpe, suffered rapid erosion. It is believed that these materials were applied too wet. Later in 1989, this material was torn out and replaced with North American Refractories Alchrome 85P, an 85% alumina plus chrome phosphate bonded plastic refractory. This material is held in place by firebrick anchors.

Loop Seals

The loop seals were gunned and cast with the same original materials (Kaolite 1600 and 2300) identified above. This area has not seen any significant erosion but has seen some heavy cracking and jacking of the refractory. It appears the useful life of these materials has a maximum service life of approximately three years. Current plans are to replace these materials with a high alumina Andalusite brick.

5.2.15 GILBERTON

The Gilberton Power Company plant in West Mahoney, Pennsylvania has two Pyropower CFB's that produce 355 kpph of steam each. The plant burns processed anthracite culm in the combustors and produces steam at 1500 psi and 955 F. The units began full operation in September of 1988 and have run approximately 80 % of the time since.

The combustors have not been a problem but the cyclones have experienced major refractory problems. The cyclones have twelve inches of refractory consisting of six inches of an insulating layer and six inches of abrasion resistant gunited refractory (Thermal Ceramics 122). Repairs have been made with Combustion Engineering (now Premier) Blue Ram plastic refractory. Problems have been encountered with spalling and anchor failures both most likely due to lack of proper expansion. Anchors consist of nuts welded to V-type anchors. The anchor failures are also felt to be due in part to selection of the wrong material (304 stainless steel). Erosion was experienced in the target zone of the cyclone barrels. In June of 1989, the roof refractory buckled and collapsed causing a forced outage. The roof and cone section of the cyclones had the abrasion resistant refractory replaced with a gunned Thermal Ceramics 128. The barrel section of the cyclones had the abrasion resistant refractory replaced with a high alumina Andalusite firebrick from the National Refractories Company. Only minor repairs have been needed in the loop seals. There is some speculation that the high alkaline content of the fuel may have led to a corrosive attack of the refractory.

5.2.16 UNIVERSITY OF MISSOURI

The University of Missouri operates a 200 kpph Riley Stoker Multisolids CFB unit at the Columbia, Missouri campus. Steam conditions of the plant are 950 psi and 850 F. Startup of the unit began in February of 1988. The unit has been operated at nominally 50% load with a 45% average availability. A. P. Green was the refractory supplier and installer.

Combustor

The lower half of the combustor consists of a rectangular cross section steel shell that is lined with a dual layer of refractory. Next to the shell is a 11-inch layer of VSL-35 which is a gunned insulating material which has a maximum service temperature of 2000 F and is resistant to thermal shock. Over this material is a 6-inch layer of R5011 abrasion resistant refractory which was poured in place. At the top of the reducing zone, the lower waterwall headers are refractory lined as is the start of the oxidizing zone. Four to five inches of Lo-Abrade, a 50% alumina abrasion resistant refractory, was gunned in this area. Stainless steel double Y-anchors welded to the steel shell hold the refractory in place. Approximately 1-inch of refractory extends beyond the end of the anchors which are installed on approximately a one-foot staggered pitch. Periodic inspection of the refractory in the lower combustor has shown it to develop cracks which with time have opened up to a maximum of 1 inch. These cracks fill with bed material which packs in the gap and causes the cracks to grow with time. No repairs have been needed to date; however, the west wall is showing some signs of bowing away from the shell and will be monitored in future outages.

The upper combustor has 1 inch of refractory on the roof and 2-1/2-inches on the sidewalls near the cyclone inlet. This material is Lo-Abrade which was gunned onto the surfaces to protect them from the dust loading which must make a 90° turn to enter the cyclones. No wear or spalling has been noted on these surfaces except for localized wear around observation ports. Anchors in these areas are on a tighter spacing (~ 4 inch square pitch).

Cyclone/Downcomer

The unit is equipped with two 10 foot diameter cyclones which are refractory lined with two layers of insulating refractory and a single layer of abrasion resistant material in the cyclone inlet and barrel sections. Starting at the shell the refractory lining consists of 3 inches of Castable Mix 219, 5 inches of VSL-35, and 6 inches of R5008GR. All materials were gunned in the field onto refractory anchors. Some minor spalling has occurred in these areas with larger pieces missing from the cyclone roof around the vortex finder. Minor wear appears to be occurring in the cyclone barrel in the target zone.

The cyclone cone section also has three layers of refractory but, instead of gunned material, are brick. The three layers from the shell toward the hot face are 3-1/2-inches of JM SUPEREX 2000 block insulation, 4-1/2-inches of G-201FB brick, and 6 inches of KX-99BF high fired abrasion resistant brick. This lining has given excellent service. Below the cone section is an eight foot transition section that delivers the solids to an external heat exchanger. This section is lined with 3 inches of Castable Mix 219, 5 inches of VSL-35, and 6 inches of Lo-Abrade which were all cast. These materials have given good service as well. The cyclone outlet refractory materials are 3 inches of Castable Mix 219, 5 inches of VSL-35, and 6 inches of KS46R from shell to gas outlet. No problems were noted in these cast materials.

External Heat Exchanger

The solids collected by the two cyclones dump into the end compartments of a refractory lined external heat exchanger (EHE). The solids in these compartments can either be recycled back to the combustor or can flow over dam walls in the EHE to a center compartment which contains in-bed evaporator surface. The EHE behaves as a low velocity bubbling fluidized bed.

The hot compartments are lined with 16 inches of refractory on the walls and roof and are made up of 4 inches of Castable Mix 219, 6 inches of VSL-35, and 6 inches of Lo-Abrade. The floor is lined with approximately 7 inches of VSL-35 and 6 inches of Kast-O-Lite 25. The cold and hot compartments are separated by a dam wall. This wall was initially constructed of tongue and groove KX99BF brick. These bricks came loose and fell into the hot compartments. During the summer of 1989, these walls were removed and replaced with cast monolithic walls which incorporate expansion joints. These have operated without any problems to date and are only seeing a normal amount of cracking.

The cold EHE compartment, which contains horizontal in-bed evaporator tubing, has 13 inches of refractory on the walls and roof. These linings are made up of seven inches of VSL-35 and six inches of Lo-Abrade. The floor has a three inch layer of Kast-O-Lite 25 on top of approximately five inches of VSL-35.

Return Lines

The L-valves, hot and cold solids recycle lines and the EHE gas outlet line were cast in the shop and use six to nine inches of refractory. The insulating refractory is Castable Mix 219 and the abrasion resistant refractory is R5011. Localized wear has occurred in these lines and appears to be more a problem with local geometry conditions rather than refractory deficiencies.

5.2.17 GENERAL MOTORS - FORT WAYNE

The General Motors Truck and Bus Group in Fort Wayne, Indiana operate two Riley Stoker Multisolids CFB's. Each unit produces 150 kpph of steam at 700 psi and 755 F. The units began operation in March of 1987.

These units have been in operation less than 365 days and are still under warranty. Because of this, the owner was reluctant to discuss specifics but did offer a synopsis of the refractory experience.

The units were originally gunited and cast in the field. Problems were experienced with the refractories in the hot and cold recycle lines, lower combustor, all ports, and cyclone inlet. Each of these areas has been repaired two to three times. Their repair criteria has been if the area is less than two square feet it is patched and if larger than two square feet a major rework or replacement is performed. All types of refractories have been used for repairs and replacement, including cast, gunned, and brick. The most successful material seems to be the new plastic refractories.

The main mode of failure is believed to be erosion, as all problem areas have high velocities and high particle loadings. The refractory has been subjected to a lot of cyclic operation due to boiler operation but no thermal shock expansion failures have been seen.

The rapid loss of refractory is at such a high rate as to make operation and maintenance unacceptable. It is felt that the refractory being used is a misapplication, i.e. it can not handle the high particulate loadings. The General Motors staff recommended that refractory R&D be performed before CFB's can be declared practical for commercial application.

5.2.18 UNIVERSITY OF IOWA

The University of Iowa operates a 170 kpph Riley Stoker Multisolids CFB at Iowa City, Iowa. Steam conditions are 475 psi and 760 F. Operations began during the fall of 1988. Total operating time to date is approximately one month, burning bituminous coal. Initial noise problems resulted in the city requiring the University to put a silencer in the stack. This modification was completed and the unit came back on line in March 1989.

No refractory problems have occurred to date which is not unexpected considering the short operating time. The combustor and cyclone were gunited and the external heat exchanger (EHE) was cast. The dividing walls between the cold and hot EHE compartments are starting to crack and appear to be the first area where refractory problems will occur. Additional operating time is needed to properly assess the refractory in this unit.

5.2.19 A. E. STALEY

A. E. Staley operates two Riley Stoker Multisolids CFB's at its plant in Decatur, Illinois. Each unit produces 375 kpph of steam at 1265 psi and 955 F. The first unit baked refractories out in August of 1988 and began operation in January of 1989. The second unit began operation in May of 1989.

Combustor

The combustors measure approximately 8 feet x 12 feet in the reducing zone and approximately 10 feet x 15 feet in the oxidizing zone. The lower combustor is not waterwall lined and therefore requires two layers of refractory. Originally the refractory was to consist of 9 inches of insulating and 8 inches of hard face refractory. Design changes dictated reducing the velocity in the lower region of the combustor. To assist in lowering the velocity, the combustor refractory installed was only 9 inches thick, consisting of 5 inches of insulating material and 4 inches of hardface material. A. P. Green refractories were installed by George P. Reintjes Company. Cracks formed in the abrasion resistant refractory and were noted to grow larger during each outage. One wall of the first unit has experienced failure of the fasteners and the wall has separated from the combustor. This resulted in an overheating of the casing.

Cyclone

The cyclone refractory is retained by corrugated brick anchors on 8-10 inch spacing. A. P. Green 85P, an 85% alumina phosphate bonded plastic, was used as the hot face refractory (also used in combustor). The cyclones have not experienced any cracking. The cyclone cones are brick lined and have not been a problem. The external heat exchanger has hot and cold recycle compartments divided by a baffle wall. This monolithic wall is full of cracks and looks susceptible to spalling. The outer walls appear in good shape but the roof has experienced some cracking with the refractory coming off as a sheet.

6.0 SUMMARY/RECOMMENDATIONS

Refractory systems represent a significant and critical portion of the overall design of a circulating fluidized bed facility. For this reason, the refractory design should be integrated early into the design of the unit and not added as a last step before the unit is commissioned. The customer needs to evaluate proposed refractory designs from a life cycle cost standpoint and not just initial capital outlay. Most refractory suppliers have comparable materials; however, it is the installation of these materials that can make or break the success of their application. It is imperative that the installation procedure be developed properly and that quality control measures be taken to see that these procedures are carefully followed. Local concrete contractors are generally not qualified to install refractory concretes yet they are frequently used to save money. Their installations are generally unsatisfactory.

It is beyond the scope and objective of this task to provide detailed design, material selection, and installation procedure recommendations. This section attempts to describe some of the lessons learned, both good and bad. CFB technology has advanced at a rapid pace during the last five years. Conventional boilers required the use of little refractory and therefore, the boiler vendor and refractory supplier/installer have had to develop CFB refractory knowledge together. Much of the work which has been done is a spin off from the petrochemical industry.

The summary/recommendations below are a result of this refractory survey which includes discussions with boiler vendors, refractory suppliers, owner/operators of CFB units, and literature reviews. Cost of materials and installation have not specifically been incorporated into any of these comments. Costs are volatile, with one boiler vendor stating the price of refractories has increased by a factor of three to four during the last four years. The customer has to weigh these costs, as well as schedule impacts, into his final selection. The customer should consult the boiler vendor and refractory supplier and installer for specific recommendations.

6.1 MATERIAL SELECTION

6.1.1 INSULATING

Insulating refractories, in general, have not been a problem in CFB's. Operating temperature in CFB's is nominally 1600 F. The temperature at the interface of the insulating refractory with the abrasion resistant refractory is even lower. However, with clinkering, temperature excursions (due to startups, shutdowns, process upsets, etc.), and potential for loss of hard face material, a margin of safety should be included. A minimum of a 2000 F material should be selected. Gunning, casting, and bricks have all been used successfully. With the lower combustor operating in a reducing environment, it would be prudent to select a low iron content material.

6.1.2 ABRASION RESISTANT

In the lower combustor where dual layers of refractory are required, high alumina castables either gunned or vibration cast appear to be successfully used. This material, used with stainless steel fibers and moisture release fibers, should provide long term operation without major problems. Low iron content is recommended due to local reducing conditions. Iron oxide can react with carbon monoxide and deposit carbon which can result in refractory cracking. Units which have waterwalls in the lower combustor require only a single layer of refractory. Silicon carbide either gunned or tile products have proven successful in this application. Gunned silicon carbide is also recommended for the combustor outlet and roof sections where refractory is required.

The cyclones have proven to be the most challenging component for developing a successful refractory design. It was the consensus opinion that gunned materials are not available today that can stand up to this harsh environment. Even though there are exceptions to this finding, most of the boiler vendors are designing all future units with brick. Hard fired high alumina brick or high alumina vibration cast materials should give good service. Phosphate bonded alumina plastic refractories have been used successfully in the target zone and roof areas of cyclones.

Similar to cyclones, many of the boiler vendors are replacing existing loop seal refractories and designing new loop seals with brick or a combination of brick and cast refractory. The major problem in the loop seal appears to be associated
with thermal expansion problems. The materials suggested for cyclones should be suitable for loop seals also. Fused silica, which is 100 % amorphous, has extremely low thermal expansion properties which give it excellent thermal shock resistance. This material would be suitable for loop seals. The maximum temperatures should be maintained below 2000 F to prevent

devitrification. The dip leg/downcomer line to the loop seal can be vibration cast.

6.2 INSTALLATION METHODS

6.2.1 GUNNING

Most of the refractory in CFB's has been applied with this technique. It allows more material to be put in place in the least amount of time. However, this installation method is dependent on the skill of the gunner/nozzleman who can make or break the success of the application. Dry refractory material is blown onto the surfaces to be lined using compressed air with water typically added at the nozzle. An improved gunning technique mixes a portion (up to half) of the water with the dry materials ahead of time with the remaining water mixed at the nozzle. Benefits of this technique are increased density, decreased rebound, and decreased dusting. Rebound is the refractory material that doesn't stick to the surface but bounces off as waste. This material is predominantly the larger coarse fraction of particles and should not be reused. Proper pre-mixing of water should allow a ball of the refractory mixture to be formed which can be easily crumbled with finger pressure. Rebound should be able to be controlled to no more than 10-15% which helps hold cost down.

The proper method of applying the gunned material is to start at the base and corners and work your way up. This allows the rebound material to fall clear of the uncoated surfaces. Once started, installation should not be stopped even for a ten minute break. It is recommended that the nozzle be perpendicular to the wall, about four feet away. Small areas should be gunned in horizontal ovals tc prevent the material from drying out which can result in laminations. The finished product should not be troweled or floated smooth. This works the fine material to the surface and closes up pores that are needed for proper dryout. Also, materials should be applied at 60-80 F and should not be allowed to freeze before the curing cycle is completed.

Gunning is recommended for installing the insulating refractory layer in CFB's, but is not the preferred installation method for the abrasion resistant refractory, except for maybe the lower combustor. Gunned materials have not, in general, performed acceptably in the cyclones and loop seals. Because gunning is fast and cost effective this would be one area where development work could help hold down the capital cost of CFB's. Gunned plastics offer some room for optimism.

6.2.2 CASTING

Refractories can also be installed by casting, which involves pouring the material into a form. This technique is quick and easy to use and requires less skill than gunning. This method requires mixing the material at the site with water. The water used should have a purity suitable for drinking, and the water, mix, and structure to be lined should be at a temperature of 65-90 F. Refractory should never be installed at temperatures below 65 F. Use of more than the recommended amount of water can result in weakened refractory. The refractory and water should be mixed mechanically for two to five minutes at the most. The proper consistency of the mixed product can be evaluated using the "ball in hand" test. A ball of the mixed product is formed and tossed 6-12 inches into the air and caught. The material should conform to the shape of the hand when caught and should not flow between the fingers (too much water) or crumble (to little water).

Vibration casting of materials uses only about one half the amount of water used for conventional casting. Vibration casting increases the density and strength of the final product and reduces its porosity. A paddle type mixer is recommended for mixing vibration cast materials to assure that the reduced amount of water is properly mixed with the solids. Longer mixing times (approximately 4 minutes) are also recommended. The refractory mix should be put in place within 30 minutes which is typically the amount of material that should be prepared in each batch. High purity materials should be put in place within 15 minutes.

The forms or molds should not absorb water from the casting during the cure cycle or else a reduced strength product will result. Pre-wetting or moisture proofing of the forms should be done as necessary to prevent this from happening. After casting, the surface should be covered (plastic) to prevent water loss during the curing cycle and the material should be maintained at the 65-90 F temperature for at least 24 hours. The forms can be removed after about eight hours. After curing, the manufacturer's dryout schedule should be followed. Typically, about 1 hour of hold time is needed for each inch of lining thickness. Free water will be driven off at approximately 212 F and hydration water will come off between 400-1600 F. Vibration casting can be performed by vibrating the form externally or with a surface vibrator. Immersion vibration is not recommended. Too much vibration will cause the aggregate to separate out of the mixture. The effect of vibration casting of a second layer of refractory on top of an installed layer should be considered.

6.2.3 RAMMING

Ramming is another method of installing refractories in CFB's, particularly plastic refractories. These materials are essentially pre-fired refractories that are prepared in a stiff plastic condition by the refractory supplier and delivered to the site with no further preparation or mixing required. These materials are rammed into place with hand held pneumatic hammers or mallets. The plastics are provided in the high density abrasion resistant form and can be either air or heat setting types. The main precaution in ramming plastics is to not put too much material down at one time. The material must be knitted together. The use of a notched hammer is recommended to perform this knitting to prevent laminations. The high success of rammed plastics is due to the improved material properties and the ease of installation with no mixing required.

6.3 ANCHORING

Proper anchoring is critical to successful refractory linings. For circulating fluidized beds, "V" or "Y" anchors are used almost exclusively, except for some use of ceramic anchors. Metal anchors should be made of 309 or 310 S.S, which are good to 1600-1800 F. Ceramic corrugated brick are good for higher temperatures. Hex mesh and road mesh screen type are not recommended as they are prone to failing in sheets. Metal anchor length should nominally be 60 to 80% of the refractory thickness. Ceramic anchors are placed full depth, flush with the outer surface. Anchors should be coated with paint, grease, wax, asphalt tape, or plastic which melt on heat up to allow room for the anchors and refractory to expand without cracking the refractory. Spacing of the anchors is dependent on the refractory thickness and orientation of the surface. Anchors are typically placed on one foot centers, except roofs which are spaced about 9 inches apart. Crowley, in reference 5, gives an analytical method to estimate anchor spacing. More anchors are needed near edges, ports, and other areas that are subjected to vibration or mechanical movement. V-and-Y-anchors should have the legs staggered 90 degrees from each other. Anchors should be properly attached to the shell. This attachment can be checked in the field by rapping the anchors with a hammer or by using a pipe to bend the legs of the anchor. The hammer rap should give a sharp ringing sound and the pipe test should allow the anchor to be bent flat without failing the attachment. If failures are found, all anchors should be tested. Sandblasting of the shell will improve the refractory adherence by creating a textured and clean surface.

Significant cost reductions could be made if uncooled shell temperatures could be increased to 650 - 700 F. These temperatures are well below the oxidation temperature limit of the materials involved but refractory suppliers and installers feel anchor designs do not exist that can function at these temperatures today. Development work in this area could result in lower capital costs for CFB's.

6.4 STAINLESS STEEL FIBERS

Stainless steel fibers are added to castable and plastic refractories to improve refractory strength, spalling resistance, abrasion resistance, thermal shock resistance, and crack resistance. Most of the CFB units use approximately 3-4% by weight of stainless steel fiber reinforcement. The fibers can be added to cast, rammed, or gunned products. Most sites indicate better performance with stainless steel fiber addition; however, at least one site saw no appreciable difference in performance with the addition of stainless fibers, and one installer indicated that stainless fibers could cause problems, such as settling out and burning out. These problems are believed to be the result of use of the wrong material and/or improper mixing of the fibers in the refractory. The use of 310 ss fibers should be suitable for CFB operating refractory temperatures. Stainless steel fibers can be provided mixed with the refractory from the suppliers or can be mixed at the site.
Fibers are typically 1-1-3/8 inches long x about 1/64 inch diameter. The metallic fibers expand more than the refractory material and cause a network of "mini-cracks" which improves thermal shock performance, as opposed to a few large cracks forming which can result in pinch spalling in CFB's. The fibers have little influence in the overall thermal conductivity of the refractory.

6.5 MOISTURE VENTING FIBER

The hydration of calcium aluminate cements is critically tied to the curing temperature. If too low a temperature is used, appreciably more moisture will be released during the drying cycle. With the use of low permeability refractories, rapid release of large amounts of moisture can build up pressure and cause explosive spalling. To minimize this problem, refractories can be purchased which contain fibers that provide paths for the steam to be vented. Some fibers actually shrink and burn out as the refractory temperature is raised close to 200 F. Other fibers are tubular in design and provide a natural path for the moisture to escape. The addition of these fibers is particularly recommended for cold weather installations. The resulting refractory installation with the addition of these fibers has better strength properties with less cracking. A typical example of this product is given in Appendix A.

6.6 CORROSION

Refractory materials are typically selected based on their insulating and abrasion resistance. Corrosion is usually a secondary factor. The circulating fluidized bed application should be less of a concern than other applications because of the low (approximately 1600 F) operating temperatures of CFB's. However, a few of the CFB units reported that it appeared corrosion played a part in the poor performance of their refractories.

Chemical reactions can contribute to the destruction of refractory linings. In CFB's, this may be somewhat masked by the removal of the corrosion products by the abrasive nature of the circulating particulate. Refractories can react with the fuel ash, sorbent, and flue gas. These reactions can result in changes in the refractory crystal structure and even produce liquids. Phase diagrams can be used to determine what reactions are possible and can estimate at what temperatures they will occur. Sodium and potassium, for instance, can react with silica at temperatures below 1500 F. Fireclay refractories can react with limestone but require a higher temperature (approximately 2500 F) than normal CFB operation. Generally, acid refractories should be used where acid fluxes exist and vice versa. Silicon nitride bonded silicon carbide has better alkali resistance. Steam environments, as in water sprayed bottom ash coolers, accelerate the transformation of silicon carbide to silica which can result in spalling.

The reducing condition in the lower portion of the combustor is an area where corrosion may be a factor. High carbon monoxide levels can react with iron oxide in the refractory. Hydrogen can attack silica bearing refractory at temperatures above 2200 F. Reducing conditions also produce lower melting temperature slags. Proper selection of metal materials for anchors and strengthening fibers need to made based on the environment and temperatures expected.

In a related subject, the use of chrome bearing refractories should be carefully considered. Chromic oxide in used refractories presents a problem for removal and disposal because of its toxicity. This material is classified as a hazardous waste.

6.7 QUALITY CONTROL

It is recommended that a third party refractory inspector be employed to oversee the installation of the refractory lining for CFB's. Refractory supplier and installer should be required to develop an installation procedure which should be reviewed and adhered to. The inspector should be responsible for testing both the raw materials and the installed materials for conformance to specifications. Since refractory installers are not required to have any type of certification, it would be prudent to have them qualify by successfully preparing test samples prior to actually beginning work on the unit. Samples should also be taken during installation to verify the as-installed quality.

7.0 REFERENCES

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2. Zychal, R.J., and Darling, S.L., "A Summary of Combustion Engineering's Erosion/Wastage Experience in CFB Boilers," EPRI Workshop on Materials Issues in Circulating Fluidized Bed Boilers, Argonne, IL, June 19-23, 1989.

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4. Elsner, R.W., and Friedman, M.A., "CFB Materials Related Issues at CUEA Nucla Station," EPRI Workshop on Materials Issues in Circulating Fluidized Bed Boilers, Argonne, IL, June 19-23, 1989.

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APPENDIX A

INFORMATION

FROM

REFRACTORY

SUPPLIERS

REFRACTORY SUPPLIERS

1. A. P. Green

2. Combustion Engineering (now Premier)

3. Harbison - Walker

4. North American Refractories

5. Norton

6. Plibrico

A. P. GREEN

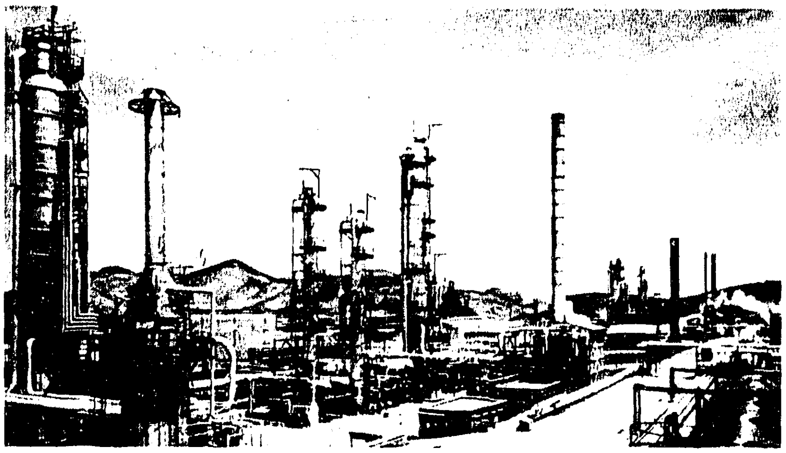
INSULATING BRICK

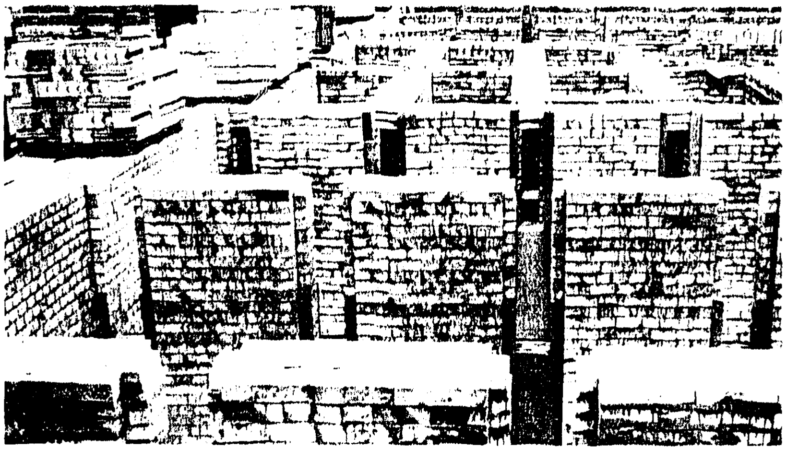
Only A. P. Green manufactures insulating brick by the revolutionary GREENLITE process . . . giving properties superior or equal to any other insulator on the market. Produced from uniform sized, multicellular lightweight aggregate having a strong, ribbed internal structure — resulting in extra high strength and low density.

GREENLITE are available in three distinct classes for use at higher temperatures . . . plus GREENLITE-KL, an insulating rotary kiln liner for use in cooler portions of the kiln.

Regular lower temperature insulating brick are also available. These possess the three most desirable properties of insulating firebrick; high insulating value, structural strength, and the ability to withstand temperatures without shrinkage.

BRAND	TEMPERATURE RANGE	REMARKS
G-20	2000° F.	Regular insulator
G-23	2300° F.	Regular insulator
G-26	2600° F.	Regular insulator
GREENLITE-28	2800° F.	Greenlite process
GREENLITE-30	3000° F.	Greenlite process
GREENLITE-33	3300° F.	Greenlite process
GREENLITE-KL		Greenlite process kiln liner



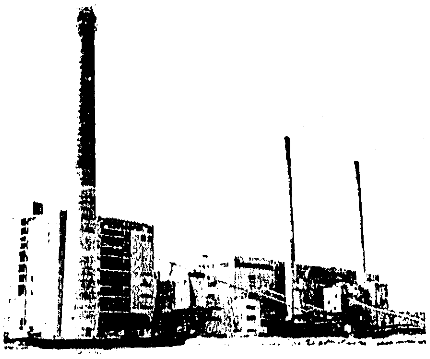


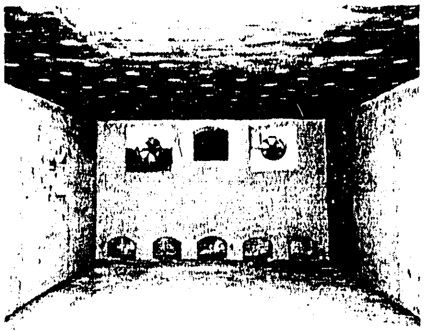
FIRECLAY BRICK

HIGH DUTY

A. P. Green high duty fireclay brick have properties that assure reliable service in all applications where tempertures or chemical attack is not beyond their recommended ranges. A. P. Green high duty fireclay brick have those features which provide longer, more trouble-free service: resistance to vitrification and spalling, good load bearing ability, slag resistance, and outstanding physical and chemical uniformity.

BRAND	PROCESS	QUALITY
EMPIRE	DP,SM	High Duty
EMPIRE S	DP	High Duty
IDAHO	DP	High Duty





SUPER DUTY

A perfect balance of physical and chemical properties, enhanced by strict laboratory control and rigid tests at every stage of manufacture, make A. P. Green super duty fireclay brick the outstanding choice for those applications where operating conditions are above normal and maintenance costs are high.

All A. P. Green super duty brick have high refractoriness, permanency of volume, amazing resistance to destructive spalling, great load bearing strength with less deformation under load at high temperatures than high duty brick, and a dense structure which resists corrosive slags, fumes, dust, and penetration of molten metal.

BRAND	PROCESS
CLIPPER	DP, SM
CLIPPER S	DP
YUKON	DP

HIGH FIRED SUPER DUTY

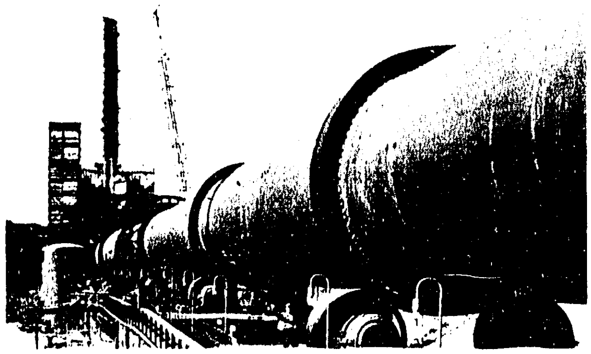
These are super duty brick fired to unusually high temperatures . . . forming a stable mineral structure which gives them exceptional strength, low porosity, and greater load bearing strength. They are highly resistant to abrasion - to the washing action or penetration of fluid slags or molten metal.

BRAND	PROCESS
KX-99	DP (also available tempered/impregnated)
KX-99-BF	DP (also available tempered/impregnated)

HIGH ALUMINA BRICK

The Green Company manufactures high alumina brick ranging from 50% to 80% alumina content. These brick are service proved to provide outstanding refractory life in a multitude of applications. Their high alumina content provides protection at higher temperatures and each features high resistance to spalling and slag attack, high strength to protect agaïnist load deformation, lack of shrinkage for tighter brick-to-brick joints, and low porosity to guard against metal, gas, and dust penetration.

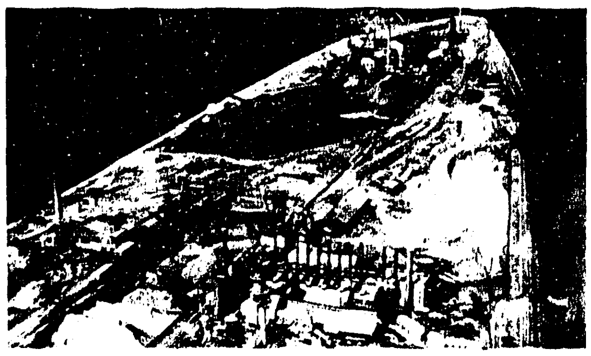
BRAND	Al_2O_3 CONTENT		P.C.E.
MIZZOU	60%	Also	Cone 36-37 (3279-3308° F.)
KRUZITE D	70%	Available	Cone 37-38 (3308-3335° F.)
KRUZITE R	70%	Tar/Impregnated	Cone 37-38 (3308-3335° F.)
80% ALUMINA	80%		Cone 38-39 (3335-3389° F.)



SPECIAL HIGH ALUMINA BRICK - MULLITE BASE

In addition to the normal types of high alumina brick, the Green Company manufactures a special 60% alumina, semi-mullite type product branded GREENMUL-60 which has superior stability and lower porosity compared with regular 60% alumina brick. A low alkali content gives GREENMUL-60 high refractoriness and excellent high hot load strength.

BRAND	Al_2O_3 CONTENT	P.C.E.
GREENMUL-60	60%	Cone 36-37 (3279-3308° F.)
GREENMUL-60 T.I.	60%, Tar/Impregnated	Cone 36-37 (3279-3308° F.)



EXTRA HIGH ALUMINA BRICK

A full line of extra high alumina content brick ranging from Cone 39-40 to Cone 42 is manufactured by A. P. Green. Compared with lower alumina brick, they have a higher modulus of rupture and crushing strength, better load bearing qualities, and are more refractory and more resistant to the fluxing action of various basic oxides. They are exceptionally volume stable and 99-AD can be used at temperatures as high as 3500° F.

BRAND	Al_2O_3 CONTENT	P.C.E.
DV	85%	Cone 39-40 (3389-3425° F.)
DV-38	85% (ceramic/chemical bond)	Cone 39-40 (3389-3425° F.)
90-B	90%	Cone 40+ (3425° + F.)
GREENAL-90	90%	Cone 40+ (3425° + F.)
GREENAL-94	94%	Cone 41-42 (3578-3659° F.)
99-AD	99%	Cone 42 (3659° F.)

MORTARS

Refractory mortars specifically developed for laying up various types of refractory brick are found in the Green Line of Mortars. In each case the mortar has the chemical composition best suited for the type of brick and service conditions for which it was designed. All A.P. Green mortars possess the fine grain sizing and smooth workablity needed to produce thin brick-to-brick joints . . . a necessity in good brick construction. Mortars are available in both heat and air setting bonds and in wet and dry consistencies.

Product	Type	Setting Characteristics	Shipping Condition	Container Size	Lbs. Req. Per 1000 9" Strts.-Dipped	Maximum Recomd. Temp.
MEXI-KOMO	Fireclay	Heat-Set	Dry	100 lb. Bags	250-300	3000° F.
SATANITE	High Alumina	Heat-Set	Dry	100 lb. Bags	250-300	3200° F.
'SAIRSET	Super Duty Fireclay	Air-Set	Wet	15, 50, 100 lb. Pails 200 lb. Drums	350-400	3000° F.
'SAIRBOND	Super Duty Fireclay	Air-Set	Dry	100 lb. Bags	250-300	3000° F.
'SAIRMIX-7	Super Duty Fireclay	Air-Set	Wet	15, 50, 100 lb. Pails 200 lb. Drums 100 lb. Cartons	350-400	3000° F.
NO. 36 REFRACTORY CEMENT	High Alumina	Air-Set	Wet	15, 50, 100 lb. Pails 200 lb. Drums	400-450	3200° F.
LOXOL-65	High Alumina	Air-Set	Dry	100 lb. Bags	350-400	3200° F.
No. T-36 REFRACTORY CEMENT	High Alumina	Air-Set	Wet	100 lb. Cartons 15, 50, 100 lb. Pails 200 lb. Drums	400-450	3200° F.
GREENSET-85-P	85% Alumina	Air-Set	Wet	50, 100 lb. Pails	450-500 Troweled	3000° F.
JADE SET SUPER	Alumina-Chromic Oxide Phos. Bonded	Air-Set	Wet	100 lb. Pails	600-650	3400° F.

PLASTIC REFRACTORIES

A. P. Green plastic refractories are in moldable form, ready to pound into place. They may be installed to form a solid monolithic refractory lining in all types of boilers and industrial furnaces . . . plus being used as an effective patching material for quick repairs. Easy to use, plastics save time and labor.

A. P. Green plastics combine high fusion, load bearing strength, spalling resistance, and lack of shrinkage. Separate and distinct brands of plastics assure the perfect plastic refractory for every industrial use.

BRAND	P.C.E.	Lbs./Cu. /Ft.	DESCRIPTION
GRAPHPAK	38-39 (3335-3389° F.)	165	83% alumina-graphite
GREENPAK-45-P	—	151	45% alumina, phosphate bonded
GREENPAK-50-P	—	156	50% alumina, phosphate bonded
GREENPAK-60	—	155	60% alumina
GREENPAK-80	38-39 (3335-3389° F.)	176	80% alumina
GREENPAK-83-MP	—	180	83% alumina, phosphate bonded
GREENPAK-85-P	—	185	85% alumina, phosphate bonded
GREENPAK-85-PF	—	185	85% alumina, phosphate bonded, fine grain
GREENPAK-90-P	—	195	90% alumina, phosphate bonded
GREEN-X	33-34 (3169-3205° F.)	140	Super duty graphite plastic
HIGH ALUMINA PLASTIC	37-38 (3308-3335° F.)	165	70% alumina, air setting
JADE PAK-88-P	—	198	Alumina-chromic oxide, phosphate bonded
JADE PLASTIC	—	196	Alumina-chromic oxide, phosphate bonded
METALKLEEN	36-37 (3279-3308° F.)	150	High alumina graphite plastic
RED-X	20-23 (2847-2921° F.)	138	Slag resistant graphite plastic
SUPER G	35-36 (3245-3279° F.)	150	50% alumina for severe service/high temp. areas
SUPER H	33-34 (3169-3205° F.)	148	Special super duty steel mill plastic
SUPER HYBOND	33-34 (3169-3205° F.)	145	Extra strong super duty, air setting

RAMMING REFRACTORIES

DAUBPAX	—	140	Siliceous
JADE RAM II	—	208	Alumina-chromic oxide, phosphate bonded

PLUS PLASTICS

Fast Firing Capability

The entire line of A. P. Green regular plastics and GREENGUN plastics are available in the PLUS version, featuring an added ingredient that gives them a fast fire capability that can be translated into extra savings on many plastic jobs. PLUS plastics have proved their worth in all types of jobs throughout the country. When your next plastic installation is approaching, inquire about A. P. Green PLUS Plastics. Their extra dimension can bring you these benefits:

SHORTER HEAT-UP SCHEDULE . . . Capable of being heated faster, PLUS Plastics mean shorter heat-up schedules, reduced downtime. A normal plastic heat-up takes from 2-5 days to bring to operating temperature. PLUS Plastics can normally be brought to operating temperatures in less than 15 hours.

LESS FUEL USAGE . . . Extensive fuel is necessary to follow the normal heat-up schedule of plastics. The greatly reduced heat-up time for PLUS Plastics translates to substantially less fuel usage and increased savings.

REDUCED LABOR COSTS . . . High labor costs are associated with properly following the normal long plastic heat-up. Labor costs are reduced due to less personnel time spent on monitoring the shorter heat-up time of PLUS Plastics.

LESS BLOATING, SHEETING, CRACKING . . . If a conventional plastic heat-up schedule is exceeded, the result is excessive bloating, sheeting, and cracking . . . harming the integrity of the lining and necessitating immediate repairs. Bloating, sheeting, and cracking are very remote with PLUS Plastic linings regardless of the heat-up rate used to bring the unit to operating temperature.

GREENGUN

A Total System For Plastic Refractory Placement

The GREENGUN System is an advanced installation method for placing plastic refractories. It features the advantages of a gunned lining - higher production rates, lower labor costs, less downtime - while producing a lining with excellent physical properties and good structural integrity.

The GREENGUN System combines the latest technology in gunning equipment, highly trained, professional installation crews, and a wide range of job-proved, scientifically developed products. The total result is a long-lasting, quality installation at a more economical installed cost. All GREENGUN materials are also available with Plus additives.

- **Fast, efficient material placement**
- **Less manpower requirements**
- **Highly compacted, long-lasting linings**
- **Wide range of specially developed materials**
- **Less downtime and lost production**

BRAND	DISCRIPTION
GREENGUN-45	Super duty fireclay
GREENGUN-45 P	Super duty, phosphate bonded
GREENGUN-45 X	Super duty, graphite
GREENGUN-46	Super duty fireclay
GREENGUN-50	50% alumina
GREENGUN-50 P	50% alumina, phosphate bonc
GREENGUN-53 XS	Silicon carbide, graphite
GREENGUN-60	60% alumina
GREENGUN-60 X	60% alumina, graphite
GREENGUN-70	70% alumina
GREENGUN-70 P	70% alumina, phosphate bonded
GREENGUN-80	80% alumina
GREENGUN-83 P	83% alumina, phosphate bonded
GREENGUN-83 X	83% alumina, graphite
GREENGUN-85 P	85% alumina, phosphate bonded
GREENGUN-90 P	90% alumina, phosphate bonded
GREENGUN-JADE	88% alumina-chromic oxide, phosphate bonded

CASTABLE REFRACTORIES

At no other single source can a line of castable refractories be obtained that will match the Green Line of Castables. This complete line features products applied by all three recognized methods: troweling, pouring, and gunning. All A. P. Green castables can be applied where other products may be difficult to handle.

Dense Castables

	Product Brand Name	Method of Install.	Max. Service Temp.	Lbs. Reqd. Per Cu.Ft.	Type	Remarks
Extreme Temperature	GREENCAST-94	Pour	3400° F.	163	94% Alumina	Extremely abrasion resistant
	GREENCAST-97	Pour	3400° F.	158	97% Alumina	For extreme temperature furnace construction
	KRUZITE CASTABLE	Pour	3200° F.	150	74-78% Alumina	Spall resistant, dense, strong
	MIZZOU CASTABLE	Pour	3000° F.	136	57-60% Alumina	Spall resistant, strong
Extra Strength	MC-30	Pour	3000° F.	145	64-67% Alumina	Very coarse for thermal shock and withstanding abrasion
	STEELKON	Pour	2800° F.	133	51-54% Alumina	Dense, strong, abrasion resistant
	MC-25	Pour	2550° F.	125	Fireclay	Very coarse for thermal shock and withstanding abrasion
	LO-ABRADE	Pour	2600° F.	133	54-57% Alumina	Resists abrasion and/or erosion
	MC-22	Pour	2350° F.	125	Fireclay	Very coarse for thermal shock and withstanding load and abrasion
Gun Applied	GREENCAST-94 GR	Gun	3400° F.	155	94% Alumina	For resisting abrasion, erosion and high temperatures
	MIZZOU GR	Gun	3000° F.	140	60-63% Alumina	Spall resistant, strong
	STEELKON BF	Gun	2800° F.	132	53-56% Alumina	For blast furnace repair
	GREENCAST-28 GR	Gun	2800° F.	123	Fireclay	For blast furnace repair
	KS-4V GR	Gun	2600° F.	121	Fireclay	For blast furnace repair
	KS-4 GR	Gun	2550° F.	125	Fireclay	Dense, abrasion resistant
	LO-ABRADE GR	Gun	2600° F.	133	47-50% Alumina	Resists abrasion and/or erosion
	GREENCAST-12 GR	Gun	2200° F.	122	Fireclay	High strength and abrasion resistance
General Purpose	SUPER KAST-SET	Pour	2800° F.	120	Fireclay	Resists vitrification, balanced properties
	KS-4V	Pour	2600° F.	122	Fireclay	Strong, abrasion resistant.
	KAST-SET	Pour	2700° F.	115	Fireclay	Outstanding general purpose mat'l.
	KS-4	Pour	2550° F.	123	Fireclay	Strong, dense, abrasion resistant
	HYDROCRETE	Pour	2200° F.	125	Fireclay	High strength, resistant to carbon monoxide atmospheres

ULTRA-GREEN.....Ultralow Cement, High Strength Castables

ULTRA-GREEN represents the new breed of ultralow cement, high strength, vibratable castables. A long list of impressive physical and chemical characteristics make these new generation materials ideal for numerous high temperature applications. The unique bond found in ULTRA-GREEN products gives them strength and hot load properties superior to regular low cement or conventional castables. Their low porosity enables them to better resist slag and hot metal penetration. In essence, properties of ULTRA-GREEN are equal or superior to fired brick of similar alumina composition, yet they are installed with the speed and ease of a vibratable castable.

ULTRA-GREEN is now available in three alumina contents:

Product	% Alumina	Wt./Ft.^{3}	Recommended Temperature
ULTRA-GREEN 45	45%	145	3000° F.
ULTRA-GREEN 70	70%	165	3100° F.
ULTRA-GREEN 80	80%	175	3200° F.

Insulating Castables

Product Brand Name	Method of Install.	Max. Service Temp.	Lbs. Reqd. Per Cu.Ft.	Type	Remarks
GREENCAST-97-L	Pour	3300° F.	85	Insulating Bubble Alumina	For very high temperatures, resists carbon monoxide disintegration
KAST-O-LITE 30	Pour	3000° F.	84	Insulating Aggregate	For high temperatures, good strength, replaces heavy and insulating brick
KAST-O-LITE 30 GR	Gun	3000° F.	98	Insul. Aggregate	For high temperatures, good strength
MC-28-L	Pour	2800° F.	110	Coar. Aggregate	Extra strength, coarse aggregate
GREENCAST-26-L	Pour	2600° F.	50	Insulating Aggregate	Low iron, excellent for highly reducing atmospheres
KAST-O-LITE 25	Pour	2500° F.	82	Insulating Aggregate	Good strength, replaces heavy and insulating firebrick
KAST-O-LITE 25 GR	Gun	2500° F.	90	Insulating Aggregate	Good strength, replaces heavy and insulating firebrick
VSL-50	Gun Pour	2300° F.	60 54	Insulating Aggregate	Low iron - excellent for use in highly reducing atmospheres
CASTABLE INSULATION NO. 22	Pour	2200° F.	50	Insulating Aggregate	Good strength, low thermal conductivity, low shrinkage
CASTABLE INSULATION NO. 22 GR	Gun	2200° F.	72	Insulating Aggregate	Light weight combined with good strength, low rebound
VSL-35	Gun Pour	2000° F.	39 29	Insulating Aggregate	Low thermal conductivity, resistant to thermal shock
CASTABLE BLOCK MIX	Pour	1600° F.	21	Insulating Aggregate	Extra low thermal conductivity block insulation in castable form

Plus Castables.....Faster, Safer Heat-Ups

All A. P. Green castable materials are available with job-proved PLUS additives. PLUS additions to castables give them Fast Fire Capability, reducing heat-up time drastically while greatly reducing the dangers of explosive spalling.

REDUCED CHANCES FOR EXPLOSIVE SPALLING . . . Explosive spalling or severe cracking is almost nonexistent with PLUS Castables, regardless of the heat-up rate, thus giving additional insurance against the possibilty of injury to personnel or equipment.

BETTER THERMAL SHOCK RESISTANCE . . . Job experience indicates that PLUS Castables have better thermal shock resistance than conventional castables when cyclic temperatures are involved.

LOWER LABOR COSTS . . . Faster heat-up means reduced labor costs associated with monitoring the faster schedules.

FUEL SAVINGS . . . The faster fire-in capability of PLUS Castables reduces the amount of fuel required for heat-up.

LESS DOWNTIME . . . Heat-ups can be reduced from 2-5 days to less than 15 hours. This faster schedule translates into reduced equipment downtime and less production losses.

Special Refractory Mixes

Product Brand Name	Description	Lbs. Req. Per Cu.Ft.	Remarks
GREENCOTE	Refractory maintenance	—	Applied as a protective coating or patch
GREENKON-26 Plus	High strength, vibrating castable	133	Outstanding hot strength for coke oven doors, car top blocks
GREENKON-28 Plus	High strength, vibrating castable	135	Outstanding hot strength for iron ladles, forge furnaces
GREENKON-30 Plus	High strength, vibrating castable	163	Outstanding hot strength for high temperature burner ports, iron ladles
GUNWELD 50	50% alumina, hot or cold gun mix	120	For hot or cold repairs with minimum downtime or for complete linings. Can be used with fireclay, silica, or high alumina linings.
GUNWELD 70	70% alumina, hot or cold gun mix	138	
GUNWELD 90	90% alumina, hot or cold gun mix	150	

A. P. GREEN INDUSTRIES, INC.
MEXICO, MISSOURI 65265 U.S.A.

TENTATIVE TECHNICAL DATA

ULTRA-GREEN 45

Ultra-Low Cement Vibrating Castable

MAXIMUM RECOMMENDED TEMPERATURE	3000°F	1650°C
QUANTITY REQUIRED	145 lb/ft^3	2.32 g/cc
QUANTITY IN PLACE	lb/ft^3	g/cc
Cured and Then Dried at 220°F (105°C)	142 - 148	2.28 - 2.37
Heated at 1500°F (815°C)	142 - 148	2.28 - 2.37
APPARENT POROSITY - ASTM C20	Approximately	
Cured and Then Dried at 220°F (105°C)	8 - 12%	
Heated at 1500°F (815°C) and Then Cooled	11 - 15%	
WATER REQUIRED FOR MIXING	Approximately	
	Pints (US)	Liters
Per 100 Pounds (45.4 kg)	4 1/2-5 1/2	2.1 - 2.6
MAXIMUM TIME FROM ADDING WATER TO PLACING MATERIAL		
Minutes	20	
PERMANENT LINEAR CHANGE - ASTM C113 and C865		
Expansion or Shrinkage		
Cured and Then Dried at 220°F (105°C)	Nil	
Heated at 1500°F (815°C) and Then Cooled	0 - 0.5% shr	
Heated at 2000°F (1095°C) and Then Cooled	0.2 - 0.8% shr	
Heated at 2500°F (1370°C) and Then Cooled	0.7 shr - 0.3% exp	
Heated at 2910°F (1595°C) and Then Cooled	1.0 - 2.5% exp	
MODULUS OF RUPTURE - ASTM C133 and C865	lb/in^2	kg/cm^2
Cured and Then Dried at 220°F (105°C)	1000-2000	70-140
Heated at 1500°F (815°C) and Then Cooled	1800-2800	125-195
Heated at 2000°F (1095°C) and Then Cooled	1500-2800	105-195
Heated at 2500°F (1370°C) and Then Cooled	800-1500	55-105
HOT MODULUS OF RUPTURE - ASTM C583 and ASTM C865		
Heated at 1500°F (815°C)	2200-3800	155-265
Heated at 2000°F (1095°C)	2500-3500	175-245
Heated at 2500°F (1370°C)	600-1200	40-85
COLD CRUSHING STRENGTH - ASTM C133 and C865		
Cured and Then Dried at 220°F (105°C)	5000-10000	350-705
Heated at 1500°F (815°C) and Then Cooled	8000-15000	560-1055
Heated at 2000°F (1095°C) and Then Cooled	10000-16000	705-1125
Heated at 2500°F (1370°C) and Then Cooled	7000-13000	490-915

(Continued)

ULTRA-GREEN 45

ABRASION LOSS - ASTM C704		cc
Heated at 1500°F (815°C) and Then Cooled --		7 - 10
Heated at 2500°F (1370°C) and Then Cooled -		5 - 9

PARTICLE SIZE - ASTM C92

Retained on 4 Mesh Tyler Screen (4.7 mm opening)

Wet Analysis ----------------------------	Trace

THERMAL CONDUCTIVITY

At a Mean Temperature of	$\frac{Btu\text{-}in}{ft^2\,hr\,°F}$	$\frac{kcal\text{-}m}{m^2\,hr\,°C}$
400°F (205°C)	6.19	0.77
800°F (425°C)	7.34	0.91
1200°F (650°C)	8.49	1.05
1600°F (870°C)	9.63	1.19
2000°F (1095°C)	10.78	1.34
2400°F (1315°C)	11.93	1.48

CHEMICAL ANALYSIS

Calcined Basis

Silica - SiO_2	44.0 - 50.0%
Alumina - Al_2O_3	44.0 - 50.0%
Iron Oxide - Fe_2O_3	1.0 - 1.6%
Lime - CaO	0.7 - 1.0%
Titania - TiO_2	2.5 - 3.5%
Alkalies - $Na_2O + K_2O$	0.4 - 0.7%

These results cannot be taken as maximum or minimum requirements for specification purposes.

June 14, 1988

TECHNICAL DATA SHEET FOR ULTRAGREEN-57-A IS NOT YET AVAILABLE. PROPERTIES WILL BE VERY SIMILAR TO R-8009 WHICH IS ULTRA GREEN-57A'S FIELD TEST PREDECESSOR.

A. P. GREEN INDUSTRIES, INC.
MEXICO, MISSOURI 65265 U.S.A.

LIMITED DATA SHEET

R-8009

Ultra-Low Cement Vibrating Castable

MAXIMUM RECOMMENDED TEMPERATURE --------------	3000°F	1650°C
QUANTITY REQUIRED ----------------------------	160 lb/ft^3	2.56 g/cc
QUANTITY IN PLACE	lb/ft^3	g/cc
Cured and Then Dried at 220°F (105°C) -----	162	2.60
Heated at 1500°F (815°C) ------------------	160	2.56
APPARENT POROSITY - ASTM C20	Approximately	
Cured and Then Dried at 220°F (105°C) -----	12%	
Heated at 1500°F (815°C) and Then Cooled --	15%	
WATER REQUIRED FOR MIXING	Approximately	
Per 100 Pounds (45.4 kg) ------------------	Pints (US)	Liters
	4-1/4	2.0
MAXIMUM TIME FROM ADDING WATER TO PLACING MATERIAL		
Minutes ------------------------------------	20	
PERMANENT LINEAR CHANGE - ASTM C113 and C865		
Expansion or Shrinkage		
Cured and Then Dried at 220°F (105°C) -----	Nil	
Heated at 1500°F (815°C) and Then Cooled --	0 - 0.3% exp	
Heated at 2000°F (1095°C) and Then Cooled -	0 - 0.5% exp	
Heated at 2500°F (1370°C) and Then Cooled -	0 - 1.0% exp	
Heated at 2700°F (1480°C) and Then Cooled -	0 - 1.3% exp	
Heated at 3000°F (1650°C) and Then Cooled -	0 - 1.3% exp	
MODULUS OF RUPTURE - ASTM C133 and C865	lb/in^2	kg/cm^2
Cured and Then Dried at 220°F (105°C) -----	2000	140
Heated at 1500°F (815°C) and Then Cooled --	1500	105
Heated at 2000°F (1095°C) and Then Cooled -	1200	85
Heated at 2500°F (1370°C) and Then Cooled -	1400	100
HOT MODULUS OF RUPTURE - ASTM C583 and ASTM C865		
Heated at 1500°F (815°C) ------------------	1900	135
Heated at 2000°F (1095°C) -----------------	2400	170
Heated at 2500°F (1370°C) -----------------	650	45
COLD CRUSHING STRENGTH - ASTM C133 and C865		
Cured and Then Dried at 220°F (105°C) -----	10000	705
Heated at 1500°F (815°C) and Then Cooled --	10000	705
Heated at 2000°F (1095°C) and Then Cooled -	10000	705
Heated at 2500°F (1370°C) and Then Cooled -	9500	670

(Continued)

ABRASION LOSS - ASTM C704		cc	
Heat at 1500°F (815°C) and Then Cooled		6 - 10	
Heat at 2500°F (1370°C) and Then Cooled		6 - 10	
100 HOUR HOT LOAD TEST - ASTM C16			
Deformation at 2600°F (1425°C)		1%	
CREEP TEST (1350°C at 2 kg/cm^2)			
20-50 Hour		0.07% subsidence	
PARTICLE SIZE - ASTM C92			
Retained on 4 Mesh Tyler Screen (4.7 mm opening) Wet Analysis		Trace	
THERMAL CONDUCTIVITY	$\frac{Btu\text{-}in}{ft^2\ hr\ ^\circ F}$		$\frac{kcal\text{-}m}{m^2\ hr\ ^\circ C}$
At a Mean Temperature of			
400°F (205°C)	10.88		1.35
800°F (425°C)	11.44		1.42
1200°F (650°C)	11.97		1.48
1600°F (870°C)	12.47		1.55
2000°F (1095°C)	12.94		1.60
2400°F (1315°C)	13.38		1.66
CHEMICAL ANALYSIS			
Calcined Basis			
Silica - SiO_2		38.0 - 42.0%	
Alumina - Al_2O_3		56.0 - 59.0%	
Iron Oxide - Fe_2O_3		0.5 - 1.0%	
Lime - CaO		0.5 - 1.0%	
Titania - TiO_2		0.5 - 1.0%	
Alkalies - $Na_2O + K_2O$		0.1 - 0.3%	

These results cannot be taken as maximum or minimum requirements for specification purposes.

A. P. GREEN REFRACTORIES CO.
MEXICO, MISSOURI 65265 U.S.A.

TECHNICAL DATA

EMPIRE DP

High Duty, Dry Press, 9" and 3" Series Fire Clay Brick
Manufactured at Mexico, Missouri

PYROMETRIC CONE EQUIVALENT - ASTM C24		
Orton Standard Cones	32 - 33	
Temperature Equivalent	3123 - 3169 °F 1717 - 1743 °C	
REHEAT (Permanent Linear Change) - ASTM C113		
Contraction or Expansion at 2550 °F (1400 °C)	0.4% Contr. - 0.2% Exp.	
HOT LOAD TEST - ASTM C16		
Deformation at 2460 °F (1350 °C)	0.2 - 2.0%	
PANEL SPALLING TEST - ASTM C107		
Preheat at 2910 °F (1600 °C) Spalling Loss	0.5 - 4%	
APPARENT POROSITY - ASTM C20	18 - 22%	
WATER ABSORPTION - ASTM C20	8.5 - 11%	
BULK DENSITY - ASTM C20	lb/ft^3 128 - 134	g/cc 2.05 - 2.15
MODULUS OF RUPTURE - ASTM C133	lb/in^2 600 - 1000	kg/cm^2 42 - 70
COLD CRUSHING STRENGTH - ASTM C133	2000 - 3000	141 - 211
CHEMICAL ANALYSIS		
Silica - SiO_2	55.0 - 58.0%	
Alumina - Al_2O_3	37.0 - 40.0%	
Iron Oxide - Fe_2O_3	1.0 - 2.5%	
Lime - CaO	0.1 - 0.6%	
Magnesia - MgO	0.1 - 0.6%	
Titania - TiO_2	1.0 - 2.0%	
Alkalies - $Na_2O + K_2O$	0.5 - 1.5%	

The test data shown above are based on average results of control tests on 9" brick and are subject to normal variation on individual tests. These results cannot be taken as maximum or minimum requirements for specification purposes.

Form TD-42-5
(5)

A. P. GREEN INDUSTRIES, INC.
MEXICO, MISSOURI 65265 U.S.A.

LIMITED DATA SHEET

GREENPAK-83-MP

High Alumina, Phosphate Bonded, Plastic Refractory

QUANTITY REQUIRED - Net	lb/ft^3	g/cc
	181	2.88

DRYING AND FIRING SHRINKAGE - ASTM C179
Shrinkage or Expansion
Percent of Original Length

Dried at 220°F (105°C)	0 - 0.8% shr
Heated at 1500°F (815°C) and Then Cooled	0.8% shr - 0.5% exp
Heated at 2550°F (1400°C) and Then Cooled	0.5% shr - 1.5% exp
Heated at 3000°F (1650°C) and Then Cooled	1.5% shr - 1.0% exp

MODULUS OF RUPTURE - ASTM C491	lb/in^2	kg/cm^2
Dried at 220°F (105°C)	900	63
Heated at 1500°F (815°C) and Then Cooled	1100	77
Heated at 2550°F (1400°C) and Then Cooled	1300	91

PARTICLE SIZE - ASTM C92
Retained on 6 Mesh Tyler Screen (3.33 mm opening)

Wet Analysis	Less Than 6%

CHEMICAL ANALYSIS
Calcined Basis

Silica - SiO_2	10.0 - 12.0%
Alumina - Al_2O_3	79.0 - 82.0%
Iron Oxide - Fe_2O_3	1.0 - 2.0%
Lime - CaO	0.05 - 0.15%
Magnesia - MgO	0.05 - 0.15%
Titania - TiO_2	1.5 - 3.0%
Alkalies - $Na_2O + K_2O$	0.2 - 0.4%
Phosphorous Pentoxide - P_2O_5	3.0 - 5.0%

These results cannot be taken as maximum or minimum requirements for specification purposes.

June 28, 1988

A. P. GREEN INDUSTRIES, INC.

MEXICO, MISSOURI 65265 U.S.A.

TECHNICAL DATA

LO-ABRADE

High Strength, Abrasion Resistant Castable

MAXIMUM RECOMMENDED TEMPERATURE ----------------	2600°F	1425°C
QUANTITY REQUIRED - Net ------------------------	132 lb/ft^3	2.11 g/cc
QUANTITY IN PLACE	lb/ft^3	g/cc
Cured and Then Dried at 220°F (105°C) -------	135-143	2.16-2.29
Heated at 1500°F (815°C) and Cooled ---------	128-136	2.05-2.18
WATER REQUIRED FOR MIXING	Approximately	
Per 100 Pounds (45.4 kg) -------------------	1 1/4 gallons (US)	4.7 liters
MAXIMUM TIME FROM ADDING WATER TO PLACING MATERIAL		
Minutes --------------------------------------	15	
PERMANENT LINEAR CHANGE - ASTM C113 and C865		
Expansion or Shrinkage		
Cured and Then Dried at 220°F (105°C) ----	Nil	
Heated at 1000°F (540°C) and Then Cooled -	0 - 0.3% shr	
Heated at 1500°F (815°C) and Then Cooled -	0 - 0.3% shr	
Heated at 2000°F (1095°C) and Then Cooled	0 - 0.5% shr	
Heated at 2300°F (1260°C) and Then Cooled	0.3 - 1.2% shr	
MODULUS OF RUPTURE - ASTM C133 and C865	lb/in^2	kg/cm^2
Cured and Then Dried at 220°F (105°C) -------	1200-1600	84-112
Heated at 1500°F (815°C) and Then Cooled ----	1000-1400	70-98
Heated at 2000°F (1095°C) and Then Cooled ---	300-700	21-49
COLD CRUSHING STRENGTH - ASTM C133 and C865		
Cured and Then Dried at 220°F (105°C) -------	5500-10000	387-703
Heated at 1500°F (815°C) and Then Cooled ----	3900-8000	274-562
Heated at 2000°F (1095°C) and Then Cooled ---	3300-7000	232-492
PARTICLE SIZE - ASTM C92		
Retained on 4 Mesh Tyler Screen (4.70 mm opening)		
Wet Analysis ------------------------------	Less Than 2%	
ABRASION LOSS - ASTM C704	cc	
Heated at 1500°F (815°C) and Then Cooled ----	12.0 - 17.0	

(Continued)

LO-ABRADE

THERMAL CONDUCTIVITY at a Mean Temperature of	$\frac{Btu\text{-}in}{ft^2\,hr\,^\circ F}$	$\frac{kcal\text{-}m}{m^2\,hr\,^\circ C}$
400°F (205°C)	5.60	0.69
800°F (425°C)	6.10	0.76
1200°F (650°C)	6.17	0.77
1600°F (870°C)	6.21	0.77
2000°F (1095°C)	6.46	0.80

CHEMICAL ANALYSIS

Calcined Basis

Silica - SiO_2	34.0 - 37.0%
Alumina - Al_2O_3	54.0 - 57.0%
Iron Oxide - Fe_2O_3	1.0 - 1.5%
Lime - CaO	4.7 - 5.3%
Magnesia - MgO	0.1 - 0.6%
Titania - TiO_2	1.0 - 2.0%
Alkalies - $Na_2O + K_2O$	0.5 - 1.5%

The test data shown above are based on average results of control tests and are subject to normal variation or individual tests. These results cannot be taken as maximum or minimum requirements for specification purposes.

COMBUSTION ENGINEERING

(NOW PREMIER)

BOILER REFRACTORIES: Technical Data and Information

COMBUSTION ENGINEERING

The importance of proper refractory product selection.

As in all industrial applications, the proper selection of refractory products depends on a variety of operational and environmental factors. Equipment processes and conditions are different between individual power generating systems. Such factors as fuel chemistry, service temperatures and operating practice have a direct bearing on refractory requirements.

It is important to select the appropriate refractory product so that a complete refractory system is incorporated into an individual power generating system. Combustion Engineering manufactures a broad range of castables, plastics, mortars and insulating refractory products designed specifically for power generating systems.

Combustion Engineering sales representatives combine power generating expertise with an excellent knowledge of refractory technology. Your C-E sales representative should always be consulted before final specifications and ordering of refractory products and materials.

PLASTICS

Product	Recommended Max. Service Temp. (°F)	Dry Material Required (lb./ft³)	Modulus of Rupture (lb./in²) at 230°F	% Permanent Linear Change at 1000°F	Thermal Conductivity (Btu – in./hr. ft²°F) 500°F	2000°F	Chemical Analysis (% Calcined Basis) Al_2O_3	SiO_2	Bond Type
90-RAM® HS	3100	185	1080	−0.6	19.8	15.4	93.4	2.7	Chemical
90-RAM® PC	3100	183	950	−1.0	14.0	16.5	91.5	4.3	Chemical
BLU-RAM® HS	3100	171	1130	−0.2	10.1	9.0	72.8	20.7	Chemical
WASP® 60	2900	156	505	−0.4	5.0	7.0	51.4	41.6	Chemical
RAMTITE® 25	2900	150	108	−0.7	6.6	7.9	45.5	51.0	Heat
WASP® 30	2550	150	450	−0.7	6.6	7.9	42.5	49.2	Chemical
EMERALD RAM® HS	3400	201	1360	−0.2	20.0	14.2	85.1	10.0 (Cr_2O_3)	Chemical

DENSE CASTABLES

Product	Recommended Max. Service Temp (°F)	Dry Material Required (lb./ft³)	Modulus of Rupture (lb./in²) at 230°F	% Permanent Linear Change at 1000°F	Thermal Conductivity (Btu – in./hr. ft²°F) 500°F	1500°F	Chemical Analysis (% Calcined Basis) Al_2O_3	CaO	Fe_2O_3
CASTABLE 141-A®	3200	165	1100	−0.1	11.2	9.9	97.0	2.7	—
CERCAST® 17	3090	164	—	−0.1	—	8.5	85.3	5.3	1.7
CERCAST™ HT	2900	144	—	−0.1	6.6	8.0	55.9	4.5	0.9
MOLDIT® CHROME	2900	196	550	—	6.3	8.7	40.5 (Cr_2O_3)	3.9	23.2
CERCAST™ SUPER LI	2700	142	—	−0.1	6.8	8.1	50.5	6.8	1.2
HOT TOP MOLDIT®	2600	129	1210	−0.2	4.9	5.6	49.1	8.2	1.2
MOLDIT® DL	2450	118	975	0.1	5.9	4.2	45.7	12.1	2.8
MOLDIT® D	2400	118	975	0.1	5.9	4.2	39.7	13.3	7.7
FSC-5™	2400	105	600	−0.1	4.0	4.8	34.4	7.7	0.1
AR-153®	2350	141	1650	[illegible]	[illegible]	6.6	56.2	6.5	0.6

This data represents average results of standard tests conducted under controlled conditions and is subject to usual variations. They should not be used in specifying products.

INSULATING CASTABLES

Product	Recommended Max. Service Temp (°F)	Dry Material Required (lb./ft³)	Modulus of Rupture (lb./in²) at 230°F	% Permanent Linear Change at 1000°F	Thermal Conductivity (Btu – in./hr ft²°F) 500°F	1500°F	Chemical Analysis (% Calcined Basis) Al_2O_3	CaO	Fe_2O_3
LITE WATE® 80	2500	80	345	–0.1	3.9	2.2	47.0	11.9	1.9
LITE WATE® 70	2300	78	450	–0.2	3.0	2.3	33.6	12.4	7.2
LITE WATE® 58	2300	58	200	–0.3	2.7	1.9	34.0	18.0	8.8
LITE WATE® 50	1800	42	130	–0.5	1.3	2.0	19.4	14.9	3.6
CER LITE® 18	1800	20	26	–0.1*	0.8	1.1	25.5	13.5	7.7

MORTARS AND INSULATION

Product	Recommended Maximum Service Temp. (°F)	Density (lb./ft³)	Thermal Conductivity (Btu – in./hr. ft²°F) 500°F	1000°F
SUPER #3000® MORTAR	3000	155	5.2	5.8
UTILITY FINISHING CEMENT	1200	45	0.7	1.1
SUPER STICTITE™	1800	32	0.7	1.3
POURABLE INSULATION	1200	35	1.1	1.2
GRIPTEX® BLOCK	1800	15	0.5	0.8
CALCINED DIATOMACEOUS SILICA BLOCK	2000	25	0.6	0.8
VERMICULITE INSULATING BLOCK	2000	25	0.6	0.8
CER-WOOL® BLANKET LT	1900	4,6,8	0.4	1.0
BLANKET RT	2400	4,6,8	0.4	1.0
BLANKET HT	2700	4,6,8	0.4	1.0
CER-WOOL® WET WRAP	2100	24	0.5	0.9
THERMOTECT® FIBER BOARD A BOARD	2300	28	0.9	1.1
RT BOARD	2200	22	0.7	0.8
HT BOARD	2700	20	0.7	0.8

Power Systems
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, CT 06095-0500
Phone: (203) 688-1911
TWX: 99297

C-E Refractories
Combustion Engineering, Inc.
P.O. Box 828
Valley Forge, PA 19482
Phone: (215) 337-1100
TWX: 510-660-4837

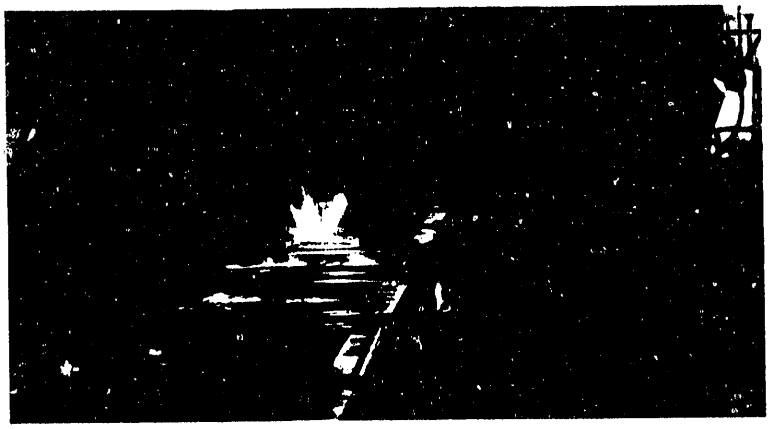
COMBUSTION ENGINEERING

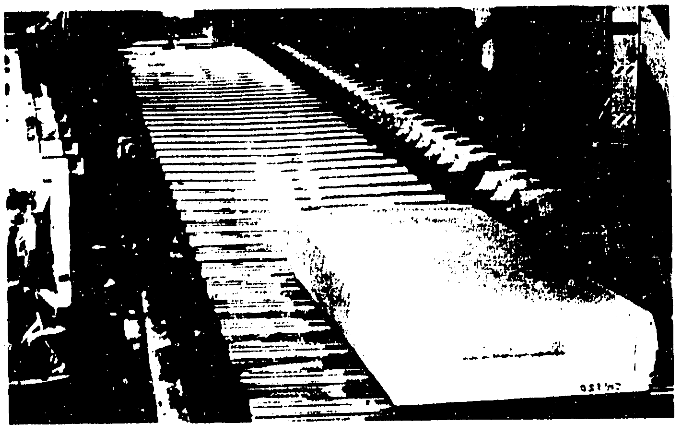
Alumina-Silica Castables and Gunning Refractories... Technical Data

PRODUCT	PRODUCT NUMBER	RECOMMENDED MAXIMUM SERVICE TEMPERATURE (°F) (°C)	DRY MATERIAL REQUIRED (lb/ft³) (Kg/dm³)	MODULUS OF RUPTURE (ASTM C-268) (lb/in²) (MPa) 230°F 110°C	MODULUS OF RUPTURE 1500°F 816°C	% PERMANENT LINEAR CHANGE (ASTM C-269) 1000°F 538°C	% PERMANENT LINEAR CHANGE 1500°F 816°C	THERMAL CONDUCTIVITY (BTU in / hr · ft² · °F) (W / m·K) 500°F 260°C	THERMAL CONDUCTIVITY 1000°F 538°C	THERMAL CONDUCTIVITY 1500°F 816°C	CHEMICAL ANALYSIS (% CALCINED BASIS) Al_2O_3	SiO_2	CaO	Fe_2O_3
Fireclays														
MOLDIT® D	5418	2400 1316	118 1.89	975 6.7	450 3.1	-0.1	-0.1	5.9 0.85	4.7 0.68	4.2 0.60	39.7	36.9	13.3	7.7
MOLDIT® DLI	5295	2450 1343	118 1.89	975 6.7	450 3.1	-0.1	-0.1	6.8* 0.98	4.8* 0.69	4.5* 0.65	45.7	37.0	12.1	2.8
MOLDIT® H&B	5240	2400 1316	120 1.92	800 5.5	300 2.1	-0.2	-0.3	5.6 0.81	5.4 0.78	5.7 0.82	39.8	41.7	9.5	6.4
HOT TOP MOLDIT®	5409	2600 1427	129 2.06	1206 8.3	646 4.5	-0.2	-0.2	4.9 0.71	5.3 0.76	5.6 0.81	49.1	39.5	8.2	1.2
MOLDIT® HT	5220	2900 1593	130 2.08	1050 7.2	700 4.8	-0.2	-0.2	6.8 0.98	4.8 0.69	4.5 0.65	48.5	43.2	6.0	0.9
RICAST®	5424	2700 1482	125 2.00	300 2.1	175 1.2	-0.2	-0.3	5.9 0.85	4.8 0.69	4.6 0.66	47.1	43.4	5.1	1.9
RP-160®	5361	2600 1427	130 2.08	950 6.5	450 3.1	-0.1	-0.1	3.5 0.50	3.8 0.55	4.0 0.58	40.1	48.9	6.8	1.2
RP-157®	5357	2350 1288	130 2.08	1200 8.3	550 3.8	-0.1	-0.2	3.7 0.53	4.0 0.58	4.1 0.59	37.6	46.1	9.1	3.0
High Alumina														
SUPER MOLDIT®	5227	2800 1538	120 1.92	(1000°F) 279 1.9	275 1.9	0.1	0.1	5.2 0.75	4.3 0.62	4.5 0.65	55.3	35.9	5.9	1.0
SUPER CASTABLE NO. 32®	5392	3000 1650	124 1.98	523 3.6	408 2.9	0.1	0.1	7.8 1.12	6.4 0.92	6.2 0.89	55.2	39.0	3.2	0.9
MOLDIT® 70	9872	3000 1650	138 2.21	550 3.9	345 2.4	—	0.2	10.1* 1.45	9.7* 1.40	9.2* 1.30	68.6	24.7	3.12	1.18
FRACTO-CRETE® 3400	5340	3200 1760	160 2.56	1750 12.1	1150 8.0	0.1	0.2	19.7 2.84	12.9 1.86	9.7 1.40	94.8	0.2	4.8	0.1
CASTABLE 141-A®	5341	3200 1760	165 2.64	1100 [illegible]	800 5.5	0.1	0.2	11.2 1.61	10.3 1.48	9.9 1.42	97.0	0.1	2.7	tr

*ESTIMATED

Alumina-Silica Castables and Gunning Refractories... Technical Data

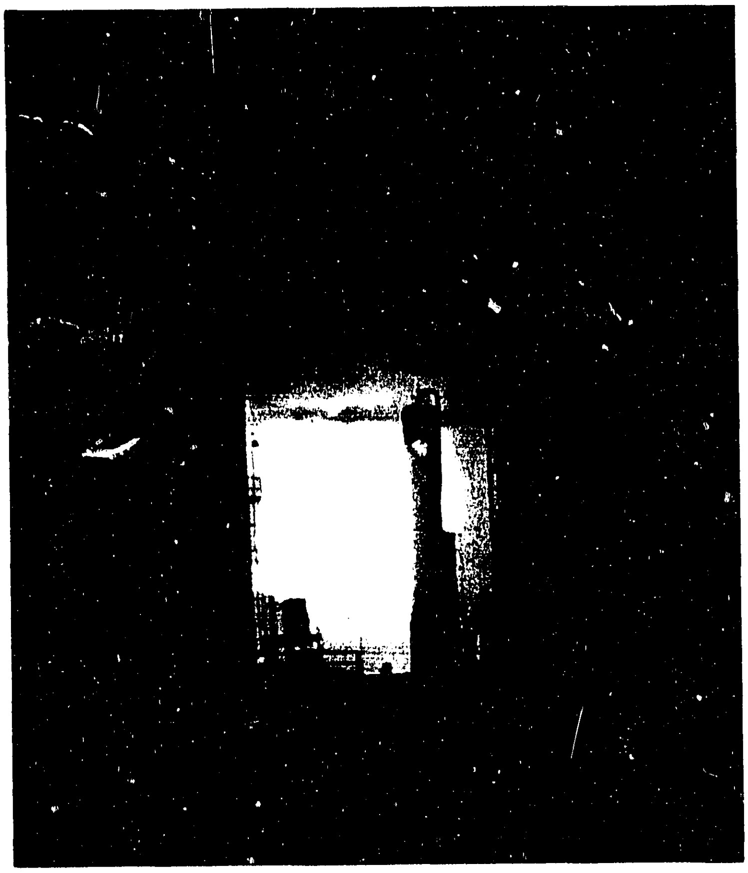


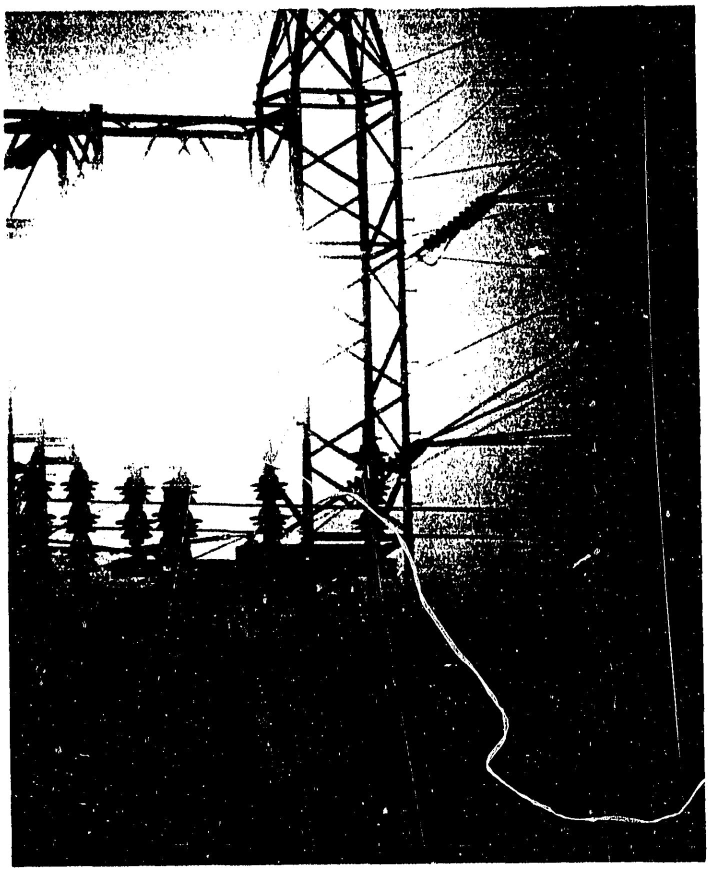


Product	Product Number	Recommended Maximum Service Temperature (°F)(°C)	Dry Material Required (lb/ft³) (Kg/dm³)	Modulus of Rupture (ASTM C-268) (lb/in²) (MPa) 230°F 110°C	Modulus of Rupture 1500°F 816°C	% Permanent Linear Change (ASTM C-269) 1000°F 538°C	% Permanent Linear Change 1500°F 816°C	Thermal Conductivity (BTU in / hr · ft² · °F) (W / m°K) 500°F 260°C	Thermal Conductivity 1000°F 538°C	Thermal Conductivity 1500°F 816°C	Chemical Analysis (% Calcined Basis) Al_2O_3	SiO_2	CaO	Fe_2O_3
Lightweight Insulations														
POURABLE INSULATION	5253	EXP 1200 649 / BACK 1600 871	35 0.56	70 0.5	(1000°F) 14 0.1	−0.65	−3.50	0.8 0.12	1.0 0.14	—	11.3	63.0	21.3	1.1
CER LITE® 18	5489	1800 982	20 0.32	—	—	—	—	0.8* 0.12	1.0* 0.15	1.2* 0.18	25.5	37.3	13.5	7.7
LITE WATE® 35	5212	2000 1093	35 0.56	200 1.4	95 0.7	−0.1	(1800°F) −0.1	1.2 0.17	1.3 0.19	1.5 0.22	31.8	19.9	27.7	12.9
LITE WATE® 50	5323	1800 982	42 0.67	130 0.9	70 0.5	−0.5	−0.9	1.3 0.18	1.2 0.17	2.0 0.29	19.4	50.3	14.9	2.3
LITE WATE® 58	5246	EXP 2150 1177 / BACK 2300 1260	58 0.93	200 1.4	100 0.7	−0.3	−0.4	2.3 0.33	2.0 0.29	1.9 0.27	34.7	37.6	16.1	8.0
LITE WATE® 70	5358	2300 1260	78 1.25	450 3.1	350 2.4	−0.2	−0.4	3.0 0.43	2.6 0.37	2.3 0.33	33.6	41.6	12.4	7.2
LITE WATE® 80	5434	2500 1371	80 1.28	290 2.0	145 1.0	−0.2	−0.2	3.6 0.52	2.9 0.42	2.3 0.33	43.7	39.2	12.0	2.4
CER LITE® 75 C	5292	2750 1510	79 1.26	250 1.7	(1000°F) 270 1.9	−0.3	(2000°F) −0.2	2.3 0.33	2.2 0.32	2.5 0.36	53.9	40.7	2.9	0.9
LINS® 50	5216	EXP 2300 1260 / BACK 2500 1371	50 0.80	250 1.7	—	−0.4	−0.5	1.7 0.24	1.6 0.23	1.5 0.22	68.2	21.3	8.0	0.6
Abrasion Resistant														
AR-400®	5360	2400 1316	165 2.64	1850 12.7	1900 13.1	−0.1	−0.1	7.1 1.02	7.3 1.05	7.4 1.06	62.0	ZrO_2 23.2	6.3	0.5
AR-153®	5353	2350 1288	141 2.26	1650 11.4	1660 11.4	−0.2	—	8.1 1.17	7.4 1.06	6.6 0.95	56.2	34.5	6.5	0.6
Aluminum														
ALUGUARD™ 75	9872	2000 1093	75 1.20	417 2.9	206 1.4	—	0.8	3.0* 0.43	2.6* 0.37	2.3* 0.33	40.0	32.6	14.8	6.1
ALUGUARD™ B	9904	2500 1371	166 2.66	—	770 5.4	—	0.1	(1832°F) 8.5* 1.23	(2192°F) 10.6* 1.53	—	86.5	2.8	5.8	0.9
ALUGUARD™ A	9902	2500 1371	173 2.77	—	875 6.1	—	0.1	19.7* 2.84	12.9* 1.86	9.7* 1.40	93.4	0.2	4.3	0.2

*ESTIMATED

Alumina-Silica Castables and Gunning Refractories... Technical Data





PRODUCT	PRODUCT NUMBER	RECOMMENDED MAXIMUM SERVICE TEMPERATURE (°F), (°C)	DRY MATERIAL REQUIRED (lb ft³) (Kg dm³)	MODULUS OF RUPTURE (ASTM C-268) (lb·in²) (MPa) 230°F 110°C	MODULUS OF RUPTURE 1500°F 816°C	% PERMANENT LINEAR CHANGE (ASTM C-269) 1000°F 538°C	% PERMANENT LINEAR CHANGE 1500°F 816°C	THERMAL CONDUCTIVITY (BTU in / hr · ft² · °F) (W / m°K) 500°F 260°C	THERMAL CONDUCTIVITY 1000°F 538°C	THERMAL CONDUCTIVITY 1500°F 816°C	CHEMICAL ANALYSIS (% CALCINED BASIS) Al_2O_3	SiO_2	CaO	Fe_2O_3
Vibracast														
CERCAST™ SUPER LI	9879	2732 1500	142 2.27	1184 8.1	632 4.3	0.1	−0.1	6.8 0.98	7.4 1.07	8.1 1.16	50.5	39.2	6.8	1.2
CERCAST™ HT	9885	2900 1593	144 2.30	1750 12.1	893 6.1	0.1	−0.1	6.6 0.96	7.5 1.08	8.0 1.15	55.9	37.2	4.5	0.9
CERCAST™ 17	9910	2500 1370	164 2.63	—	—	(1832°F) 0.1	(2192°F) −0.2	11.9 1.72	10.8 1.56	8.2 11.9	85.3	4.9	5.3	1.7
AR-153® VC	5349	2350 1274	135 2.16	1455 10.0	1615 11.1	0.5	−0.1	13.7 1.97	10.2 1.47	9.4 1.30	60.4	31.2	6.1	0.7
AR-400® VC	5302	2400 1316	165 2.64	1850 12.7	1900 13.1	0.1	−0.1	7.1* 1.02	7.3* 1.05	7.4* 1.06	62.0	ZrO_2 23.2	6.3	0.5
Special Mixes														
FSC-5™	9940	2400 1316	105 1.68	800 5.6	1050 7.4	(230 F) 0.0	0.2	—	5.0* 0.72*	—	34.4	57.6	7.7	0.1
MOLDIT® CHROME	5217	2900 1593	196 3.14	550 3.8	415 2.9	—	—	—	8.9 1.28	8.7 1.25	17.2	Cr_2O_3 40.5	3.9	23.2

*ESTIMATED

Engineered Monolithic Lining Construction... Anchoring Systems

Engineered Monolithic Lining Systems

C-E Refractories supplies engineered monolithic lining systems to meet specific energy-saving, abrasion resistance, strength, chemical compatibility and durability requirements.

These lining systems can be customized to satisfy individual customer needs. A full range of engineering, installation and technical support capabilities allows C-E Refractories to offer total monolithic linings systems. In addition to castables, these systems often involve other refractories, ceramic fiber insulations, metallic and/or ceramic anchoring, trained installation crews and detailed lightup schedules.

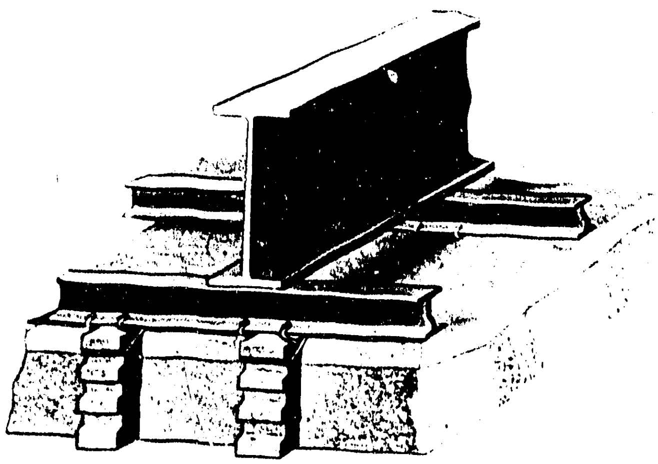
1) Roof lining with engineered ceramic anchoring (A-60 series).

2) Abrasion-resistant lining with engineered hexagonal steel mesh anchoring welded to shell.

3) Single component lining with engineered S-bar anchoring.

4) Single component lining with engineered "V" anchors welded to shell.

5) Two-component lining with engineered "V" anchors and E-bolt attachments welded to shell.



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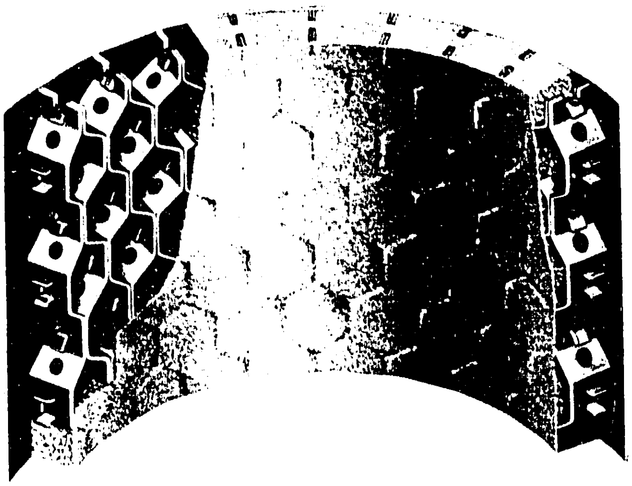
Engineered Monolithic Lining Construction... Anchoring Systems



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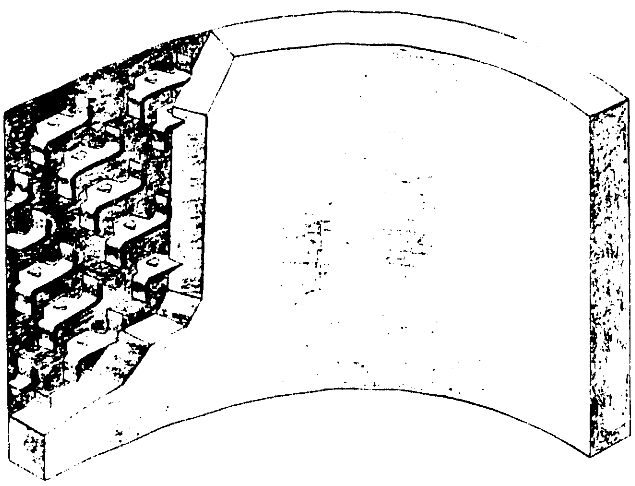

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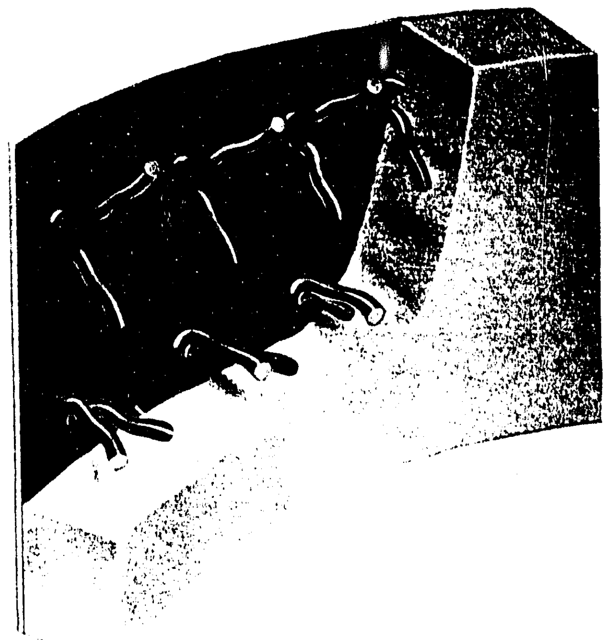

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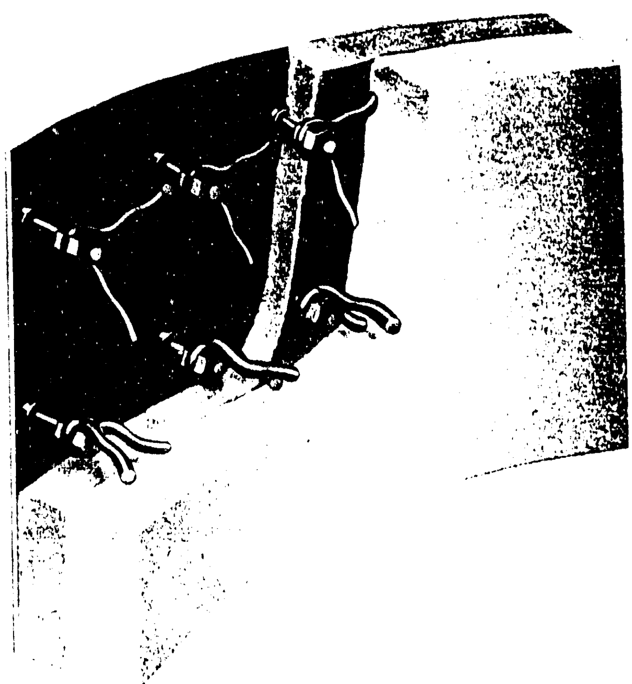

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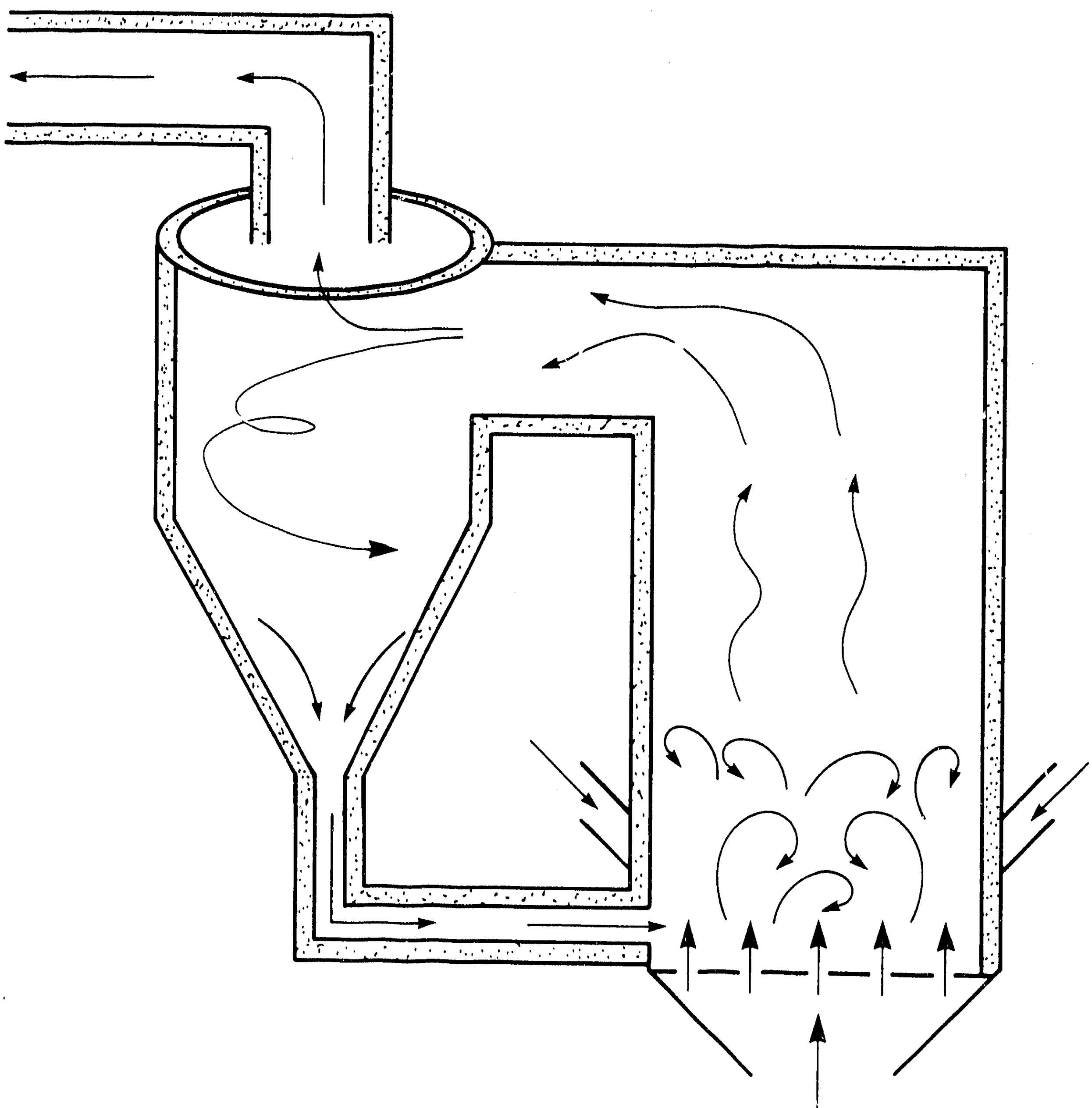
HARBISON - WALKER

REFRACTORY SYSTEMS FOR FLUIDIZED BED COMBUSTION SYSTEMS



HARBISON-WALKER REFRACTORIES
Division of Dresser Industries, Inc.
One Gateway Center, Pittsburgh, Pennsylvania 15222

A) PRODUCT APPLICATIONS

- FOR SEVERE ABRASION CONDITIONS UP TO 2400°F -

Areas: Combustor and Cyclone (Hot face lining)

Recommended Products

GUN MIXES

*HARGUN ER
Abrasion resistant fireclay gun mix containing a high strength high purity cement.
Maximum service temperature - 2400°F

CASTABLES

*HARCAST ER
Abrasion resistant fireclay based castable containing a high strength, high purity cement.
Maximum service temperature - 2400°F

BRICK

*H-W 61-65, KALA
50% Alumina Brick

- FOR SEVERE ABRASION CONDITIONS UP TO 2800°F -

Areas: Combustor and cyclone (hot face lining)

Recommended Products

GUN MIXES

*HARGUN ES
Abrasion resistant fireclay based gun mix
Maximum service temperature - 2800°F

VIBRATION CASTING MIXES

*HARVIBE
Abrasion resistant fireclay based mix designed for vibration casting.
Maximum service temperature - 2800°F

CASTABLES

*HARCAST ES
Abrasion resistant fireclay based castable
Maximum service temperature - 2800°F

BRICK

*CORAL BP
Burned, phosphate bonded 85% alumina brick

*KORUNDAL XD - mullite bonded, 90% alumina brick

- FOR HEAT CONTAINMENT WITH MINIMUM OR NO ABRASION, UP TO 2400°F -

Recommended Products

GUN MIXES

*TUFSHOT - fireclay based gun mix with a standard refractory cement.
Maximum service temperature - 2400°F

CASTABLES

*ES CASTABLE - fireclay based castable with a standard refractory cement.
Maximum service temperature - 2400°F

*ES CASTABLE C - coarse aggregate version

BRICK

*ALAMO S - superduty fireclay
*KALA - 50% alumina
*UFALA - 60% alumina

- FOR INSULATION -

Areas: Combustors and Cyclones (back-up lining)

Recommended Products

GUN MIXES

*LT. WT. GUN MIX 20 - 2000°F insulating gun mix
*LT. WT. GUN MIX 22 - 2200°F insulating gun mix
*LT. WT. GUN MIX 26 - 2600°F insulating gun mix

CASTABLES

*LT. WT. CASTABLE 16 - 1600°F insulating castable
*LT. WT. CASTABLE 20 - 2000°F insulating castable
*LT. WT. CASTABLE 22 - 2200°F insulating castable
*LT. WT. CASTABLE 26 - 2600°F insulating castable
*LT. WT. CASTABLE LI - 2200°F insulating castable

BRICK

*H-W 20 LI - 2000°F (max.)
*H-W 23 LI - 2300°F (max.)

MINERAL WOOL

*H-W Block Insulation - 1900°F (max.)

NOTE: The possibility of "rat-holes" exists when applying block insulation to units with pressure differentials.

- FOR WATERWALL BOILER TUBE PROTECTION -

Recommended Products

GUN MIXES

*HARBIDE GUN MIX 80 (H-W 39-82)
80% silicon carbide gun/trowelling mix with a high strength, high purity cement.

CASTABLES

*HARBIDE CASTABLE 80 (H-W 2-80)
80% silicon carbide castable with a high strength, high purity cement.

NOTE: It is suggested that the above silicon carbide products be applied over studded boiler tubes.

- FOR HEAT CONTAINMENT WITH MINIMUM OR NO ABRASION, UP TO 2600°F -

Recommended Products

GUN MIXES

*TUFSHOT LI - fireclay based gun mix with an improved, low iron refractory cement.
Maximum service temperature - 2600°F

CASTABLES

*ES CASTABLE LI - fireclay based castable with an improved, low iron refractory cement.
Maximum service temperature - 2600°F

*KILNCAST 26 - Extra coarse aggregate, fireclay based castable with an improved, low iron refractory cement.
Maximum service temperature - 2600°F

*SUPER CASTABLE - fireclay based castable with an improved refractory cement.

BRICK

*UFALA - 60% alumina
*ALUSA - 70% alumina

▪MINIMIZE STEAM SPALLING AND INITIAL CRACKING ▪MAXIMIZE INITIA

H-W's ADTECH™ System: designed to maximiz

THE ADTECH SYSTEM APPROACH

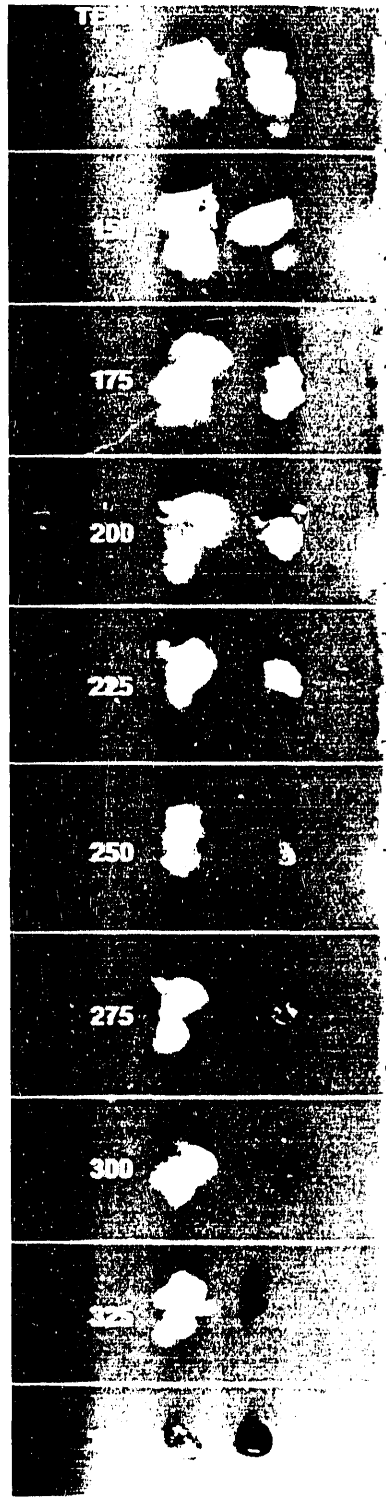
During heatup, the ADTECH additive's special properties cause it to shrink and burn, thus producing minute, non-continuous passageways in the refractory. This slight increase in permeability reduces the danger of steam spalling and allows faster heatup rates by means of a fast, evenly distributed release of both the mechanically and chemically combined water.

IMPROVED TECHNOLOGY/NEW CAPABILITIES

H-W's advanced technology system utilizes extremely small additions that shrink and allow for release of steam and water from the lining at critical temperatures during the heatup. And because the additive in the ADTECH System is considerably smaller than in any other commercially available system, the passageways have little or no effect on properties such as strength and resistance to metal penetration. *The H-W ADTECH System is the first technology-that produces steam passageways of the right size at the right time!*

Laboratory testing shows that the ADTECH System begins working as the steam evolves from the lining and has virtually disappeared long before other commercially available additives show significant shrinkage.

▶



FOR ADDED SAFETY AND SECURITY AGAINST STEAM SPALLING, H-W'S ADTECH SYSTEM FACILITATES WATER RELEASE—WITH MINIMAL EFFECT ON PROPERTIES.

COMPARE THE RESULTS.

Product	Density After 230°F	Modulus of Rapture (PSI) After 230°F	Modulus of Rapture (PSI) After 1500°F	Cold Crushing Strength (PSI) After 230°F	Cold Crushing Strength (PSI) After 1500°F	Permanent Linear Change (%) 230°F	Permanent Linear Change (%) 1500°F
*Castolast® G	167	1500-2100	1400-1800	7000-12000	7000-12000	Negligible	Negligible
Castolast® G Adtech™	165	1400-1800	1300-1700	7000-11000	7000-10000	Negligible	Negligible
*Castolast® GC	175	1200-1700	1200-1700	7000-12000	7000-12000	Negligible	Negligible
Castolast® GC Adtech	174	1200-1700	1200-1700	7000-12000	7000-12000	Negligible	Negligible
Harcast® ES	137	1000-1500	900-1300	6000-9000	5000-7000	Negligible	Negligible
Harcast® ES Adtech™	134	1000-1300	800-1100	6000-9000	5000-7000	Negligible	Negligible
**HW® Lightweight Gun Mix 26	88	170-270	100-200	500-800	350-650	Negligible	−0.2 to −0.6
**HW® Lightweight Gun Mix 26 Adtech™	84	150-250	75-150	450-750	300-600	Negligible	−0.2 to −0.6

Values shown in table are based on actual manufacturing runs (not merely lab samples) of typical H-W refractories. All data is subject to reasonable deviation, and therefore should not be used for specification purposes. *H-W can supply Quality Control data on every shipment to show representative properties.*

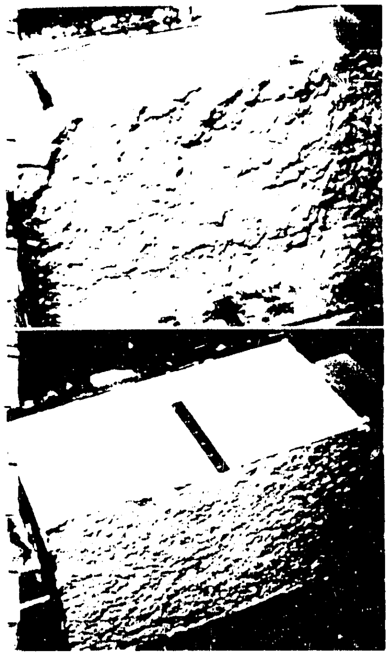
Cover photo courtesy of Westinghouse Electric Corporation. Photograph by Mark Portland

*Cast properties

**Due to minimal differences in measurable physical properties and potential improvements in spall and crack resistance, all CASTOLAST G and CG brand shipments will include the ADTECH™ system.

IL/ .TUP RATE • MAINTAIN PHYSICAL PROPERTIES

ater release—for safer, accelerated heatups.*



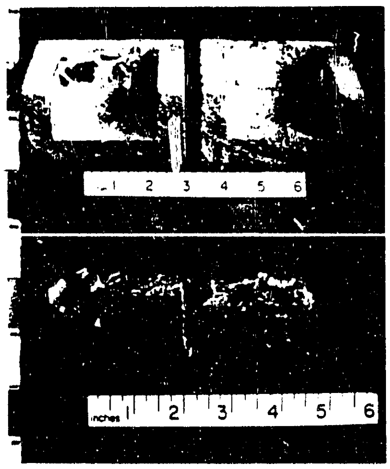
To approximate a furnace environment, the H-W steam spalling test incorporates a large 18" x 12" x 9" section of castable that is fired from one side. The material is air cured for 24 hours and brought to 2550°F in two hours.

The upper photo shows a dense, high purity, high alumina castable after 30 minutes in the spalling test. The 3" spalled section illustrates typical spalling experienced in many applications.

The lower photo shows the H-W ADTECH version of the same product. Of the many other samples of ADTECH castables and gun mixes also tested under the extreme conditions of the steam spalling test, none experienced spalling.

HEATUP SCHEDULES

When ADTECH castables or gunning mixes are used, initial heatup rates can be accelerated. However, as with brick and plastic linings, the initial heatup rates of ADTECH linings must be examined individually. Parameters such as furnace size, lining thickness, material quality, expansion and temperature gradient vary with every furnace and affect the heatup rate. Based on laboratory heatup tests, microscopic analysis of the ADTECH material, and actual field installations, an accelerated heatup schedule can be formulated that shortens heatup time and maximizes energy savings, material properties, and safety. Please discuss your specific situation with the Harbison-Walker Contractor-Installer or field representative.



Extensive tests demonstrate a ADTECH refractory's resistance to metal penetration and cracking.

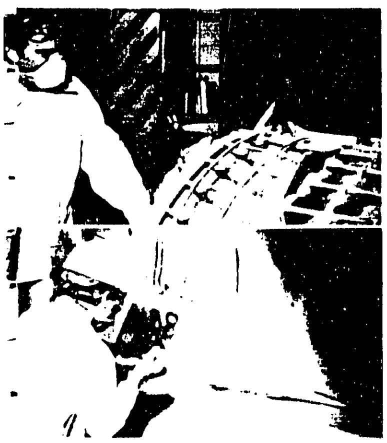
CRACK RESISTANCE

Minimized "Craze Cracking"

Just as the ADTECH System can reduce steam spalling and maximize heat-up rates with passageways of the right size at the right time, the system also enables a lining to efficiently evolve water vapor during standard heat-ups, thereby reducing "craze cracks" that eventually propogate into spalls. With fewer shrinkage and "craze cracks", ADTECH linings have maximized service life in furnaces across the country.

Maximized Metal Handling

In our tests and in the field, we have found minimal penetration into ADTECH metal contact refractories. In fact, because of the reduction of "craze cracks", some ADTECH metal contact refractories have shown less penetration and cracking than their standard counterparts.



ADTECH castables and gun mixes require no change in mixing with water, nor in application.* The ADTECH System is available with most H-W castables and gun mixes.

*Additives in the ADTECH System are considered non-toxic; however, the general application of any gunning material can produce nuisance dust, and for that reason, respirators should be used.

APPLICATION

To maximize heatups and maintain properties, please follow the mixing and curing instructions shown on the bag.

PROVEN IN A WIDE VARIETY OF APPLICATIONS.

Harbison-Walker experience with the ADTECH System includes successful installations in dozens of furnaces. Examples include rotary kilns, petrochemical vessels, coke oven repairs, AOD hoods, vertical channel induction furnaces, and other ferrous and nonferrous furnaces.

TO LEARN MORE ABOUT HOW YOU CAN GET THE SAFETY AND SECURITY OF ADTECH REFRACTORIES, CALL YOUR NEAREST H-W OFFICE.

*NOTE OF CAUTION: The danger of steam spalling exists with all castables and gun mixes, with or without non-metallic additions. However, when used properly, the ADTECH System offers great improvement over conventional gunning mixes and castables.

COMPETITIVE ADDITIVE | ADTECH ADDITIVE

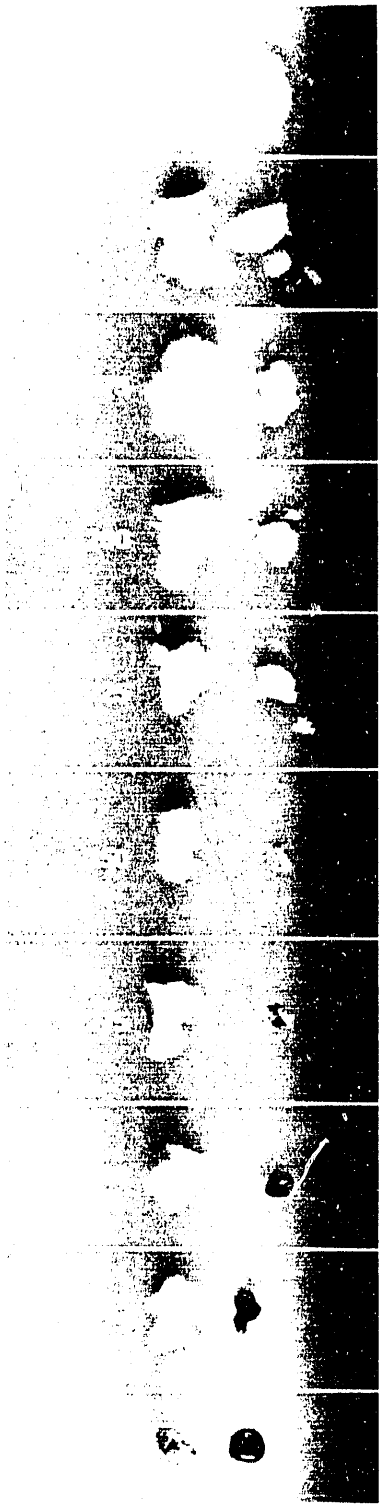


Figure 1. Laboratory testing shows that the ADTECH™ refractory system shrinks **as steam** evolves from the refractory lining, **well below** temperatures of shrinkage of other **additives.**

WATER RELEASE PASSAGEWAYS ARE THE KEY

Safer Heat-ups

During heat-up of castable and gun mix installations, the ADTECH™ refractory system shrinks and burns producing minute, water release passageways in the refractory. These tiny passageways greatly reduce the danger of steam spalling and allow safer maximum heat-ups by means of fast even release of both mechanical and chemically combined water. ADTECH™ refractory system protection is especially important for cold weather installation.

The Right Time

To be effective, any steam release system must be required to shrink and burn **at the right time,** i.e., when the mechanical water begins to turn to steam.

Figure 1 shows the results of laboratory tests. They reveal that the ADTECH™ refractory system permits shrinking and channel formation at 200°F or less—well below the 212°F boiling point of water—while competitive additives do not begin shrinkage and channel formation until 300°F or more.

According to a recent technical paper,[1] approximately one-half of the water loss in a castable or gunning mix occurs between 200 and 230°F.

The Right Size

Channel formation in the refractory must also be of the right size, i.e., very fine, in order not to impair such properties as strength and ability to contain molten metal and slag.

The ADTECH™ refractory system forms smaller channels than are found in other commercially available castable or gunning mix systems. Figure 2 shows scanning electron microprobe images from laboratory studies which revealed the channels in ADTECH™ refractory specimens to be at least 20% smaller than the competition. Permeability and resistance to metal penetration tests are run on samples of ADTECH™ refractory products from commercial production to check on proper physical characteristics.

Laboratory Designed

With the speed and safety of furnace turnarounds becoming increasingly more important, Harbison-Walker turned to their research and development facility to be sure that the approach they brought to the market place would provide the customer the best protection while having the least possible effect on other properties of their products. The ADTECH™ refractory system described here is the result of that intensive testing program.

ADTECH™ Refractory System | **Competitive Additive**

Figure 2. Enlarged 300 times, the ADTECH™ channel forming elements are 10 to 20% smaller than those developed in other products. Very small passages are necessary to maintain the properties of the monolith.

BETTER INSTALLATIONS

ADTECH™ Refractory System	A	B	C
Zonal Crushing Strength	0%	X%	Current ADTECH™ Refractory System
0-2 in. from Hot Face	Steam Spalled	Extensive cracking —no measurable strength	8200 psi
3-5 in. from Hot Face	9970 psi	9960 psi	11,560 psi
7-9 in. from Hot Face	9030 psi	10,700 psi	11,440 psi

Table 1: Experimental Castolast® G Samples

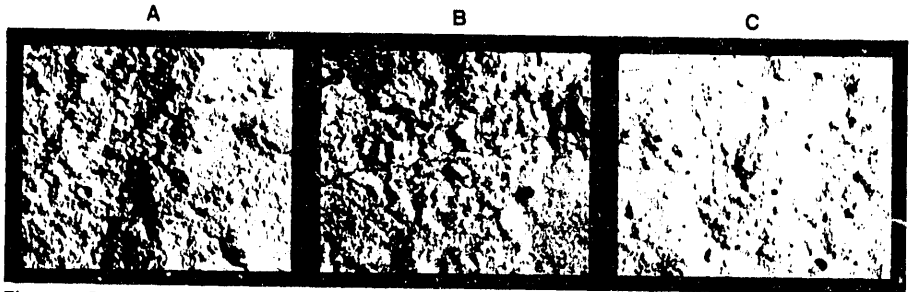


Figure 1: Photographs of samples from Table 1.

Better Installations

On initial heat-up of any dense castable or gunning mix installation must relieve the vapor pressure created as the water is driven off. Conventional compositions will spall away and/or create a network of cracks and crazes that weaken the structure and shorten service life. Often this damage is not visible on the surface of the lining.

With the ADTECH™ refractory system, cracking or crazing is reduced to a minimum and, therefore, the strength and integrity of the lining is increased. In other words, a **better installation can result.**

Faster initial heat-up rates demand the extra measure of protection afforded by the ADTECH™ refractory system.

Laboratory Testing

To provide documentation for the above proposition, we performed explosion tests on large 300 lb. blocks of CASTOLAST® G with and without the ADTECH™ refractory system. The test block is air dried only for 24 hours and then placed in the test furnace. A raging burner heats the block from one side, reaching 1900°F in 30 minutes and 2500°F in one hour. Table 1 shows the results obtained on specimens without an additive and with increasing amounts according to the patented ADTECH™ refractory system.

Two primary points emerge from this study:

1. The hot face of the samples visibly and dramatically improved in soundness as the ADTECH™ refractory system was increased to the current standard level (sample C).

2. However, even at a depth of 7 to 9 in. from the hot face, the strength of sample C was more than 25% greater than sample A without any treatment. This is strong evidence that damage in the form of micro cracking can penetrate deep into a castable lining and that the ADTECH™ refractory system provides **better linings as well as safer heat-ups.**

The technology incorporated into sample C is now incorporated into all ADTECH™ brand products.

Value Added Feature

The ADTECH™ refractory system is being furnished with all shipments of refractory brands such as CASTOLAST® G and GC, CASTOLAST® Gun Mix and DESCON™ A98 at no extra charge. Other products are available with the ADTECH™ refractory system feature at a slight premium.

Heat-up Schedules

When ADTECH™ castables or gunning mixes are used, initial heat-up rates can be accelerated. However, as with brick or plastic linings, the initial heat-up rates of ADTECH™ installations must be examined on an individual basis. Furnace size, lining thickness, material quality, expansion and temperature gradients vary with every installation and will affect the heat-up rates. Please discuss specific heat-up schedules with a Harbison-Walker field representative or your contractor installer.

The initial laboratory studies of the ADTECH™ refractory system were primarily directed toward safer heat-ups and sound, strong installations.

Additional technical work by Virginia Polytechnical Institute[1], Harbison-Walker and an independent laboratory has provided further evidence as to why the ADTECH™ refractory system works. It is also shown that ADTECH™ castable and gunning mix installations will be safer to dry out and heat up in cold weather, and that they have good metal contact properties and are more resistant to thermal shock.

The various technical studies and the field benefits they have yielded are tabulated in Table 1.

ADDITIONAL BENEFITS THROUGH TECHNOLOGY

Table 1

Technology	Field Benefits
• Fiber shrinkage studies (Bulletin #1) • SEM studies (Bulletin #1) • VPI internal pressure studies	Safer, faster heat-ups
• Explosion testing (Bulletin #2) • Zonal crushing strength tests (Bulletin #2)	Stronger installation
• Metal contact tests	Good metal contact properties
• Thermal cycling tests	Better resistance to thermal shock
• Curing temperature studies	Additional measure of protection in cold weather installations
• Crack resistance studies	Reduction of dry out cracks, improves service life

Table 2

Maximum Internal Pressure of 90% Alumina Castable Heated on One Face at 275°C/hr.		
Depth From Hot Face CM	Pressure, KPa Standard Castable	ADTECH™ Castable
2.5	723	572
7.6	723	614

Virginia Polytechnical Institute Studies

A unique probe, developed by VPI and reported to the ACS in 1982, is capable of measuring pressures developed within castables at various depths during the heat-up process. This probe was used to study internal pressures developed with 90% alumina castables both with and without ADTECH™ treatment, at two different depths in the casting. At the same depths the pressures developed within the ADTECH™ refractory system is 15 to 20% lower than in conventional castables—further evidence that the ADTECH™ refractory system can better facilitate steam release and provide safer heat-ups. (Shown in Table 2.)

Metal Contact Studies

The ability to use the ADTECH™ refractory system products in metal contact applications is indicated by the condition of laboratory samples shown in Figure 1. These cup samples held 7075 aluminum alloy—one which has great penetrating power—at 815°C for 5 days. There was no difference in aluminum penetration between the fiber free product and the ADTECH™ product. The residual aluminum was easily peeled off the ADTECH™ sample but stuck to the standard sample. This non-wetting phenomenon has been seen in a variety of ADTECH™ castables tested in the laboratory and is the subject of continuing investigation.

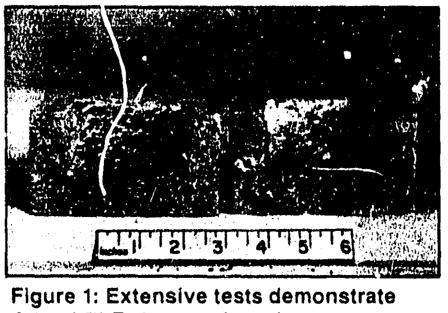


Figure 1: Extensive tests demonstrate Adtech™ Refractory's resistance to metal penetration.

Laboratory test results are now supported by two years of excellent field experience in metal contact applications.

Thermal Cycling Studies

The laboratory prism spalling test cycles samples between a hot furnace and a water quench repeatedly until they fail by cracking. In such procedures ADTECH™ refractory samples endured between 30 to 60% more cycles than did the standard samples.

Resistance to thermal cycling is not unexpected for products that contain the ADTECH™ refractory system. Crack propagation theory teaches that cracking is inhibited in ceramic bodies by discontinuities in the matrix. In the ADTECH™ refractory system, the discontinuities occur as regularly placed micro channels rather than macro pores or voids that are present in other spall resistant ceramics.

Such evidence indicates that ADTECH™ castables and gun mixes should be quite resistant to thermal shock under field conditions. Thermal shock occurs with removable roofs, intermittently heated chambers, ladles and runners where metal filling or flow is frequently interrupted.

Independent Laboratory Studies

Extensive published work by others[2] has shown that a major contributing factor to steam spalling in castables is the gel-like cement phases formed when castables are cured at temperatures below 70°F. The gel structure can act as an impenetrable barrier to the escape of steam during the drying and firing cycles.

The ADTECH™ refractory system successfully reduces the steam spalling tendency by increasing the micro permeability of castables and gun mixes during the drying and curing cycles, as shown in Figure 2. It is never recommended that castables or gun mixes be cured at temperatures as low as 50°F because strength will be impaired and steam spalling tendencies increased, whether or not they have the ADTECH™ refractory system. However, it is apparent that the ADTECH™ refractory system provides additional protection against steam spalling during heat-up even under these adverse conditons.

Crack Resistance—The Basic Benefit

On initial heat-up, any dense castable or gunning mix installation must relieve the vapor pressure created as the water is driven off. Often a network of cracks and crazes will be created which may not be visible to the naked eye but which can be penetrated by the furnace charge and then be more rapidly eroded. Studies of both laboratory samples and field samples reveal that with the ADTECH™ refractory system such cracking and crazing is minimized and furnace wear by penetration and erosion thereby minimized.

90% ALUMINA HIGH PURITY CEMENT CASTABLE EXPLOSION TEMP. °F vs CURING TEMP. °F

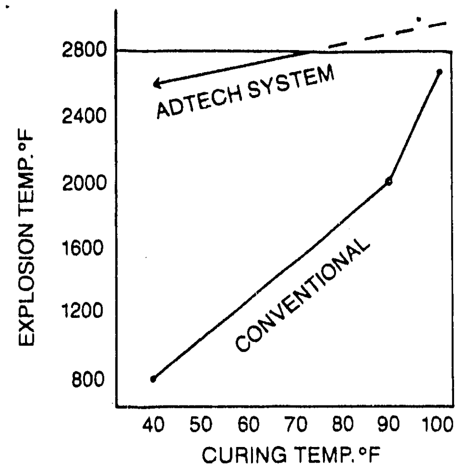


Figure 2: The steam spalling temperature is the highest furnace temperature that an undried 2.5 in. cube can withstand when placed in a hot furnace. The spalling temperature changes relative to the 24-hour curing conditions.[2]

Additives in the ADTECH™ refractory system are considered non-toxic; however, the general application of any gunning material can produce nuisance dust, and for that reason, respirators should be used.

NOTE OF CAUTION: The danger of steam spalling exists with all castables and gun mixes, with or without non-metallic additions. However, when used properly, the ADTECH™ refractory system offers greater improvement over conventional gunning mixes and castables.

TO LEARN MORE ABOUT THE SAFETY AND ENERGY SAVING FEATURES OF ADTECH™ REFRACTORIES, CALL YOUR NEAREST HARBISON-WALKER OFFICE.

[1] Hipps, D. L. and Brown, J. J. "Measurement of Internal Pressure in High Alumina Castable During Curing" presented to annual meeting of ACS, 1982.

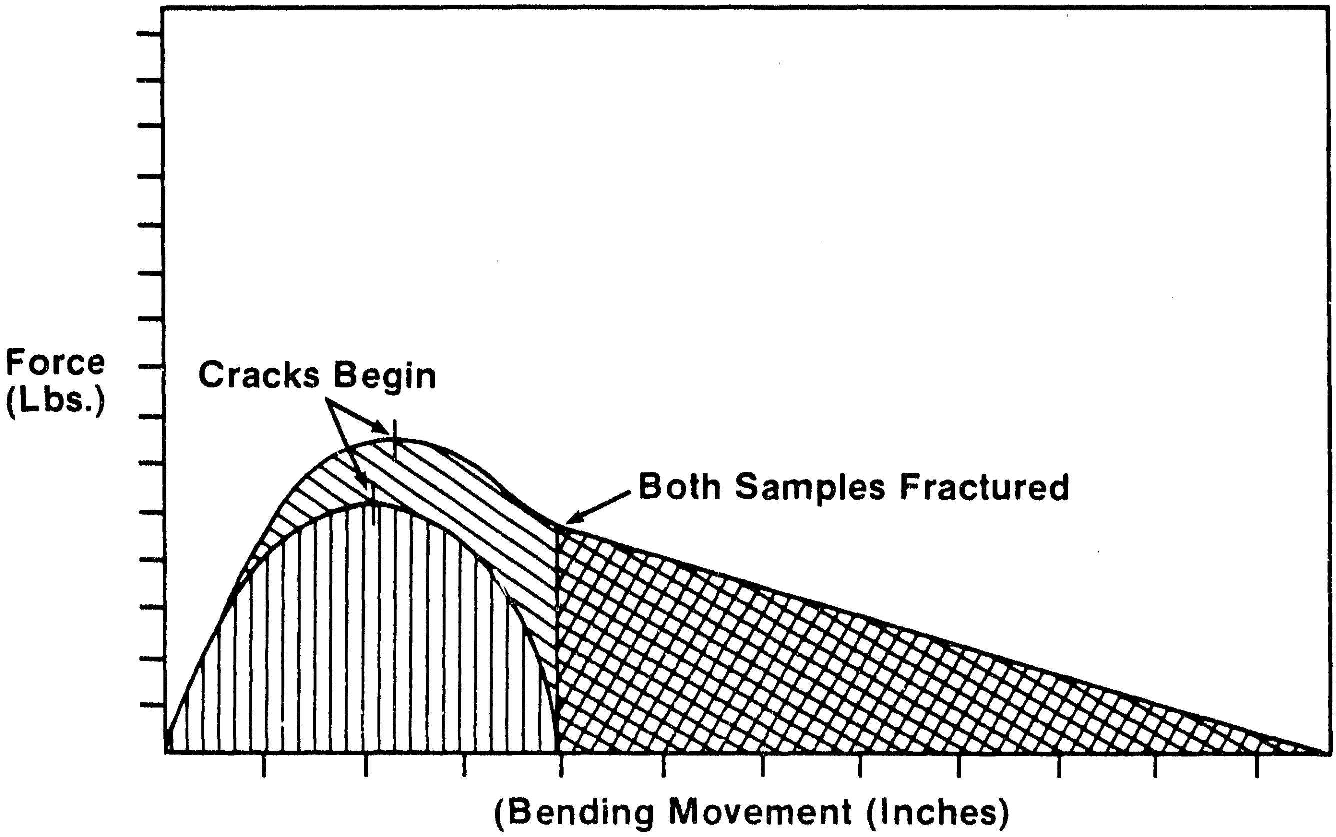
[2] Gitzen, W. H. and Hart, L. D. "Explosive Spalling of Refractory Castables Bonded with Calcium Aluminate Cement", Aluminum Company of America.

HARBISON-WALKER REFRACTORIES
Division of Dresser Industries, Inc.,
2 Gateway Center, Pittsburgh, Pennsylvania 15222

FIGURE A

TYPICAL WORK OF FRACTURE

Standard Refractory Castable
vs
Fiber Reinforced Refractory Castable



Standard Sample — Work or Energy Required to Crack, Fracture and Separate (Work of Fracture)

Fiber Sample — Additional Work Necessary to Crack and Fracture Fiber Reinforced Sample (Extra Crack Resistance)

Fiber Sample — Additional Work Necessary to Separate Fiber Reinforced Sample (Extra Holding Power)

- LIMITED DATA -

HARGUN ER

Technical Data:

Physical Properties: (Typical)	English Units	SI Units
Maximum Service Temperature	2,400°F	1,316°C
	lb/ft^3	kg/m^3
Gunning Mix Required (Net)	133	2,130
Bulk Density		
After Drying at 230°F (110°C)	141	2,260
	lb/in^2	kPa
Modulus of Rupture		
After Drying at 230°F (110°C)	1,200 to 1,800	8,300 to 12,400
After Heating at 1500°F (815°C)	1,000 to 1,600	6,900 to 11,000
Cold Crushing Strength		
After Drying at 230°F (110°C)	7,000 to 12,000	48,300 to 82,700
After Heating at 1500°F (815°C)	6,000 to 11,000	41,400 to 75,800
Permanent Linear Change, %		
After Drying at 230°F (110°C)	Negligible	
After Heating at 1500°F (815°C)	-0.0%	

Chemical Analysis:
(Approximate)
(Calcined Basis)

Silica	(SiO_2)	31.0%
Alumina	(Al_2O_3)	60.3
Titania	(TiO_2)	1.6
Iron Oxide	(Fe_2O_3)	0.7
Lime	(CaO)	6.1
Magnesia	(MgO)	0.1
Alkalies	$(Na_2O+K_2O+Li_2O)$	0.2

All data based on gunned specimens. ASTM procedures, where applicable, used for determination of data.

All data subject to reasonable deviation, and therefore, should not be used for specification purposes.

 (Continued)

- LIMITED DATA -

HARCAST ER

Technical Data:

Physical Properties: (Typical)	English Units	SI Units
Maximum Service Temperature	2,400°F	1,316°C
	lb/ft^3	kg/m^3
Dry Weight Required for Casting	135	2,160

Approximate Amount of Water Required
Per 100 Lbs. 1 1/4 to 1 1/2 U.S. Gallons
Per 45.36 Kg. 4.72 to 5.68 Liter

	lb/ft^3	kg/m^3
Bulk Density		
After Drying at 230°F (110°C)	142	2,270
	lb/in^2	kPa
Modulus of Rupture		
After Drying at 230°F (110°C)	1,850	12,800
After Heating at 1500°F (815°C)	2,310	15,900
After Heating at 2700°F (1480°C)	3,710	25,600
Cold Crushing Strength		
After Drying at 230°F (110°C)	8,740	60,300
After Heating at 1500°F (815°C)	9,190	63,400
After Heating at 2700°F (1480°C)	9,400	64,800

Permanent Linear Change, %	
After Drying at 230°F (110°C)	Negligible
After Heating at 1500°F (815°C)	0.0
After Heating at 2700°F (1480°C)	-4.4

Chemical Analysis:
(Approximate)
(Calcined Basis)

Silica	(SiO_2)	31.0%
Alumina	(Al_2O_3)	60.3
Titania	(TiO_2)	1.6
Iron Oxide	(Fe_2O_3)	0.7
Lime	(CaO)	6.1
Magnesia	(MgO)	0.1
Alkalies	($Na_2O+K_2O+Li_2O$)	0.2

(Continued)

-LIMITED DATA-

HARGUN ES

Technical Data:

Physical Properties: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Gunning Mix Required	130	2,080
Bulk Density		
After Drying at 230°F (110°C)	135	2,160
	lb/in^2	kPa
Modulus of Rupture		
After Drying at 230°F (110°C)	900 to 1,400	6,200 to 9,700
After Heating at 1500°F (816°C)	700 to 1,200	4,800 to 8,300
After Heating at 2700°F (1482°C)	2,000 to 2,500	13,800 to 17,200
Cold Crushing Strength		
After Drying at 230°F (110°C)	4,000 to 8,000	27,600 to 55,200
After Heating at 1500°F (816°C)	4,000 to 8,000	27,600 to 55,200
After Heating at 2700°F (1482°C)	9,000 to 13,000	62,100 to 89,600
Permanent Linear Change, %		
After Heating at 1500°F (816°C)	0.0 to -0.3	
After Heating at 2700°F (1482°C)	-0.3 to -0.8	

Chemical Analysis:
(Approximate)
(Calcined Basis)

Silica	(SiO_2)	35.3%
Alumina	(Al_2O_3)	55.7
Titania	(TiO_2)	1.6
Iron Oxide	(Fe_2O_3)	0.8
Lime	(CaO)	5.5
Magnesia	(MgO)	0.3
Alkalies	($Na_2O+K_2O+Li_2O$)	0.8

All data based on gunned specimens. ASTM procedures, where applicable, used for determination of data.

All data subject to reasonable deviation and therefore should not be used for specification purposes.

 (Continued)

- LIMITED DATA -

HARVIBE
(Formerly H-W 18-84)

Technical Data:

Physical Properties: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Dry Weight Required for Casting	140	2,240
Approximate Amount of Water Required		
Per 100 Lbs.	1 to 1 1/8 U.S. Gallons	
Per 45.36 Kg.		3.79 to 4.26 Liters
	lb/ft^3	kg/m^3
Bulk Density		
After Drying at 230°F (110°C)	148	2,370
	lb/in^2	kPa
Modulus of Rupture		
After Drying at 230°F (110°C)	1,500	10,300
After Heating at 1500°F (815°C)	1,700	11,700
After Heating at 2700°F (1480°C)	1,900	13,100
Cold Crushing Strength		
After Drying at 230°F (110°C)	8,600	59,300
After Heating at 1500°F (815°C)	16,600	114,500
After Heating at 2700°F (1480°C)	12,000	82,700
Permanent Linear Change, %		
After Drying at 230°F (110°C)	Negligible	
After Heating at 1500°F (815°C)	-0.2	
After Heating at 2700°F (1480°C)	+1.3	

Chemical Analysis: (Approximate)
(Calcined Basis)

Silica	(SiO_2)	32.4%
Alumina	(Al_2O_3)	59.7
Titania	(TiO_2)	1.4
Iron Oxide	(Fe_2O_3)	0.7
Lime	(CaO)	5.0
Magnesia	(MgO)	0.2
Alkalies	($Na_2O+K_2O+Li_2O$)	0.6

 (Continued)

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One Gateway Center, Pittsburgh, PA 15222

HARCAST ES

Technical Data:

Physical Properties: (Typical)	English Units	SI Units
Maximum Service Temperature	2,800°F	1,540°C
	lb/ft^3	kg/m^3
Dry Weight Required for Casting	132	2,115
Approximate Amount of Water Required		
Per 100 Lbs.	1 1/4 to 1 1/2 U.S. Gal.	
Per 45.36 Kg.		4.73 to 5.68 Liters
Bulk Density	lb/ft^3	kg/m^3
After Drying at 230°F (110°C)	138	2,210
	lb/in^2	kPa
Modulus of Rupture		
After Drying at 230°F (110°C)	1,000 to 1,500	6,900 to 10,30
After Heating at 1000°F (540°C)	900 to 1,300	6,200 to 9,000
After Heating at 1500°F (815°C)	900 to 1,300	6,200 to 9,000
After Heating at 2700°F (1480°C)	1,200 to 1,900	8,300 to 13,10
Cold Crushing Strength		
After Drying at 230°F (110°C)	6,000 to 9,000	41,400 to 62,10
After Heating at 1000°F (540°C)	5,000 to 7,000	34,500 to 48,30
After Heating at 1500°F (815°C)	5,000 to 7,000	34,500 to 48,30
After Heating at 2700°F (1480°C)	8,000 to 10,000	55,200 to 69,00
Permanent Linear Change, %		
After Drying at 230°F (110°C)	Negligible	
After Heating at 1000°F (540°C)	Negligible	
After Heating at 1500°F (815°C)	Negligible	
After Heating at 2700°F (1480°C)	-1.5 to 0.0	

Chemical Analysis:
(Approximate)
(Calcined Basis)

Silica	(SiO_2)	35.6%
Alumina	(Al_2O_3)	55.6
Titania	(TiO_2)	1.6
Iron Oxide	(Fe_2O_3)	0.8
Lime	(CaO)	5.4
Magnesia	(MgO)	0.3
Alkalies	($Na_2O+K_2O+Li_2O$)	0.7

(Continued)

KALA

(Formerly H-W 1-77)

Classification: High Alumina Brick

Physical Data: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Bulk Density	150 to 155	2,400 to 2,480
Apparent Porosity, %	13.0 to 15.0	13.0 to 15.0
	lb/in^2	kPa
Cold Crushing Strength, psi	6,000 to 9,000	41,400 to 62,100
Modulus of Rupture, psi	1,500 to 2,500	10,300 to 17,200

Reheat Test
Permanent Linear Change, %
After Heating at 2910°F (1600°C) — 0.0 to +0.5

Load Test, 25 psi (172 kPa)
% Linear Subsidence
After Heating to 2640°F (1450°C) — 0.0 to 0.5

Chemical Analysis:
(Approximate)

Silica	(SiO_2)	46.4%
Alumina	(Al_2O_3)	49.6
Titania	(TiO_2)	2.2
Iron Oxide	(Fe_2O_3)	1.4
Lime	(CaO)	0.1
Magnesia	(MgO)	0.1
Alkalies	($Na_2O+K_2O+Li_2O$)	0.2

The above data are typical of properties of commercial 9" straight brick. The data are subject to reasonable variations and therefore, should not be used in specification purposes.

ASTM Test Methods, where applicable, used for determination of data.

HARBISON-WALKER REFRACTORIES
DRESSER
Dresser Industries, Inc.
One Gateway Center, Pittsburgh, PA 15222

UFALA

Classification: High-Alumina Brick

Physical Data: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Bulk Density	156 to 160	2,500 to 2,565
Apparent Porosity, %	12.0 to 16.0	12.0 to 16.0
	lb/in^2	kPa
Cold Crushing Strength	7,000 to 10,000	48,300 to 69,00
Modulus of Rupture	2,500 to 3,300	17,300 to 22,80

Reheat Test Permanent Linear Change (%) After Heating at 2910°F (1600°C)	0.0 to -0.5
Load Test, 25 psi (172 kPa) % Linear Subsidence After Heating at 2640°F (1450°C)	0.1 to 0.5
Panel Spalling Test % Loss Preheat - 3000°F (1650°C)	0 to 3

Chemical Analysis:
(Approximate)

Silica	(SiO_2)	37.0%
Alumina	(Al_2O_3)	58.7
Titania	(TiO_2)	2.5
Iron Oxide	(Fe_2O_3)	1.4
Lime	(CaO)	0.[illegible]
Magnesia	(MgO)	0.1
Alkalies	($Na_2O+K_2O+Li_2O$)	0.2

The above data are typical of the properties of commerical 9" straight brick. The data are subject to reasonable variations and therefore should not be used for specification purposes.

ASTM Test Methods, where applicable, used for determination of data.

Protected by U.S. Patent No. 3,241,989.

See reverse side for cutting recommendations.

CORAL BP

Classification: High Alumina Brick - Phosphate Bonded (Burned)

Physical Data: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Bulk Density	175 to 180	2,800 to 2,880
Apparent Porosity, %	14.0 to 18.0	14.0 to 18.0
	lb/in^2	kPa
Cold Crushing Strength	10,000 to 16,000	69,000 to 110,300
Modulus of Rupture	2,700 to 3,500	18,600 to 24,100
Reheat Test Permanent Linear Change, % After Heating at 2910°F (1600°C)	+0.5 to -0.6	
Load Test, 25 psi (172 kPa) % Linear Subsidence After Heating at 2640°F (1450°C)	0.5 to 1.2	

Chemical Analysis:
(Approximate)

Silica	(SiO_2)	9.6%
Alumina	(Al_2O_3)	81.8
Titania	(TiO_2)	2.1
Iron Oxide	(Fe_2O_3)	1.1
Phosphorous Pentoxide	(P_2O_5)	5.4

The above data are typical of the properties of commercial 9" straight brick. The data are subject to reasonable variations and therefore should not be used for specification purposes.

ASTM Test Methods, where applicable, used for determination of data.

Patent Applied For.

See reverse side for cutting recommendations.

HARBISON-WALKER REFRACTORIES
Dresser Industries, Inc.
One Gateway Center, Pittsburgh, PA 15222

KORUNDAL XD

Classification: High Alumina Brick

Physical Properties: (Typical)	English Units	SI Units
	lb/ft^3	kg/m^3
Bulk Density	181 to 185	2,900 to 2,960
Apparent Porosity, %	14.0 to 18.0	14.0 to 18.0
	lb/in^2	kPa
Cold Crushing Strength	9,000 to 14,000	62,100 to 96,600
Modulus of Rupture	2,000 to 3,000	13,800 to 20,700

Reheat Test Permanent Linear Change, % After Heating at 3140°F (1725°C)	+0.6 to +1.0
Load Test, 25 psi (172 kPa) After Heating at 3300°F (1815°C)	0.3 to 1.4
Panel Spalling Test % Loss Preheat - 3000°F (1650°C)	0 to 0

Chemical Analysis:
(Approximate)

Silica	(SiO_2)	11.0%
Alumina	(Al_2O_3)	88.1
Titania	(TiO_2)	0.3
Iron Oxide	(Fe_2O_3)	0.2
Lime	(CaO)	0.1
Magnesia	(MgO)	0.04
Alkalies	($Na_2O+K_2O+Li_2O$)	0.2

The above data are typical of the properties of commercial 9" straight brick. The data are subject to reasonable variations and therefore should not be used for specification purposes.

ASTM Test Methods, where applicable, used for determination of data.

See reverse side for cutting recommendations.

Protected by U.S. Patent #3,067,050

HARBIDE GUNNING MIX 80

Technical Data:	English Units	SI Units
Physical Properties: (Typical)	lb/ft^3	Kg/m^3
Gunning Mix Required (Net)	140	2,240
Bulk Density	lb/ft^3	Kg/m^3
After Drying at 230°F (110°C)	145	2,320
Modulus of Rupture	lb/in^2	KPa
After Drying at 230°F (110°C)	800 to 1,100	5,500 to 7,600
After Heating at 1500°F (815°C)	800 to 1,100	5,500 to 7,600
After Heating at 2730°F (1500°C)	2,200 to 2,800	15,200 to 19,300
Cold Crushing Strength		
After Drying at 230°F (110°C)	3,000 to 6,000	20,700 to 41,400
After Heating at 1500°F (815°C)	2,000 to 5,000	13,800 to 34,500
After Heating at 2730°F (1500°C)	3,000 to 6,000	20,700 to 41,400
Permanent Linear Change %		
After Drying at 230°F (110°C)	Negligible	
After Heating at 1500°F (815°C)	0.0 to - 0.1	
After Heating at 2730°F (1500°C)	- 0.1 to - 1.0	

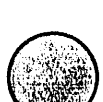
Chemical Analysis:
(Approximate)

Silicon Carbide	(SiC)	77.0%
Silica	(SiO_2)	1.7
Alumina	(Al_2O_3)	16.6
Titania	(TiO_2)	0.1
Iron Oxide	(Fe_2O_3)	0.7
Lime	(CaO)	3.7
Magnesia	(MgO)	0.1
Alkalies	($Na_2O+K_2O+Li_2O$)	0.1

(Continued)

E SHOT Products

se products combine some of the features of dense, face gunning mixes and lightweight products. They used where a single material must contain heat and ure low thermal conductivity as well. Some typical lications include process heaters, regenerators, ters and stacks in the petrochemical and chemical istries.



HOTGUN® Products

These products are designed for low rebound application to hot surfaces for purposes of maintenance.

Hot Gunning Applications:

- Slagline maintenance in induction furnaces and other melting equipment in the ferrous foundry.
- Dressing upper sidewalls and door jambs in aluminum reverb furnaces
- General maintenance in copper converters and copper reverb furnaces.

-W® LIGHTWEIGHT ES efractory	H-W® 28-75	HOTGUN® 28	HOTGUN® 29	KORUNDAL® GUN MIX
escription, applications: combination of standard calcium aluminate ement and calcined ays. This material has isulating value, as well high intermediate mperature strengths. nlike most high caliber ixes this product can so be used in cast stallations.	**Description, applications:** Another single lining material that by itself can perform like a backed up or two-component lining. This blend of high temperature calcines, lightweight aggregate and high purity calcium aluminate cement features highest refractoriness combined with good insulation and strength.	**Description, applications:** HOTGUN 28 is a combination of superduty fireclay plus improved calcium aluminate cement intended for application to hot surfaces. It features good strength, high refractoriness and extremely low rebound loss.	**Description, applications:** HOTGUN 29 is a high (70%) alumina, high purity, calcine mix blended with an improved calcium aluminate binder. It is characterized by good volume stability, strength and high refractoriness. HOTGUN 29 is specifically designed for application to hot surfaces.	**Description, applications:** KORUNDAL® GUN MIX is the hot application version of a famous high purity 90% alumina refractory family. Its blend of high purity calcium aluminate binder yields excellent gunnability plus superior slag and corrosion resistance.
2300 F	2900 F	2800 F	2900 F	3100 F
88 pcf	80 pcf	114 pcf	142 pcf	147 pcf
8-10%	10%	None	None	None
30/30 psi	30/30 psi	40/35 psi	40/35 psi	40/25 psi
5-10%	5%	15-20%	5-10%	10-15%
pcf	pcf	pcf	pcf	pcf
96	83	122	144	150
88	80	114	142	147
psi	psi	psi	psi	psi
760	190	260	250	250 to 400
450	60	—	270	300 to 500
—	880 @ 2550 F	240 @ 200 F	1320 @ 3000 F	1500 to 3000 @ 3000 F
450 @ 2500 F	1820 @ 2850 F	900 @ 2730 F	—	—
psi	psi	psi	psi	psi
4330	450	700	3070	300 to 600
2750	370	—	3880	1000 to 3000
—	1510 @ 2550 F	960 @ 200 F	4330 @ 3000 F	4000 to 8000 @ 3000 F
2240 @ 2500 F	2470 @ 2850 F	3290 @ 2730 F	—	—
%	%	%	%	%
Negligible	Negligible	Negligible	Negligible	—
0.0	−0.5	—	0.0	0.0 to −0.3
—	+0.5 @ 2550 F	−0.2 @ 2000 F	+5.6 @ 3000 F	−1.8 to −3.5 @ 3000 F
+1.7 @ 2500 F	−0.8 @ 2850 F	−1 to +1 @ 2730 F	—	—
%	%	%	%	%
39.1	37.5	48.5	23.0	9.1
33.7	54.0	43.8	70.2	88.1
1.9	1.6	2.5	2.6	0.5
6.9	1.1	1.9	1.6	0.7
14.8	4.4	1.9	1.9	1.3
1.3	0.1	0.3	0.2	0.1
2.3	1.3	1.1	0.3	0.2

****LABORATORY PROPERTIES OF AS-GUNNED MATERIAL**

All data based on specimens resulting from actual gunning performed as described under Installation Data, Note 1. ASTM procedures, where applicable, were used for determination of data. All data are subject to reasonable deviation and, therefore, should not be used for specification purposes.

DENSE Products

For application as original hot face linings and for repairs in furnaces, process vessels and lines, stacks and process equipment of all kinds. These products provide graded resistance to elevated temperatures, abrasion and chemical atmospheres. When installed according to directions, these products will yield properties close to those shown in these tables. All products were designed for minimum loss due to rebounds during installation.

	ALKAGUN®	TUFSHOT®	TUFSHOT® LI	HARGUN®
	Description, applications: A blend of semi-vitreous aggregate with portland cement binder. ALKAGUN® refractory gunning mix has high strength and excellent resistance to abrasion and to alkaline and caustic solutions.	**Description, applications:** TUFSHOT® refractory gunning mix is a composition of hardfired fireclay base and standard calcium aluminate binder. It exhibits low permeability plus good resistance to mechanical impact and abrasion throughout its temperature range.	**Description, applications:** TUFSHOT® LI refractory gunning mix is composed of hardfired fireclay aggregate with calcium aluminate binder that's especially low in iron oxide. It has excellent resistance to destruction by carbon monoxide due to its low iron content.	**Description, applic** HARGUN® refractory ning mix is a blend superduty fireclay c cines and high puri cium aluminate bin features resistance t high temperatures high resistance to abrasion.
GUN INSTALLATION DATA*				
Maximum service temp.	2200 F (continuous)	2400 F	2600 F	2800 F
Gunned density after firing	125 pcf	121 pcf	121 pcf	120 pcf
Predampened water req'd by wt.	4%	4%	4-6%	5%
Air and mix feed pressures	40/25 psi	40/25 psi	40/25 psi	40/25 psi
Rebound loss, approx. by wt.	5-10%	10-15%	10-15%	5-10%
PROPERTIES OF GUNNED REFRACTORY**				
Bulk density	pcf	pcf	pcf	pcf
After drying at 230 F	129	124	131	124
After heating at 1500 F	125	117	121	120
Modules of rupture	psi	psi	psi	psi
After drying at 230 F	900 to 1300	500 to 800	1000 to 1300	540
After heating at 1500 F	300 to 600	300 to 500	400 to 700	290
After heating at temp. shown, F	—	—	—	1080 @ 2550 F
After heating at temp. shown, F	—	400 to 800 @ 2300 F	600 to 1000 @ 2500 F	1890 @ 2730 F
Cold crushing strength	psi	psi	psi	psi
After drying at 230 F	4000 to 7000	2500 to 3500	5000 to 8000	1650
After heating at 1500 F	1500 to 3000	2000 to 3000	3000 to 5000	1770
After heating at temp. shown, F	—	2700 @ 1000 F	—	2610 @ 2550 F
After heating at temp. shown, F	—	2000 to 4000 @ 2300 F	4000 to 6000 @ 2500 F	5680 @ 2730 F
Permanent linear change	%	%	%	%
After drying at 230 F	Negligible	Negligible	Negligible	Negligible
After heating at 1500 F	−0.4 to 0.6	−0.2 to −0.5	0.0 to −0.4	−0.2
After heating at temp. shown, F	—	—	—	−1.3 @ 2550 F
After heating at temp. shown, F	—	−0.6 to −1.0 @ 2300 F	0.0 to +1.0 @ 2500 F	+0.7 @ 2730 F
Chemical analysis (approximate)	%	%	%	%
Silica (SiO_2)	45.8	40.0	39.2	44.1
Alumina (Al_2O_3)	35.7	44.2	46.5	47.2
Titania (TiO_2)	1.8	2.5	2.2	2.1
Iron Oxide (Fe_2O_3)	1.6	4.0	1.3	1.0
Lime (CaO)	13.7	8.2	9.7	4.7
Magnesia (MgO)	0.7	0.4	0.4	0.3
Alkalies ($Na_2O+K_2O+Li_2O$)	0.7	0.7	0.7	0.6

***INSTALLATION DATA**
These data were obtained under laboratory conditions as follows: indoors at normal room ambient temperatures using an Allentown N-1 gun with a 24.6:1 feed motor to wheel ratio and 50 feet of hose. Air and material feed pressure were controlled. Water and gunning mix temperatures were normal indoor ambient. Gunning was done on a flat vertical wall. Gunned material thickness was about 8 inches. Note: Actual field gunning conditions may vary and therefore yield different results. These data are presented only as ideals and for comparing one mix with another under identical conditions.

HARGUN® BF	HARGUN® ES	HARGUN® ER	ALUSA® Gun Mix	CASTOLAST® Gun Mix
Description, applications: HARGUN® BF is a higher strength version of HARGUN compounded particularly for gunning blast furnace linings. It is made of selected superduty fireclay calcines and a binder of high purity calcium aluminate cement.	**Description, applications:** HARGUN® ES refractory gunning mix offers excellent strength in a fireclay based gunning product. It is made of selected superduty fireclay calcines and a binder of high strength, high purity calcium aluminate cement. It has excellent strength and abrasion resistance throughout its temperature range.	**Description, applications:** HARGUN® ER gunning mix uses a fireclay base and a high strength, high purity calcium aluminate cement binder to offer the best abrasion resistance in its class. HARGUN ER is designed to maximize erosion resistance in extreme abrasion areas in refineries and other tough applications.	**Description, applications:** ALUSA® GUN MIX is a high alumina refractory mix of high purity bauxite aggregate and high strength, high purity calcium aluminate binder. Features are exceptional refractoriness and volume stability.	**Description, applications:** CASTOLAST® GUN MIX is the gunning version of a famous castable refractory generally specified for the most extreme conditions. It consists of a blend of tabular alumina aggregate and high strength, high purity calcium aluminate cement.
2800 F	2800 F	2400 F	3000 F	3300 F
120 pcf	130 pcf	133 pcf	130 pcf	157 pcf
4-6%	4-6%	3-4%	4%	4%
40/25 psi	40/25 psi	40/25 psi	40/25 psi	40/25 psi
10-20%	15%	10-20%	10-20%	10-20%
pcf	pcf	pcf	pcf	pcf
125	135	141	135	165
120	130	132	130	157
psi	psi	psi	psi	psi
750	900 to 1400	1200 to 1800	770	1300 to 1900
—	700 to 1200	1000 to 1600	580	1000 to 1500
550 @ 1750 F	2000 to 2500 @ 2700 F	—	1630 @ 2550 F	1300 to 1900 @ 2550 F
2800 @ 2800 F	—	—	2520 @ 2910 F	1500 to 2100 @ 3000 F
psi	psi	psi	psi	psi
3200	4000 to 8000	7000 to 12000	2200	8000 to 12000
—	4000 to 8000	6000 to 11000	2680	6000 to 10000
2600 @ 1750 F	9000 to 13000 @ 2700 F	—	4510 @ 2550 F	6000 to 10000 @ 2550 F
8200 @ 2800 F	—	—	7240 @ 2910 F	5000 to 9000 @ 3000 F
%	%	%	%	%
Negligible	—	Negligible	Negligible	—
—	0.0 to −0.3	0.0	−0.2	0.0 to −0.3
−0.4 @ 1750 F	−0.3 to −0.8 @ 2700 F	—	−0.1 @ 2550 F	−0.4 to −0.6 @ 2550 F
−0.5 @ 2800 F	—	—	+1.6 @ 2910 F	−0.2 to −1.0 @ 3000 F
%	%	%	%	%
41.4	35.3	31.0	32.1	0.2
51.1	55.7	60.3	61.0	94.0
1.8	1.6	1.6	2.2	—
0.6	0.8	0.7	0.9	0.2
4.1	5.5	6.1	3.2	5.3
0.3	0.3	0.1	0.2	0.1
0.7	0.8	0.2	0.4	0.2

****LABORATORY PROPERTIES OF AS-GUNNED MATERIAL**
All data based on specimens resulting from actual gunning performed as described under Installation Data, Note 1. ASTM procedures, where applicable, were used for determination of data. All data are subject to reasonable deviation and, therefore, should not be used for specification purposes.

Fireclay Castable Refractories

Brands	H-W® ES Castable	H-W® ES Castable LI	KILNCAST-26®	HARCAST®
Maximum Service Temperature °F.	2400	2600	2600	2800
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	1.75-2.0	1.5-1.75	1.25-1.5	1.5-1.75
Lbs. Dry Mix Required/cu. ft.	121	122	130	123
Application	C-R-T	C-R-T	C	C
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	130	130	135	129
MOR, psi After Drying at 230°F. (110°C)	900-1200	1000-1500	800-1200	800-1100
After Heating at 1000°F. (540°C)	500-800	500-800	300-600	300-450
at 1500°F. (815°C)	500-800	500-800	300-600	300-450
at 2300°F. (1260°C)	500-800			
at 2500°F. (1370°C)		600-1000	700-1200	
at 2700°F. (1480°C)				600-900
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	4500-7000	6000-9000	6000-9000	3500-5000
After Heating at 1000°F. (540°C)	3500-5000	4000-6000	4000-7000	3000-4000
at 1500°F. (815°C)	3100-4500	4000-6000	4000-7000	3000-4000
at 2300°F. (1260°C)	2500-4000			
at 2500°F. (1370°C)		3000-5000	2000-5000	
at 2700°F. (1480°C)				7000-9000
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible	Negligible	Negligible
After Heating at 1000°F. (540°C)	0.0 to −0.3	0.0 to −0.3	Negligible	Negligible
at 1500°F. (815°C)	0.0 to −0.3	0.0 to −0.3	Negligible	Negligible
at 2300°F. (1260°C)	+1.5 to −1.0			
at 2500°F. (1370°C)		+1.0 to +3.0	+0.5 to +4.0	0.0 to +1.5
Chemical Analysis: Silica (SiO_2)	32.8%	37.0%	39.7%	49.2%
Alumina (Al_2O_3)	43.6	48.0	46.5	42.7
Titania (TiO_2)	2.9	2.5	2.5	1.5
Iron Oxide (Fe_2O_3)	7.3	1.2	1.5	0.7
Lime (CaO)	12.0	10.3	8.5	5.0
Magnesia (MgO)	0.4	0.4	0.5	0.3
Alkalies ($Na_2O + K_2O + Li_2O$)	1.0	0.6	0.8	0.6

Application methods: C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†This castable is bonded with high purity strength calcium aluminate cement. If proper procedures for preparation, application and heat-up of this castable are not observed, steam spalling during heat-up may occur. (See instructions on product bag wrapping).

Fireclay Castable Refractories

Brands	HARCAST* C	HARCAST* ES*	HARCAST* ER*†
Maximum Service Temperature °F.	2800	2800	2400
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	1.5-1.75	1.25-1.5	1.25-1.5
Lbs. Dry Mix Required/cu. ft.	129	132	135
Application	C	C-T	C
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	133	138	142
MOR, psi After Drying at 230°F. (110°C)	800-1100	1000-1500	1850
After Heating at 1000°F. (540°C)	300-500	900-1300	
at 1500°F. (815°C)	300-500	900-1300	2310
at 2700°F. (1480°C)	1000-1300	1200-1900	3710
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	5000-7000	6000-9000	8740
After Heating at 1000°F. (540°C)	3000-5000	5000-7000	
at 1500°F. (815°C)	3000-5000	5000-7000	9190
at 2700°F. (1480°C)	4000-7000	8000-10,000	9400
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible	Negligible
After Heating at 1000°F. (540°C)	Negligible	Negligible	
at 1500°F. (815°C)	Negligible	Negligible	0.0
at 2700°F. (1480°C)	+1.0 to +2.0	−1.5 to 0.0	−4.4
Chemical Analysis:			
Silica (SiO_2)	49.2%	35.6%	31.0%
Alumina (Al_2O_3)	42.7	55.6	60.3
Titania (TiO_2)	1.5	1.6	1.6
Iron Oxide (Fe_2O_3)	0.7	0.8	0.7
Lime (CaO)	5.0	5.4	6.1
Magnesia (MgO)	0.3	0.3	0.1
Alkalies ($Na_2O + K_2O + Li_2O$)	0.6	0.7	0.2

Application methods: C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†This castable is bonded with high purity strength calcium aluminate cement. If proper procedures for preparation, application and heat-up of this castable are not observed, steam spalling during heat-up may occur. (See instructions on product bag wrapping).

Harbison-Walker High-Alumina Castable Refractories

Brands	H-W® High-Alumina Castable	UFALA® Castable*†	ALUSA® Castable*	CASTOLAST® G*† With C-CURED™	CASTOLAST® GC* With C-CURED™
Maximum Service Temperature °F.	3000	3100	3200	3300	3300
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	1.25-1.5	1.0-1.25	1.0-1.25	1.0-1.25	.75-1.0
Lbs. Dry Mix Required/cu. ft.	137	143	143	160	170
Application	C-T	C-T	C-T	C-T	C-T
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	139	144	146	165	174
MOR, psi After Drying at 230°F. (110°C)	400-800	600-900	400-800	1400-1800	1200-1700
After Heating at 1000°F. (540°C)	250-550		400-800		
at 1500°F. (815°C)	250-550		400-800	1300-1700	1200-1700
at 3000°F. (1650°C)	1000-1800				1100-1600
at 3140°F. (1725°C)			1700-2100	1300-1700	
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	1500-3500	3500-5500	2000-5000	7000-11,000	7000-12,000
After Heating at 1000°F. (540°C)	1700-3000		2000-4000		
at 1500°F. (815°C)	1700-3000		2000-4000	7000-11,000	7000-12,000
at 3000°F. (1650°C)	6000-9000				5000-9000
at 3140°F. (1725°C)			5000-9000	6000-9000	
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible		Negligible		
After Heating at 1000°F. (540°C)	Negligible		Negligible		
at 1500°F. (815°C)	0.0 to −0.5	Negligible	Negligible	Negligible	Negligible
at 3000°F. (1650°C)	+1.0 to +3.5	0.0 to 0.7			−0.2 to −1.2
at 3140°F. (1725°C)			−0.5 to +2.0	0.0 to −1.0	
Chemical Analysis: Silica (SiO_2)	31.5%	34.9%	23.3%	0.2%	0.1%
Alumina (Al_2O_3)	60.5	59.3	70.8	94.0	94.9
Titania (TiO_2)	2.9	2.3	2.4	Trace	Trace
Iron Oxide (Fe_2O_3)	1.1	1.0	1.0	0.2	0.2
Lime (CaO)	3.5	2.2	2.2	5.3	4.5
Magnesia (MgO)	0.2		0.1	0.1	0.1
Alkalies ($Na_2O + K_2O + Li_2O$)	0.3	0.2	0.2	0.2	0.2

Application methods: C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†This castable is bonded with high purity strength calcium aluminate cement. If proper procedures for preparation, application and heat-up of this castable are not observed, steam spalling during heat-up may occur. (See instructions on product bag wrapping).

Harbison-Walker Lightweight, Insulating Castables

Brands	H-W® Lightweight Castable 16	H-W® Lightweight Castable 20	H-W® Lightweight Castable 22	H-W® Lightweight Castable 26	H-W® Lightweight Castable 28
Maximum Service Temperature °F.	1600	2000	2200	2600	2800
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	4.0-5.0	5.0-6.5	2.5-3.0	3.0-3.5	3.0-3.5
Lbs. Dry Mix Required/cu. ft.	23	32	56	55	85
Application	C-T	C-T	C-T	C-T	C-T
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	25	37	62	56	93
MOR, psi After Drying at 230°F. (110°C)	20-60	60-100	130-200	90-200	200-350
After Heating at 1000°F. (540°C)	10-50	30-60	100-150	50-100	100-150
at 1500°F. (815°C)	10-50	30-60	110-170	50-100	100-150
at 1900°F. (1040°C)		30-60			
at 2100°F. (1150°C)			110-170		
at 2500°F. (1370°C)				200-400	
at 2700°F. (1480°C)					800-1000
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	40-120	200-300	500-800	200-400	500-1000
After Heating at 1000°F. (540°C)	70-110	150-200	300-600	200-300	500-700
at 1500°F. (815°C)	30-100	150-200	300-550	200-300	400-650
at 1900°F. (1040°C)		100-150			
at 2100°F. (1150°C)			250-450		
at 2500°F. (1370°C)				500-1000	
at 2700°F. (1480°C)					2000-3000
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible	Negligible	Negligible	Negligible
After Heating at 1000°F. (540°C)	−0.5 to −1.0	−0.1 to −0.5	−0.2 to −0.5	−0.2 to −0.4	0.0 to −0.3
at 1500°F. (815°C)	−1.0 to −1.5	−0.2 to −0.7	−0.3 to −0.7	−0.2 to −0.5	0.0 to −0.3
at 1900°F. (1040°C)		−1.5 to −2.0			
at 2100°F. (1150°C)			−0.5 to −1.5		
at 2500°F. (1370°C)				+1.0 to +3.0	
at 2700°F. (1480°C)					−2.0 to +2.0
Thermal Conductivity:Btu/hr. ft² °F./in. at 500°F. (246°C)	1.00	1.15	1.44	1.47	3.18
at 1000°F. (540°C)	1.30	1.33	1.63	1.68	3.41
at 1500°F. (815°C)		1.54	1.86	1.94	3.76
at 2000°F. (1093°C)		1.80	2.18	2.24	4.22

Application methods: C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†This castable is bonded with high purity strength calcium aluminate cement. If proper procedures for preparation, application and heat-up of this castable are not observed, steam spalling during heat-up may occur. (See instructions on product bag wrapping).

Harbison-Walker Lightweight, Insulating Castables

Brands	H-W® Lightweight Castable 30	H-W® Lightweight Castable 33	H-W® Lightweight Castable LI	H-W® Lightweight ES Refractory
Maximum Service Temperature °F.	3000	3300	2200	2300
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	3.0-3.5	2.0-2.5	4.0-4.5	3.5-4.0
Lbs. Dry Mix Required/cu. ft.	88	91	44	76
Application	C	C	C	C
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	92	102	52	80
MOR, psi After Drying at 230°F. (110°C)	150-250	400-800	100-250	300-500
After Heating at 1000°F. (540°C)	50-100		50-100	200-400
at 1500°F. (815°C)	100-150	300-400	50-100	200-400
at 2100°F. (1150°C)			50-100	
at 2900°F. (1595°C)	700-1300			
at 3000°F. (1650°C)		200-400		
at 3200°F. (1760°C)		200-400		
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	500-1000	2500-3500	400-600	1100-2100
After Heating at 1000°F. (540°C)	400-600		300-400	800-1500
at 1500°F. (815°C)	500-700	2000-2800	300-400	800-1500
at 2100°F. (1150°C)			200-300	
at 2900°F. (1595°C)	2100-2600			
at 3000°F. (1650°C)		1500-2500		
at 3200°F. (1760°C)		2000-2800		
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible	Negligible	Negligible
After Heating at 1000°F. (540°C)	0.0 to −0.2		−0.2 to −0.4	−0.1 to −0.4
at 1500°F. (815°C)	0.0 to −0.2	Negligible	−0.2 to +0.2	−0.1 to −0.4
at 2100°F. (1150°C)			−1.0 to −2.0	
at 2900°F. (1595°C)	−1.0 to +2.0			
at 3000°F. (1650°C)		+1.0 to +2.0		
at 3200°F. (1760°C)		0.0 to +1.0		
Thermal Conductivity: Btu/hr. ft² °F./in. at 500°F. (246°C)	3.48	6.3	1.67	2.40
at 1000°F. (540°C)	3.61	5.4	1.80	2.58
at 1500°F. (815°C)	3.87	5.05	1.98	2.70
at 2000°F. (1093°C)	4.20	5.05	2.20	2.90

Application methods: C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†This castable is bonded with high purity strength calcium aluminate cement. If proper procedures for preparation, application and heat-up of this castable are not observed, steam spalling during heat-up may occur. (See instructions on product bag wrapping).

Harbison-Walker Special Castable Refractories

Brands	ALKACAST®	VISIL® Castable	Harbison-Walker® 17-67*	HARMIX AL®	HARCHROME® Castable†
Maximum Service Temperature °F.	1000	2000	2000		2500
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	1.75-2.0	1.25-1.5		.75	1.25-1.5
Lbs. Dry Mix Required/cu. ft.	117	112		165	161
Application	C-T	C-T	C	C	C
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	120	120	117	168	173
MOR, psi After Drying at 230°F. (110°C)	1000-1400	800-1200		800-1100	1000-1300
After Heating at 1000°F. (540°C)	600-1000	200-500			550-750
at 1500°F. (815°C)		200-500		500-800	550-750
at 2000°F. (1093°C)				500-800	
at 2300°F. (1260°C)		300-500			
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	5500-8000	6000-9000		4000-7000	6000-8000
After Heating at 1000°F. (540°C)	4000-6500	4000-6000			4000-6000
at 1500°F. (815°C)		3500-5500	4000-7000	3000-5000	4000-6000
at 2000°F. (1093°C)				3000-5000	
at 2300°F. (1260°C)		2500-4000			
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible		0.0	Negligible
After Heating at 1000°F. (540°C)	0.0 to −0.5	Negligible			0.0 to −0.3
at 1500°F. (815°C)		Negligible		0.0	0.0 to −0.3
at 2000°F. (1093°C)				0.0 to +0.2	
at 2300°F. (1260°C)		0.0 to −1.0			
at 2500°F. (1370°C)					−1.0 to −2.7
Chemical Analysis: Silica (SiO_2)	50.0%	71.7%		1.2%	5.6%
Alumina (Al_2O_3)	22.0	17.1		90.6	32.8
Titania (TiO_2)	1.2	0.8		0.3	
Iron Oxide (Fe_2O_3)	2.2	0.6		0.4	15.5
Lime (CaO)	20.5	9.6		7.2	12.5
Magnesia (MgO)	1.4	0.2		0.2	12.1
Alkalies ($Na_2O + K_2O + Li_2O$)	2.7			0.1	
Chrome Oxide (CR_2O_3)					21.5

Application methods. C, Cast; R, Rammed, and T, Trowelled. For Gunning refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†Note concerning chrome bearing castables: Process variables may sufficiently alter castable chemistry so as to require solid waste disposal under applicable local, state or federal hazardous waste laws.

Harbison-Walker Special Castable Refractories

Brands	HARCROME* G†	CHROMEPAK* †	FUSIL Castable 820 I	FUSIL Castable 840
Maximum Service Temperature °F.	2700		2000	2000
Approximate Amount Water Required per 100# (46.26Kg) U.S. Gal.	.75-1.0	.75-1.0	1.75-2.0	1.75-2.0
Lbs. Dry Mix Required/cu. ft.	171	175	110	110
Application	C-T	C-R	C	C
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	179		113	117
MOR, psi After Drying at 230°F. (110°C)	1000-1400	600-1000		
After Heating at 1000°F. (540°C)	1200-1700	350-750		
at 1500°F. (815°C)	1200-1700	350-750		
at 2900°F. (1595°C)		750-1100		
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	6500-8500	2500-4500	4000-7000	3000-6000
After Heating at 1000°F. (540°C)	7000-9000	3000-5000		
at 1500°F. (815°C)	7000-9000	2000-4000		
at 2000°F. (1093°C)			3000-5000	2500-5000
at 2900°F. (1595°C)		6000-8000		
Permanent Linear Change % After Drying at 230°F. (110°C)	Negligible	Negligible	Negligible	Negligible
After Heating at 1000°F. (540°C)	Negligible	Negligible		
at 1500°F. (815°C)	Negligible	−0.1 to −0.3		
at 2000°F. (1093°C)			−0.5 to −1.0	−0.1 to −0.4
at 2700°F. (1480°C)	−1.0 to −2.3			
at 2900°F. (1595°C)		−0.6 to −1.3		
Chemical Analysis: Silica (SiO_2)	3.8%	8.0%	64.8%	70.4%
Alumina (Al_2O_3)	41.1	22.6	28.8	24.3
Iron Oxide (Fe_2O_3)	11.1	10.8		
Lime (CaO)	4.3	0.6	6.4	5.3
Magnesia (MgO)	14.1	33.4		
Chrome Oxide (CR_2O_3)	25.1	24.6		

Application methods: C. Cast, R. Rammed, and T. Trowelled. For Gunn...g refer to Harbison-Walkers' "High Caliber Gunning Mix" Brochure.

*Limited Data
All data based on cast specimens. ASTM procedures, where applicable, used to determination of data.
All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

†Note concerning chrome bearing castables: Process variables may sufficiently alter castable chemistry so as to require solid waste disposal under applicable local, state or federal hazardous waste laws.

Harbison-Walker Vibration Castables Demanding Ultra-High Strengths

Brands	DESCON® A93/C*	DESCON® A98*	DESCON® A94*	DESCON® A80*
Maximum Service Temperature °F.	3300	3300	(In Load Bearing Service) 2600	3200
Water Required For Vibration Casting	5.0-7.0%	4.0-6.0%	3.5-5.0%	5.0-6.5%
Dry Weight Required Per Unit of Volume, pcf	180	187	186	168
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	181	188	185	171
MOR, psi After Drying at 230°F. (110°C)	1500	2000	2000	1750
After Heating at 1500°F. (815°C)	1200	2000	2300	1500
at 3000°F. (1650°C)	1300		6000	
at 3140°F. (1725°C)		1500		2400
Hot MOR, at 2000°F. (1093°C)			1640	2700
at 2500°F. (1370°C)			730	
at 2700°F. (1480°C)				410
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	8000	12,000	13,000	10,000
After Heating at 1500°F. (815°C)	6000	10,000	12,000	9000
at 3000°F. (1650°C)	8000		15,000	
at 3140°F (1725°C)		12,000		10,000
Permanent Linear Change % After Heating at 1500°F. (815°C)	-0.1%	-0.1%	-0.2%	-0.2%
at 3000°F. (1650°C)	+0.6%		-1.4%	
at 3140°F. (1725°C)		-0.7%		-0.5%
Chemical Analysis: Silica (SiO_2)	0.3%	0.1%	5.0%	11.3%
Alumina (Al_2O_3)	92.5	97.6	93.0	82.5
Titania (TiO_2)	Trace	Trace	0.1	3.2
Iron Oxide (Fe_2O_3)	0.2	0.2	0.2	1.1
Lime (CaO)	1.6	1.5	1.5	1.6
Magnesia (MgO)	0.1	Trace	0.1	0.1
Alkalies ($Na_2O + K_2O + Li_2O$)	0.1	0.1	0.1	0.2
Chrome Oxide (CR_2O_3)	5.2	—	—	—

Application methods: VC, Vibration Casting using external vibration

*Limited Data

All DESCON brands include H-W's C-CURED System

All data based on cast specimens. ASTM procedures, where applicable, used for determination of data. All data subject to reasonable deviation and, therefore, should not be used for specification purposes

Harbison-Walker Vibration Castables Demanding Ultra-High Strengths

Brands	DESCON* A70/CU*	DESCON* A60*	DESCON* F45*	DESCON* S97*
Maximum Service Temperature °F.	3100	3100	2800	3000 (Continuous Service) 2000 (Intermittent Service)
Water Required For Vibration Casting	6.5-7.5%	4.5-6.0%	5.0-6.0%	7.0-9.5%
Dry Weight Required Per Unit of Volume, pcf	151	145	139	109
Bulk Density, lbs./cu. ft. After Drying at 230°F. (110°C)	164	150	140	116
MOR, psi After Drying at 230°F. (110°C)	1600	1350	1000	1200
After Heating at 1500°F. (815°C)	1000	2400	1200	
at 2550°F. (1397°C)	950			
at 2700°F. (1480°C)			900	650
at 3000°F. (1650°C)		820		
Cold Crushing Strength, psi After Drying at 230°F. (110°C)	7200	10,000	7000	6500
After Heating at 1500°F. (815°C)	7000	10,500	10,000	
at 2550°F. (1397°C)	5440			
at 2700°F. (1480°C)			7500	9800
at 3000°F. (1650°C)		8500		
Permanent Linear Change % After Heating at 1500°F. (815°C)	+0.1%	-0.3%	-0.3%	
at 2550°F. (1397°C)	+0.5%			
at 2700°F. (1480°C)			+1.1%	-0.2%
at 3000°F. (1650°C)		+0.5%		
Chemical Analysis: Silica (SiO_2)	14.5%	37.8%	50.0%	96.3%
Alumina (Al_2O_3)	70.7	57.0	44.2	0.5
Titania (TiO_2)	2.2	2.3	2.1	Trace
Iron Oxide (Fe_2O_3)	1.1	1.0	0.9	0.1
Lime (CaO)	1.5	1.6	1.8	3.0
Magnesia (MgO)	0.1	0.1	0.3	Trace
Alkalies ($Na_2O + K_2O + Li_2O$)	0.1	0.2	0.7	0.1
Chrome Oxide (CR_2O_3)				
Penetration Inhibitor	10.0			

Application methods: VC. Vibration Casting using external vibration.

*Limited Data
All DESCON brands include H-W's C-CURED System
All data based on cast specimens. ASTM procedures, where applicable, used for determination of data. All data subject to reasonable deviation and, therefore, should not be used for specification purposes.

Stainless Steel Fibers Add Strength and Long Life to Refractory Linings.

Work of Fracture Testing Shows Benefits of Stainless Steel Fiber Additions.

All Harbison-Walker castables and gunning mixes can be installed with stainless steel fiber additions. The best demonstration of the benefits stainless steel fibers impart to monolithic refractories is provided by work of fracture testing.

Harbison-Walker pioneered large-scale work of fracture testing programs for refractories because this test most accurately measures crack propagation, the major cause of refractory failure in monoliths under thermal cycling service conditions similar to ash hoppers.

The procedure for work of fracture testing is similar to modulus of rupture testing, although not only refractory strength but also crack resistance and holding power after fracture are measured. In the test, a sample of refractory with a notch cut in the underside is placed in tension. Pressure on the sample continues until it fails and the pressure exerted as well as the time expired is noted. Pressure is then continued after failure until the sample breaks apart completely, and the force and time required are noted.

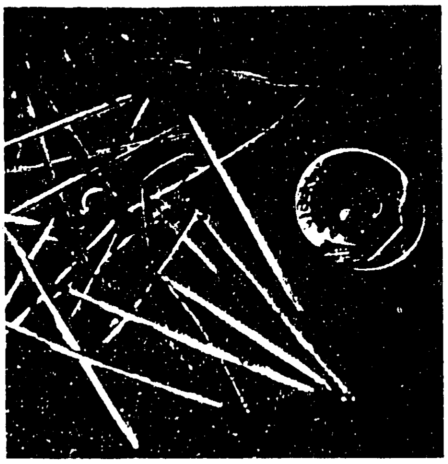


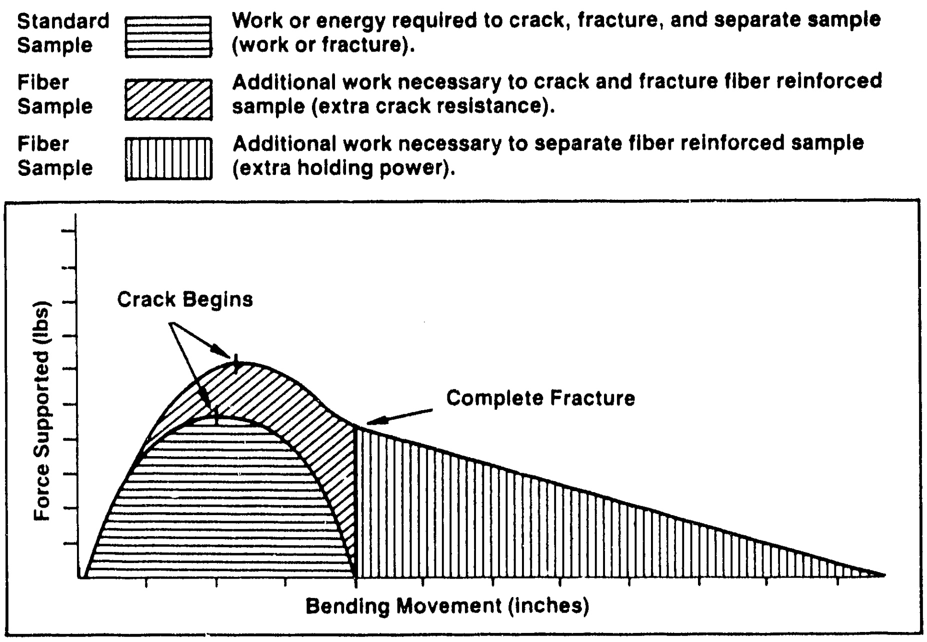
Fig. 29 Addition of stainless steel fibers to castable and gunned refractories increases strength and service life.

Figure 30 shows the typical results of work of fracture testing on samples of monolithic refractory with and without stainless steel additions. As the graph illustrates, fiber additions not only increase the ultimate strength of the refractory, more importantly they yield dramatic increases in crack resistance and holding power after cracking. Testing with various types of refractories has shown that all monoliths tested showed improvement in crack resistance and holding power, although the improvement varied according to density, cement content, and aggregate size of the material. Stainless steel fiber additions were also shown to increase K factors very little since the steel fiber is dispersed in the refractory mass. Tests have shown that thermal conductivity of monoliths with stainless steel fiber additions should increase no more than 5 percent.

A typical fiber for addition to gunning mixes and castables is one inch long and .015 to .020-inch in diameter. Fibers of this size should pass through standard 1.25-inch diameter gunning nozzles with no obstruction. Fibers may be ordered separately and mixed with the refractory prior to pouring castable or charging the emplacement gun. And, although stainless steel fibers produce significant performance benefits when added to castables and gunning mixes, they do not affect the pouring or gunning properties of the mixes and present no rebound problems.

The grade of fiber used for refractory reinforcement will be dictated by the operating conditions to which it will be subjected. If the temperature of the majority of the refractory lining is below 1800°F, Type 304 stainless steel fibers should serve well. At soaking temperatures, where the majority of the lining is approximately 2000°F Type 310 fibers can give satisfactory performance. However, ash hoppers some times present acid conditions that may require a special grade of stainless steel fiber. Please consult a Harbison-Walker representative or the fiber manufacturer for details.

Fig. 30 Work of fracture test results for monolithic refractory samples with and without stainless steel fiber additions.

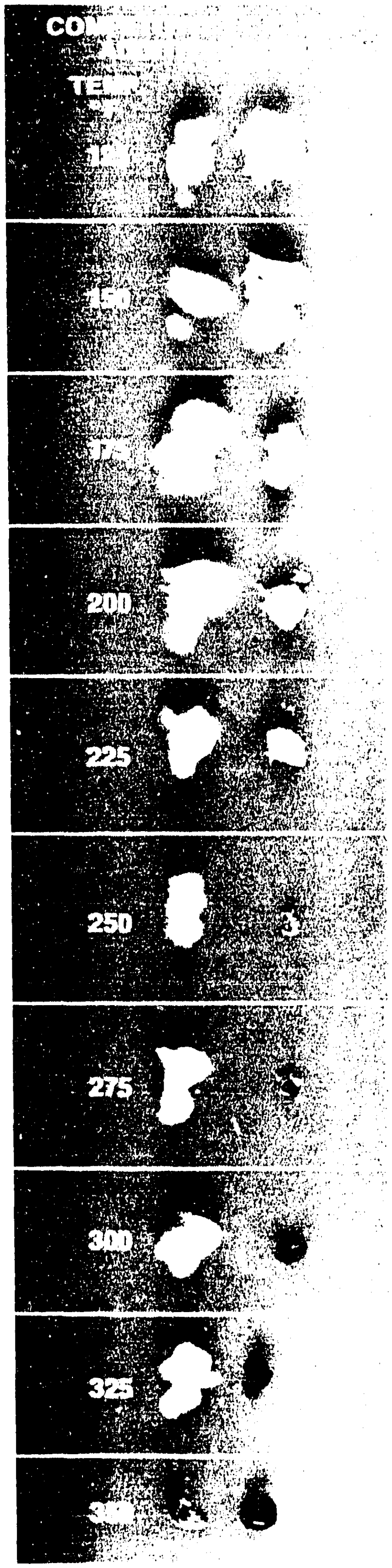


The C-CURED™ System Approach

H-W's advanced-technology system utilizes a specially sized non-metallic addition that shrinks and burns at very low temperatures, thus producing minute, non-continuous passageways in the refractory. The unique shrinkage characteristics of the C-CURED™ additive allows water release at critical temperatures during the heatup. The increase in permeability reduces the danger of steam spalling and allows faster heatup rates by means of a fast, evenly distributed release of both the mechanically and chemically combined water. And because the additive in the C-CURED System is considerably smaller than in any other commercially available system, the passageways have little or no affect on properties such as strength and metal handling.

The H-W C-CURED System is the first techology that produces steam passageways of the right size at the right time.

When C-CURED castables or gunning mixes are used, initial heatup rates can be accelerated. However, as with brick and plastic linings, the initial heatup rates of C-CURED linings must be examined individually. Parameters such as furnace size, lining thickness, material quality, expansion and temperature gradient vary with every furnace and affect the heatup rate. Based on laboratory heatup tests, microscopic analysis of the C-CURED material, and actual field installations, a heatup schedule can be formulated that maximizes energy savings, material properties, and safety. Please discuss your specific situation with a Harbison-Walker representative.



Harbison-Walker's experience with the C-CURED System includes successful installations in dozens of furnaces. Examples include rotary kilns, petrochemical vessels, AOD hoods, vertical channel induction furnaces, and other ferrous and non-ferrous furnaces.

The C-CURED System is available in most H-W castables and gun mixes. For actual physical properties of H-W C-CURED material, consult the C-CURED brochure or call your nearest Harbison-Walker office.

Note of Caution: The C-CURED System offers great improvements over conventional gunning mixes and castables. However, as with all castables and gun mixes with non-metallic additions, the danger of steam spalling still exists.

Fig. 31 Laboratory testing shows that the C-CURED™ refractory system shrinks as steam evolves from the refractory lining, well below temperatures of shrinkage of other additives.

NORTH AMERICAN REFRACTORIES

CUSTOMER LIST

PROJECT LIST WHERE NARCO REFRACTORY PRODUCTS HAVE BEEN INSTALLED

1. Hyperion Energy Recovery System
Sludge Combustion Facility, Element 12A
EPA Project No. C-06-2417-410
City of Los Angeles, California

2. CAL-MAT, Inc.
California Portland Cement Division
Cogeneration System for Cement Kiln
Colton, California

3. Garrett Air Research Corporation
Combustion Power Corporation
Circulating Fluidized Bed Incinerator
Torrance, California

*4. Ione Energy Project
Lurgi Corporation
Circulating Fluidized Bed Incinerator
Ione, California

5. Colorado Ute Electric
Pyropower Corporation
Circulating Fluidized Bed Incinerator
Nucla, Colorado

6. Port of Stockton
Combustion Power Corporation
Circulating Fluidized Bed Incinerator
Stockton, California

7. Biogen Project
Combustion Power Corporation
Circulating Fluidized Bed Incinerator
Ivanpah, California

8. Shasta-Signal Power
Zurn Industries
Anderson, California

**9. Scott Paper Company
Lurgi Corporation
Circulating Fluidized Bed Unit
Chester, Pennsylvania

*10. Ultrasystems Inc.
Lurgi Corporation
Circulating Fluidized Bed
Fresno, California

11. Union Oil
Rodeo, California

12. Koppers Company, Inc.
Oroville, California

13. Dinuba Energy Inc.
Dinuba, California

14. Martel Cogeneration Ltd.

15. Pacific Lighting Energy
Oroville, California

16. Ultrapower III
Blue Lake

17. Sierra Pacific Inc.
Susanville, California

18. Collins Pine Lumber
Chester, California

**19. Ultrasystems Inc.
Combustion Engineering
Circulating Fluidized Bed
Rocklin, California

**20. Ultrasystems Inc.
Combustion Engineering
Circulating Fluidized Bed
Mt. Poso, California

**21. Ultrasystems Inc.
Combustion Engineering
Circulating Fluidized Bed
Bakersfield, California

* Denotes units that have NIKE 50 AR installed in the cyclones.

** Denotes units that have NIKE 60 AR installed in the cyclones.

NARCO PRODUCTS FOR THE POWER GENERATION INDUSTRY

Product	Recommended Applications	Advantages
NIKE 60 AR	Recycle cyclones, inlet duct walls and floor, loop seal.	Exhibits both excellent thermal shock resistance and abrasion resistance.
NARCO 68	Less severe areas of cyclone such as the cone.	Excellent thermal shock shock resistance.
MOHAWK BF	Loop seal, areas that are highly abrasive.	High fired super-duty brick which offers excellent abrasion resistance.
GUNCRETE	Monolithic gun mix for combustion chambers and cyclone walls and roofs.	Good gunability, abrasion resistant with low iron content.
NARMUL P	Burner throats, feed chutes, bull nose of cyclone.	Excellent strength and abrasion resistance.
ALCHROME 85 P	Target walls of cyclone, high impact areas, refractory shelf in combustor.	Highly resistant to slag attack, tough and abrasion resistant.
NARPHOS 85 P	Combustion chamber working lining, patch material for cyclones.	Good abrasion resistant phosphate-bonded material.
LO-CAST 50 HS	Inlet floor, burner throats, manway doors.	Low moisture castable which offers very high strengths.
NARCOSET TENAX	Mortars used with all super-duty brick in cyclones.	Excellent workability for tight joints.

NARCO PRODUCTS FOR THE POWER GENERATION INDUSTRY

Product	Recommended Applications	Advantages
NIKE 60 AR	Recycle cyclones, inlet duct walls and floor, loop seal.	Exhibits both excellent thermal shock resistance and abrasion resistance.
NARCOGUN AR-50	Cyclone inlet ducts and roofs, walls and roof of combustors. Fluid bed heat exchanger walls and roof.	Excellent abrasion resistance at 1500-1800°F. Low rebound with good gunability.
GUNCRETE	Monolithic gun mix for combustion chambers and cyclone walls and roofs. FBHE walls and roof.	Good gunability, abrasion resistant with low iron content.
NARMUL P	Burner throats, feed chutes, bull nose of cyclone.	Excellent strength and abrasion resistance.
ALCHROME 85 P	Target walls of cyclone, high impact areas, refractory shelf in combustor.	Highly resistant to slag attack, tough and abrasion resistant.
NARPHOS 85 P	Combustion chamber working lining, patch material for cyclones.	Good abrasion resistant phosphate-bonded material.
LO-CAST 50 HS	Inlet floor, burner throats, manway doors.	Low moisture castable which offers very high strengths.
NARCOSET TENAX	Mortars used with all super-duty brick in cyclones.	Excellent workability for tight joints.
HPV-50 DURAKAST 56	Cyclone inlet floors, seal pot floors, combustor grate, FBHE grate.	Ultra-high strengths up to 1800°F. Excellent abrasion resistance, extreme resistance to erosion by hot abrasive gases.
AEROCAST L	Cyclone inlet duct floors, seal pot floors, FBHE floor, cyclone domed outlet duct floors.	Heat saving product used for working lining or back-up. High refractoriness, good high temperature strengths and negligible shrinkage.
HPV-SX	FBHE inlet ducts, seal pot and seal pot inlet and outlet duct hot face lining.	Very abrasion resistant, fused silica makes HPV-SX resistant to thermal shock. High strength and erosion resistance at 1800°F.
LITECRETE HS 2065 GUN	Cyclone inlet duct and roof, seal pots and connective ductwork FBHE.	Lightweight hydraulic setting gun mix offering great strengths up to operating temperatures of 2000°F.

North American Refractories Co.

500 Halle Building
1228 Euclid Avenue
Cleveland, Ohio 44115
216/621-5200

HPV-SX

Low Moisture Castable

CHARACTERISTICS

HPV-SX exhibits very high strengths at temperatures up to 1800°F. This strength makes HPV-SX very resistant to erosion by hot gases and also mechanical abuse. Due to its low density and fused silica aggregate, HPV-SX has a very low thermal conductivity. The low porosity and fused silica present in HPV-SX makes it very resistant to damage by thermal shock. HPV-SX was designed to be cast vibrated with a very low water content. Thus, it has a very low drying shrinkage and less sintering shrinkage in service.

APPLICATION AREAS

(A) Seal pot and seal pots inlet and outlet duct hot face lining.
(B) FBHE's inlet ducts.

TEST DATA

Method of Installation	Gunning
Maximum Service Temperature, °F	2600
Bulk Density, pcf	
Fired to 230°F	127
Fired to 1500°F	122
Cold Crushing Strength, psi	
Fired to 230°F	8500
Fired to 1500°F	7500
Fired to 2000°F	5900
Abrasion Resistance, cc	12
	1500/15
Thermal Conductivity - $\frac{\text{Btu-in.}}{°F \times hr \times ft^2}$	
@ 500°F (260°C)	6.1
@ 1000°F (538°C)	6.5
@ 1500°F (816°C)	7.2

CHEMICAL COMPOSITION, %

Al_2O_3	27.5
SiO_2	66.8
Fe_2O_3	0.3
TiO_2	0.4
CaO	4.7
MgO	0.1

North American Refractories Co.

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HPV-50

Low Moisture Castable

CHARACTERISTICS

HPV-50 offers ultra-high strength up to 1800°F which makes it extremely resistant to erosion by hot abrasive gases and mechanical abuse.

Due to the high density and low porosity, HPV-50 exhibits very good abrasion resistance. HPV-50 is also volume stable due to the low water content required in comparison to a conventional castable.

APPLICATION AREAS

(A) Cyclone inlet duct floors.
(B) Floors of domed cyclone outlet ducts.
(C) Seal pot floors.
(D) Combustor grate.
(E) Duct - FBHE to combustor floors.
(F) FBHE grate.

TEST DATA

Method of Installation	
Maximum Service Temperature, °F	3000
Bulk Density, pcf	
Fired to 230°F	145
Fired to 1500°F	141
Cold Crushing Strength, psi	
Fired to 230°F	9000
Fired to 1472°F	8000
Abrasion Resistance, cc	8

CHEMICAL COMPOSITION, Wt. %

Al_2O_3	50
SiO_2	46
CaO	2.5

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NARCOGUN AR-50

Abrasion Resistant Gun Mix

CHARACTERISTICS

NARCOGUN AR-50 offers excellent abrasion resistance at operating temperatures between 1500°F-1800°F. Due to its excellent gunability, NARCOGUN AR-50 is easily applied with low rebound loss.

APPLICATION AREAS

(A) Cyclone inlet duct roofs and cyclone roofs.
(B) Cyclone domed outlet duct walls and roofs.
(C) FBHE solids return ducts, walls and roof to combustor.
(D) FBHE walls and roof.

TEST DATA

Method of Installation	Gunning
Maximum Service Temperature, °F	2600
Bulk Density, pcf	
Fired to 230°F	135
Fired to 1500°F	126
Cold Crushing Strength, psi	
Fired to 230°F	8800
Fired to 1500°F	5300
Abrasion Resistance, cc	230/6 1500/11
Thermal Conductivity - $\frac{\text{Btu-in.}}{°\text{F} \times \text{hr} \times \text{ft}^2}$	
@ 752°F (400°C)	6.1
@ 1112°F (600°C)	6.5
@ 1472°F (800°C)	7.2
CHEMICAL COMPOSITION, Wt. %	
Al_2O_3	49
SiO_2	37
Fe_2O_3	0.6
Na_2O	0.1
K_2O	0.2
CaO	6.3
Rebound Loss, Without Fibers	11%

North American Refractories Co.

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1228 Euclid Avenue
Cleveland, Ohio 44115
216/621-5200

LITECRETE HS 2065 GUN

Insulating Gun Mix

CHARACTERISTICS

LITECRETE HS 2065 GUN is a lightweight hydraulic-setting gun mix which offers extra strength without decreasing its insulating value. This material provides a structurally sound heat barrier and can be used at operating temperatures up to 2000°F.

APPLICATION AREAS

(A) Cyclone inlet duct and cyclone roof.
(B) Cyclone domed outlet ducts.
(C) Seal pots and connective duct-work.
(D) FBHE connective duct-work.
(E) FBHE.

TEST DATA

Method of Installation	
Maximum Service Temperature, °F	2000
Bulk Density, pcf	
Fired to 230°F	65
Fired to 1520°F	63
Cold Crushing Strength, psi	
Fired to 230°F	750
Fired to 1112°F	575
Fired to 1472°F	500
Thermal Conductivity - $\frac{\text{Btu-in.}}{°F \times hr \times ft^2}$	
@ 392°F (200°C)	1.7
@ 752°F (400°C)	1.8
@ 1112°F (800°C)	2.0
@ 1472°F (800°C)	2.2
CHEMICAL COMPOSITION, Wt. %	
Al_2O_3	33
SiO_2	41.1
CaO	20.2
Rebound Loss	16%

North American Refractories Co.

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1228 Euclid Avenue
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216/621-5200

AEROCAST L

Insulating Castable

CHARACTERISTICS

AEROCAST L combines good refractory qualities with heat-saving insulating values. AEROCAST L can be used as a back-up or as a working lining exposed to furnace atmospheres. This hydraulic setting castable offers high refractoriness while providing a strong cold set, good high temperature strength, negligible shrinkage and low thermal conductivity. AEROCAST L is also not affected by cyclical furnace operation and is free from rehydration.

APPLICATION AREAS

(A) Cyclone inlet duct floors.
(B) Seal pot floors.
(C) FBHE floor.
(D) Cyclone domed outlet duct floors.

TEST DATA

Method of Installation	
Maximum Service Temperature, °F	2000
Bulk Density, pcf	
Fired to 230°F	52
Fired to 1200°F	45
Thermal Conductivity - $\frac{\text{Btu-in.}}{°F \times hr \times ft^2}$	
@ 392°F (200°C)	1.6
@ 752°F (400°C)	1.7
@ 1112°F (800°C)	1.8
@ 1472°F (800°C)	1.9

CHEMICAL COMPOSITION, Wt. %

Al_2O_3	32.4
SiO_2	38
CaO	15

NORTON

FLUIDIZED BED FACILITES UTILIZING
NORTON CRYSTOLON SILICON CARBIDE MONOLITHIC REFRACTORY OR
NORTON CRYSTON SILICON CARBIDE SHAPES

Operational Date	Facility	Number of Boilers	Capacity (PPH)	Boiler Supplier	Material
B & W/Ultrasystems					
1986	Jonesboro, ME	1	218,640	Babcock & Wilcox	LC904
1986	West Enfield, ME	1	218,640	Babcock & Wilcox	LC904
Energy Factors					
1986	Feather River Project Marysville, CA	1	164,000	Babcock & Wilcox	LC904
Archer Daniels Midland					
1987	Decater, IL	5	425,000	Keeler-Dorr Oliver	LC904
1988	Ceder Rapids, IA	3	477,000	Keeler-Dorr Oliver	LC904 +CN183
Constellation Investments/ Ultrapower/CE					
1987	Fresno, CA	1	220,000	C-E Lurgi	CN183
1989	Rocklin, CA	1	220,000	C-E Lurgi	CN183
1989	Bakersfield, CA	1	220,000	C-E Lurgi	CN183
Wheelabrator					
1988	Frackville, PA	1	410,000	Keeler-Dorr Oliver	LC904
Northeastern Power					
1989	Schuylkill Co., PA	1	485,000	C-E Lurgi	CN183
Schuylkill Energy Resource					
1990	Mahanoy City, PA	1	825,000	C-E Lurgi	CN183
AES-Thames					
1989	Montville, CT	2	672,000	C-E Lurgi	CN183

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Operational Date	Facility	Number of Boilers	Capacity (PPH)	Boiler Supplier	Materia
Westwood Energy Properties					
1987	Joliett, PA	1	271,000	C-E Lurgi	LC904 +CN18
Bechtel/Pyropower Cogen.					
1989	Bakersfield, CA	1	500,000	Pyropower	LC904
Air Products & Chemical					
1988	Stockton, CA	1	500,000	Pyropower	LC904
Ione Energy					
1989	Ione, CA	1	146,000	C-E Lurgi	LC904 +CN18

March 1989

INSTALLATION & STARTUP PROCEDURES

FOR GUNNING REFRACTORIES

INTRODUCTION

Norton Company's Gunning Mixes have been designed to assure that not only maximum refractory performance is attained but that rebound is minimized. In order that this is achieved, proper installation and curing techniques must be followed. Outlined in the following are specific recommendations relating to procedures and equipment that will more easily allow the efficient attainment of a good installation.

PREWETTING

Obviously water controls the stickiness of a gunning mix and stickiness retards rebound which maximizes density. If water is only added near the nozzle end, it has minimum time to penetrate the fast flowing stream of dry refractory and properly wet it. Therefore, it is strongly recommended that water be mixed with the cement in a paddle type mixer before gunning is started. The amount added, obviously must not affect the mix's ability to flow through the gunning equipment and hoses. Generally this will be approximately 0.5% by weight, however it can be more precisely determined on site by squeezing a handful. When the correct maximum amount is added, the handful will form a ball which will easily break up into a granular form when finger pressure is applied. Unfortunately this maximum amount can not always be used. Depending on hose diameter, length, number of bends, etc. clogging could occur and then the amount of water added must be reduced. Prewetted gunning mix must not be allowed to dry out before gunning as its bond ingredients will harden, this is particularly true of hydraulically bonded products.

In order to obtain the highest density and minimum rebound, predampening to the maximum amount is required. In addition using a wet mix will eliminate the discharge of static electricity to the gun operator.

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EQUIPMENT

Gun Machine

Although virtually all types of gunning equipment could be utilized, Norton Co. strongly recommends those that utilize a rotating feed wheel under a hopper as they provide a much more even and steady material flow. This makes accurate water control at the nozzle easier and results in better control of density and rebound. It has been found that nozzle size should be no larger than 1". The gun should be equipped with working pressure gauges and valves to individually control air pressure to the drive motor and material feed connections.

Air Compressor

As hose lengths are usually quite long, it is advantageous to have a compressor capable of delivering air at approximately 500 cubic feet per minute at 90-100 psi to insure clog free even refractory delivery. The piping and/or hoses from the compressor to the gun should be the same size or larger than the material delivery hose in order to assure that enough air is available. Separate air hoses should be run from the compressor to the air motor drive and material feed connections.

The air should be free of oil and excess moisture. Oil will affect the refractories bonding and water could cause flow/clogging problems. Air should be checked for oil content by bubbling it into a container of water. A slick on the water surface will be noted if oil is present.

Water Delivery

Water pressure must exceed air pressure so that it is properly distributed into the refractory stream. Obviously both pressure and flow must be uniform and therefore a water pump is often advantageous.

Mixer

A paddle type mixer is recommended for uniform prewetting. A backup mixer is good insurance against installation delays.

Communication Equipment

Normally the gun is located some distance from the nozzle man and direct communication is impossible, therefore a radio or telephone headset system of some type is required in order that proper coordination is maintained during installation.

PREPARATION

Prior to starting actual gunning, equipment should be checked out. Hoses should have no kinks or tight bends that would retard refractory flow. No fittings in pipe or hose should be a smaller diameter in air, material flow, or water lines. Pressures and flows should be measured to ascertain they are correct. The staging used must allow unobstructed access. Cross bracing, as typically used with "ladder" type staging can be a hindrance and therefore "pipe" staging is usually preferred if not required.

Staging or some type of platform should be erected and positioned so that the nozzle operator can maintain a distance of approximately four feet at right angles to the surface to be gunned.

The surface being gunned should be clean, sandblasted to remove most rust and any scale. It should also be dry and free of oil. Finally a system should be established to assure that prewetting (mixing) will keep up with refractory usage. Actually mixing should stay far enough ahead of gunning requirements so that proper moisture levels can be easily monitored and maintained.

To enhance clean up of rebound plastic sheets or fabric tarpaulin should be laid down.

INSTALLATION

There are several major objectives to be pursued and achieved

(1) Obtain proper maximum density
(2) Maintain minimum/maximum thickness control
(3) Obtain a reasonably smooth surface
(4) Minimize rebound

Water control at the nozzle is absolutely critical to all of the above. The amount of water and its distribution is what must be maintained. Even distribution is aided by the use of a 18"-24" section of hose between the water ring and the nozzle as it lengthens mixing time. Using the recommended 1" maximum I.D. nozzle and running the feed motor on the gun at a moderately slow speed slows down refractory delivery and makes water control easier. It also aids thickness and surface control. If the feed motor speed is too slow, it will not rotate smoothly and delivery will be pulsing and erratic. Air pressure to the material feed hose should be controlled (typically 35-40 psig) to minimize rebound.

When correctly applied, the refractory surface will exhibit a smooth, slightly wet sheen appearance. Slumping is the result of entirely too much water and requires removal and reapplication as the refractory's density has been affected. Maintaining a distance of approximately 4 feet from the nozzle to the tube surface and maintaining the gun at a 90° angle is the best procedure. In order to prevent laminations, the surface must not be allowed to dry out between passes, therefore it is best not to work on an area of more than 50 square feet.

In order to eliminate gunning over fallen rebound, it is best to start at the bottom of walls and work up. Rebound will be greatest on the first pass as it is more difficult to bond to the walls than refractory.

Ideally, once applied, the gunned refractory should not be disturbed. However, when a very smooth or contoured surface is required, some surface adjustment may be necessary. A curry comb is the best tool to remove excess thickness as it leaves an open texture. Trowels and/or floats tend to close up surface porosity making water removal more difficult during the dryout cycle. Trowels should be used only when a very smooth surface is required. Overspraying a thin veneer after trimming back is acceptable but must be done before any setting occurs. This is usually no problem with phosphate bonded refractory, but must be done quickly (within 15 minutes) with cement (i.e., calcium aluminate) bonded refractories.

REBOUND

Rebound is mainly composed of coarse particles. The properties of the refractory rely on proper distribution of particle sizing therefore if rebound is reused the properties (strength, density, thermal conductivity, etc.,) will be adversely affected. Rebound cannot therefore be regunned directly or reblended into new gun mix.

Once installed and before sufficient heat has been introduced to eliminate all moisture from the Norton Gunning mixes, they must not be allowed to be frozen. Remember that water expands when it freezes and this will at the least weaken the soundness of the lining and could actually cause refractory to spall off the walls.

March 1989

CRYSTOLON SILICON CARBIDE CASTABLE

LC 904

LC904 is an extremely dense high purity silicon carbide castable designed specifically for use on studded tube walls in boilers. It utilizes Norton Company's exclusive CRYSTOLON silicon carbide and a hydraulic bond to achieve its unique high strength properties that develop within 12-24 hours after installation. High strength development in this calcium aluminate bonded monolithic occurs throughout its applied thickness whereas heat setting mixes develop minimum strengths in the cool areas adjacent to water cooled tubes. These features allow its usage along grate lines where erosion can be very severe. On the upper tube wall areas, its high thermal conductivity allows maximum heat transfer which assures minimum ash/slag buildup.

It can be installed using conventional gunning and casting techniques. To achieve maximum physical and heat transfer properties, gunning is recommended.

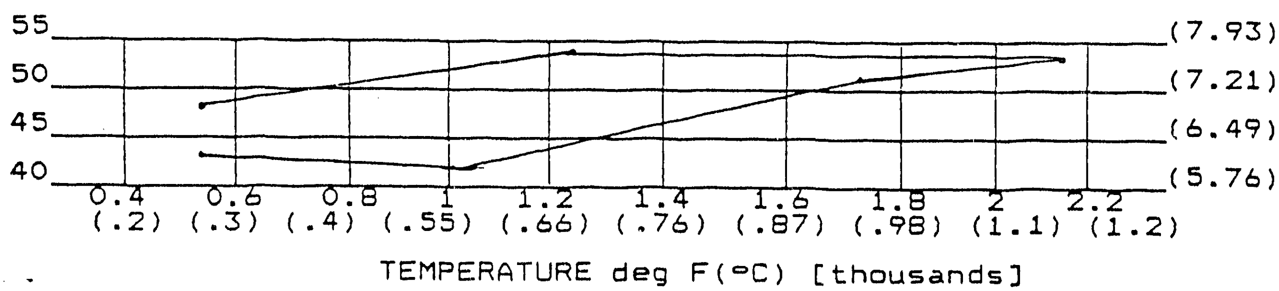
TYPICAL CHEMICAL ANALYSIS %

SiC	Al_2O_3	SiO_2	CaO	Other
82	12.2	2	2.5	1.3

TYPICAL PHYSICAL PROPERTIES

Grain Size	Installed Density lbs/ft3 (Kg/m^3)	Maximum Use Temperature
10F	160 (2563)	2900°F 1593°C

THERMAL CONDUCTIVITY ASTM C202 BTU.in/(hr.ft^2 deg.F) (W/mK)



COLD CRUSHING STRENGTHS

	After Firing To: 212°F (100°C)	932°F (500°C)	1832°F (1000°C)	2552°F (1400°C)
PSI	11000	15000	18000	20000
Mpa	76	103	124	138

COLD & HOT MODULUS OF RUPTURE

	Dried	After Firing to / Holding at 392°F (200°C)	752°F (400°C)	1112°F (600°C)
PSI	1700	1700/1500	2200/2200	2400/2300
Mpa	12	12/10	15/15	17/16

ABRASION LOSS (ASTM C704) 10 cc

PACKAGING - Supplied dry in 100 lb (45.4 kg) polyethylene lined paper bags standard pallet weight size is 3000 lbs(1364 Kg)

SHELF LIFE - Twelve months when stored under optimum cool & dry conditions.

INSTALLATION - Instructions and supervision are available.

"PERFORMANCE NOT PRICE DETERMINES REFRACTORY COST."

October 1988

CRYSTOLON® SILICON CARBIDE CASTABLE

LC 904

DRYING AND CURING SCHEDULE

Once installed and before sufficient heat has been introduced to eliminate all moisture from Norton's Crystolon Gunning mixes, they must not be allowed to be frozen. Water expands when it freezes and this will, at the least, weaken the soundness of the lining and could cause actual spalling off the tube walls.

Because LC-904 is a hydraulic bonded refractory, it must be kept in a high humidity environment immediately after installation for a period of at least 24 hours to allow formation of this bond; temperature during this period should be held at approximately 70°F.

The next step is to remove the water from the refractory. It can be accomplished with hot air inside the boiler or with hot water inside the boiler tubes. The temperature of either should be brought up to approximately 190°F. (not to exceed 212°F) and held for a minimum of 24 hours with forced air movement inside the boiler. If air is used (instead of hot boiler tube water), the boiler tubes should be empty to assure optimum dryout.

The next step is to raise air or water temperature to a maximum of 220°F and hold for 24 hours minimum.

Thermocouples located on the tube faces and the refractory surface should be used to assure proper temperature measurement. Enough thermocouples should be installed so that the walls are uniformly heated throughout the boiler.

The final step is controlled heat input to gradually achieve normal water tube temperature at the end of 24 hours. If possible, burning during this period should be away from the sidewalls. During these steps, the walls should be inspected periodically to assure that any water vapor arising from the refractory surface is only similar to that off a hot cup of coffee. If it is apparent that steam under pressure is being developed within the refractory; water tube temperature should be dropped as soon as possible and remain at that lower level until the steaming subsides. Holes drilled through the membranes between the tubes can be very useful in assuring this.

This essentially completes the refractory drying and curing cycle and normal operating procedures can now occur.

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ADVANCED CERAMICS

NORTON

TECHNICAL BULLETIN

April 1989 S-P-CR-BD4

CRYSTON SILICON NITRIDE BONDED SILICON CARBIDE
CN-183

This is a new high bond content nitride bonded silicon carbide that has exceptional abrasion resistance and outstanding oxidation resistance in the 1650 to 2000°F (900-1100°C) temperature range.

Principal uses have been as tube blocks in fluidized bed boiler applications where long life is important and wear of refractory components is a concern.

CN-183 is available in tubes, brick and other heavy shapes.

Typical Characteristics:

Density	163 lbs./ft.^{3} (2.65 Mg/m^3)	
Modulus of Elasticity	19 x 10^6 psi (130 GPa)	
Chemical Analysis	%	
Silicon Carbide	78	
Bond (Si_3N_4)	20	
Oxides	2	
Maximum Use Temperature	2900°F (1590°C)	
Apparent Porosity	15%	
Modulus of Rupture	psi	MPa
room temperature	6500	44
2280°F (1250°C)	7500	51
2640°F (1450°C)	5300	36
Thermal Conductivity	BTU - in. / hr. ft.^{2} °F	W / m·K
600°F (315°C)	113	16.3
1200°F (649°C)	120	17.3
1800°F (982°C)	104	15.0
2100°F (1149°C)	100	14.4
Linear Thermal Expansion		
per °F (90-2730°F)	2.7 x 10^{-6}	
per °C (30-1500°C)	5.0 x 10^{-6}	
Abrasion Loss (ASTM C704)	5cc	

"PERFORMANCE NOT PRICE DETERMINES REFRACTORY COST."

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FLUID BED BOILER AND INCINERATOR BOILER
CRYSTON TUBE BLOCK INSTALLATION

Tube block such as that shown in Figure 1 are designed to be fastened to boiler walls by threaded studs and nuts. Also a thin layer of silicon carbide mortar on the back side of the block is applied to bond the block to the waterwall providing maximum contact and heat flow. The studs are welded to either the center line of the tubes or membrane and each tile is held in place by a single stud.

The tube block is designed with an allowance for thermal expansion on each edge. All edges of the block are shiplapped so that, even with variations in tube spacing in the waterwall, the blocks fully cover the wall. For this reason the shiplapped joints should not be mortared.

WHERE CRYSTON TUBE BLOCKS ARE USED

FLUID BED BOILERS

The area to be protected with CRYSTON tube block will be the walls of the combustion chamber from the bottom to a height of approximately 30 feet where the fluidized bed creates abrasion.

INCINERATOR BOILERS

All straight tube areas above the grate can use the protection from corrosion and erosion provided by tube blocks. Block also maximize heat transfer and deter slag/ash buildup.

Within the installation area all flat surfaces of the water wall will be covered with block. Burner openings, sight ports, or other openings where tubes are bent will not be flat enough for block installation. These areas will be covered with other refractory materials.

Small areas in the corners of the fire box will also be difficult to cover with block and will be covered by a troweling mix or a gunning mix such as Norton LC904.

CUTTING OF BLOCK

Some blocks must be cut to fit around openings and in corners. Use a Norton Christensen diamond blade specification R-5194. It is available in 14", 18" and 20" diameters.

BOILER WALL ACCURACY

Boiler waterwalls are fabricated in panel sections in the shop and these sections are welded together at the job site. Tube spacing in the shop welded panels is usually very accurate, but panels welded together in the field may have wide welds at the membrane between sections.

For nominal tube spacing of 3" the field welds at section edge may cause a spacing of up to 3-1/4" between tubes. The shiplap on the CRYSTON tube block will usually allow coverage of spacing up to 1/4" above nominal (3-1/4" in this example). If a wider spacing is encountered, the block will have to be mounted on adjacent tubes and block cut to fit.

BLOCK ORIENTATION IN THE BOILER AND START OF INSTALLATION

Refer to Figure 1. Block should be installed with the inside (fire side) of the shiplap pointing down.

In fluidized bed boilers the motion of the solids at the wall is generally downward due to boundary layer effects, so the inside shiplap should be installed downward. Installation should start at the bottom of the pattern..

In incinerators the inside shiplap is installed down so that slag or ash will not run in behind the tile. When the inside shiplap is installed down, the installation should start at the bottom of the tile pattern in the unit.

INSTALLATION STEPS

1. Build necessary scaffolding.

2. Measure and mark area to be covered with block.

3. Sandblast all tubes in the area to be covered; removing all paint, rust, dirt or other foreign substances.

4. Refer to specifications for that boiler and mark where the top row of studs is to be welded. This line can be established by first marking the location of the studs on the two edges of the wall and snapping a chalk line between these two points. The line must be straight. The studs may be on the center line of the tube or on the membrane. Check blueprint for tile installation.

5. Location of all other studs can be found by:

   (a) use of a template that has the stud pattern accurately located or

   (b) by measuring from the first row of studs and using a chalk line to establish a straight line between each row of studs. The location of individual studs is then marked on the centerline of the correct tubes (or on the membrane).

6. Accuracy of stud placement should be within 1/16". The tube block have 1/8" space between blocks when perfectly positioned so if adjacent tile are both -1/16 on position there will be interference between block and they will have to be cut to provide clearance. Correct stud spacing will save this cutting.

7. If tube spacing is less than nominal, and there is an interference fit, edges of the block must be cut to provide clearance. See figure 2. If tube spacing at panel welds is too great then the stud spacing must be changed so that block is attached to adjacent tubes and block cut to fit between those tubes. (figure 3) Stud location must be checked for fit before studs are welded.

8. Once stud location is established, and fit is checked at panel welds, all studs can be welded. See boiler specification and welding code for welding procedure and testing of welds.

9. Mix the Norton CRYSTOLON LC959 mortar so that it is a thin consistency suitable for buttering the back of block.

10. Test mortar on block. If the mortar stiffens quickly when applied to the block, the block must be dampened with water.

11. Start at the bottom of the wall (unless the assembly blueprint differs from "Block Orientation" as described on page 2).

12. Mortar the block with LC959 mortar,taking care to avoid getting mortar in the shiplap joint. Place the tube block over a stud and press it firmly against the tube wall. Assemble washer (if required) and nut. Check block occasionally to be sure mortar fills all space between block and tube wall.

13. Tighten nut as much as possible using a socket wrench. Then pound on the block with a leather or rubber mallet while continuing to tighten. When the nut is fully tightened using this method it should then be backed off slightly to relieve tension (less than 1/8 turn).

14. Nuts must be tightened within approximately 10 minutes after block is mortared to ensure a good fit to tubes. If too long a period elapses between mortaring of block and tightening, the mortar will stiffen and the block will not seat snug to the tubes. This would reduce heat transfer to the water wall from the block.

15. Cut block to fit as required around openings and at edges of the pattern. Block should not overhang an opening as ramming of cement behind the block may break it. Cuts should be at least 3/4" from the stud hole in the block. See figure 4. If block is too tight, cut edge to provide clearance between block. Cut both steps of shiplap. Do not remove shiplap.

16. At panel welds on the water wall cut or notch the back of the block to clear the welds allowing the block to seat against the tubes.

    On vertical welds cut the "fin" on the block that is over the weld to clear the weld.

    On horizontal welds the back of the block can be grooved with the diamond saw to clear the weld.

17. After all blocks are assembled, tack weld the nut to the stud using the welding rod specified by the boiler specification.

18. If required by the design, fill stud holes with cement such as Norton LC959 silicon carbide mortar.

DRY OUT AND INITIAL HEATING

Because there is little moisture in the block and in the LC959 mortar behind it, the heating schedule dictated by other refractories in the unit will be satisfactory for the CRYSTON tube block system. Once installed and before sufficient heat has been introduced to eliminate all moisture from Norton's Crystolon mortar it must not be allowed to be frozen. Water expands when it freezes and this will, at the least, weaken the soundness of the mortar.

PLIBRICO

FLUIDIZED BED INSTALLATIONS

Co-Generators	Locations	Designers	New or Repair	
Gulf Oil Company	Bakersfield, CA	Pyropower	New	(CFB)
California Cement	Colton, CA	Pyropower	New	(CFB)
Central Soya	Chattanooga, TN	Pyropower	New	(CFB)
A.D.M. Company	Mankato, MN	Asea Stal	New	
General Motors	Fort Wayne, IN	Riley	New	(CFB)
Ultra Power Unit #1	Burney, CA	Ultra Power	Repair	(CFB)
Ultra Power Unit #3	Blue Lake, CA	Ultra Power	Repair	(CFB)
Thermo Electrons	Mendotta, CA	Gotaverken	New	(CFB)
Thermo Electrons	Woodland, CA	Gotzverken	New	(CFB)
(Factory Installations)	York, PA	York Shipley	New	
(Factory Installations)	Ferrysburg, MI	Johnston Boiler	New	

Sewage	Locations	Designers	New or Repair
Lincoln Park	Lincoln Park, NJ	Dorr Oliver	Repair
Onieda County	Utica, NY	Zimpro	New
Key West Waste Water Treatment	Key West, FL	Zimpro	New
City of Dubuque	Dubuque, IA	Copeland	Repair

Dryers	Locations	Designers	New or Repair
Blue Circle Atlantic Cement	Sparrows Point, MD	Dorr Oliver	Repair
J.R. Simplot	Pocatella, ID	Dorr Oliver	Repair

Black Liquor	Locations	Designers	New or Repair
Stone Container	Ontonogon, MI	Copetech	New
Weston Paper	Terre Haute, IN	Dorr Oliver	Repair

A COMPLETE CHOICE OF REFRACTORY PRODUCTS AND SERVICES

Traditional Plibrico plastics, Plicast castables, Pligun gunning mixes, and Plistix servicing/injection mixes all add up to provide a wide variety of solutions for your refractory requirements, whatever the application.

A brief description of some special interest product lines follows below, with laboratory data on the succeeding pages. Consult your local Plibrico representative for additional current selections.

FEATURING . . .

PLICAST' HyMOR' SERIES CASTABLES

The original low cement castable for applications requiring superior hot strengths and the ability to resist abrasion. With years of proven cost-effective service in severe environments, the HyMOR family of materials can solve your problems in high temperature ranges.

PLICAST' HyREZIST' SERIES CASTABLES

A low moisture design for applications that demand abrasion resistant qualities, and the strength to stand up to abusive operating conditions. HyREZIST Series castables also offer inherent flow properties that make placement simple. An excellent performer at low to intermediate temperature ranges.

THE HyRATE' PROCESS

Combining the speed and ease of installation allowed by gunning, with the technology of plastic refractories. The uniquely developed HyRATE plastics are a restructured plastic refractory, designed for pnuematic placement, while retaining all the beneficial properties of the grades from which they were derived.

THE AL-TUFF' SYSTEM

A family of non-wetting aluminum refractories, including plastics, castables, and gunning mixes. The special formulation, fortified with a surface barrier that is impenetrable at normal operating conditions, yields longer life and less downtime. From the metal line to the sub-hearth, including insulating materials, AL-TUFF products make aluminum production less of a challenge.

PLISTIX' Injec-Tite" PROCESS

A pumpable refractory process for general boiler and furnace repair applications. The ceramic fiber based injection mix is designed to restore worn insulation and fill voids between a refractory lining and shell. Material is applied through furnace exterior via pneumatic pump, while the unit is either on-line or down.

FerREZIST' SERIES

A line of graphite enriched refractories specifically designed for demanding applications in the foundry industry. Offering excellent resistance to ferrous metals penetration and slag attack, while retaining the field proven physical properties of the traditional Plibrico products

ADDITIONAL PLIBRICO PRODUCTS

REDI-SHAPES

Custom engineered, pre-fired shapes are available in virtually unlimited sizes, configurations, and weights. Wherever a recurring wear zone demands extra attention, the Redi-Shape concept allows instant maintenance.

Redi-shapes can be cast or rammed of refractories fully compatible with your existing lining. Select from exotic materials formulated and available only in Redi-Shapes, or choose from a range of traditional high performance Plibrico plastics and castables.

DRY SKID BLOCK

An "off the shelf" product for furnace hearth requirements. Featuring a uniformly cast and vibrated HyMOR Series material with excellent resistance to scale and slag attack. With pre-fired skid block, downtime is minimized. Choose from a variety of sizes for simple installation.

PLISUL-GRIP COMPONENTS

Plisul-Grip pipe covering components offer protection for skid pipes, cross pipes, and jacks. Designed for the severe service zones of a piping network, Plisul-Grip stands up to slagging and high temperatures, while providing an insulating efficiency that cuts bare pipe heat loss by 80% to 90%.

PLISULATE BLOCK INSULATION

Plisulate block insulation is available in two grades, 1900 and 1300. Plisulate 1900 is a rigid block insulation manufactured from semi-refractory fibers using an organic/inorganic binder system. The 1900 block is used in industrial applications where service temperatures range from 1000°F to 1900°F, and as a refractory backup in kilns, ovens and furnaces.

The 1300 block is a semi-rigid thermal and acoustical block insulation which is recommended for design applications that require rigidity, but not the residual compressive strength of other block products.

PLISULATE CEMENT

Plisulate Insulating Cement is an all purpose high temperature bonding and insulating cement, recommended for use in pointing or sealing refractories and insulating blocks on furnaces, kilns and other high temperature equipment.

Plisulate Finishing Cement is a one-coat, hydraulic setting finishing cement. This material is recommended for use on furnaces, kilns, valves, pipe fittings, and other insulations

ANCHORS

Plibrico provides a complete line of anchors. Metallic clips, hooks, wall seats and brackets are all available as are ceramic tile anchors

SERVICE

Plibrico's commitment to industry is founded on service. From small boiler repairs through complete turn-key installations, our single source capabilities benefit you in project speed, efficiency and economy

Plibrico®
PLASTIC REFRACTORY

	PLIBRICO SUPER AIR BOND	PLIBRICO SUPER F AIR BOND	PLIBRICO 60 AIR BOND	PLIBRICO 80 AIR BOND	PLIBRICO SUPER F
Recommended Service Limit °F	2800	2900	3200	3300	2900
Setting Characteristics	Air & Heat	Air & Heat	Air & Heat	Air & Heat	Heat
Packaging lbs/ctn	100	100	100	100	100
Shelf Life—Months	12	12	12	12	12
Weight to Place lbs/ft³	142	148	154	170	148
Weight in Service lbs/ft³	132	138	142	158	138
Min. Time Before Firing	None	None	None	None	None
Typical Chemical Analysis—%					
Al_2O_3	41.4	41.6	58.2	79.1	42.3
SiO_2	49.8	50.9	35.4	14.8	53.5
Fe_2O_3	1.4	1.4	1.4	2.4	1.5
TiO_2	1.1	1.5	2.2	2.1	1.9
CaO	0.6	0.5	0.4	0.2	0.3
MgO	0.4	0.1	0.3	0.1	0.1
Alk	1.3	0.5	0.9	0.2	0.3
Permanent Linear Change—% ASTM C-179					
@ 230F	−0.6	−0.6	−0.7	−0.7	−0.6
@1000F	−0.7	−0.7	−0.8	−0.8	−0.7
@1500F	−0.7	−0.7	−0.8	−0.8	−0.8
@2000F	−1.0	−1.0	−1.0	−1.0	−1.0
@2500F	+1.1	+0.5	+0.9	+0.2	+0.5
@3000F	+1.7*	+1.0*	+1.6	+2.0	+1.0*
Cold Modulus of Rupture—psi ASTM C-491					
@ 230F	230	350	300	350	100
@1000F	220	300	280	350	100
@1500F	240	300	280	350	160
@2000F	310	450	390	500	280
@2500F	710	600	450	500	470
@3000F	1200*	1500*	1100	1000	1500*
Hot Modulus of Rupture—psi ASTM C-583					
@1000F	220	300	300	300	100
@1500F	270	450	350	500	200
@2000F	540	800	550	900	750
@2500F	120	150	150	200	130
Cold Crushing Strength—psi ASTM C-133					
@ 230F	450	700	700	700	250
@1500F	800	1200	1200	1200	500
Thermal Conductivity btu . in/hr . ft² . °F					
@ 500F	4.5	4.5	4.8	11.8	4.5
@1000F	5.5	5.5	6.0	10.7	5.5
@1500F	6.2	6.2	6.8	10.5	6.2
@2000F	6.7	6.7	7.2	10.3	6.7
Bake Out Schedule	A	A	A	A	A
Applicable Specifications ASTM C-673	Super Duty	Super Duty	60% Alumina	80% Alumina	Super Duty
Product Number	10006	10008	10013	10016	10007

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

Plibrico®

PLASTIC REFRACTORY

	PLIBRICO 55-S	PLIBRICO SR-68	PLIBRICO 68-S	PLIBRICO SR-85	PLIBRICO 85-S Special	PLIBRICO 85-S	PLIBRICO SR-90	PLIBRICO 90-S	PLIBRICO SIC 80
Recommended Service Limit °F	3000	3100	3100	3300	3300	3300	3400	3400	2700
Setting Characteristics	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical	Chemical
Packaging lbs/ctn	100	100	100	100	100	100	100	100	100
Shelf Life—Months	4	4	4	4	4	4	3	3	3
Weight to Place lbs/ft³	156	163	162	178	184	185	187	188	160
Weight in Service lbs/ft³	141	150	152	165	170	171	172	187	145
Min. Time Before Firing	None	None	None	None	None	None	None	None	None
Typical Chemical Analysis—%									
Al_2O_3	53.6	69.0	69.3	83.1	84.2	86.0	90.7	93.0	7.1
SiO_2	38.5	25.5	24.7	10.1	8.2	9.3	5.3	3.4	7.9
Fe_2O_3	1.1	0.9	0.9	1.1	1.2	0.2	0.2	0.2	0.1
TiO_2	1.2	1.0	1.3	1.7	1.8	0.2	0.1	0.4	—
CaO	0.5	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
MgO	0.3	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2
Alk	0.6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
P_2O_5	2.8	2.7	2.7	2.7	2.7	2.8	2.7	1.6	2.7
SiC	—	—	—	—	—	—	—	—	80.6
Permanent Linear Change—% ASTM C-179									
@ 230F	−0.4	−0.5	−0.4	−0.6	−0.4	−0.4	−0.8	−0.5	−0.3
@1000F	−0.5	−0.6	−0.4	−0.7	−0.5	−0.5	−1.0	−0.6	−0.4
@1500F	−0.5	−0.7	−0.4	−0.6	−0.6	−0.6	−1.1	−0.6	−0.5
@2000F	−0.6	−0.5	−0.4	−0.5	−0.6	−0.6	−1.3	−0.6	−0.2
@2500F	−0.3	−0.1	+0.2	+0.5	+0.1	+0.2	−0.8	−0.9	−0.4
@3000F	0.0	−0.5	+0.6	−0.6	−0.8	−0.6	−1.5	−1.4	−1.3*
Cold Modulus of Rupture—psi ASTM C-491									
@ 230F	920	1130	1200	1240	1300	1300	1200	1200	1000
@1000F	1100	1580	1700	1750	1900	2000	2000	1400	1100
@1500F	1100	1600	1250	1870	2000	2000	1800	1600	1200
@2000F	1500	1980	1400	2400	2200	2400	2400	1900	1200
@2500F	1900	2900	2050	2500	2500	2500	2500	2400	2000
@3000F	2500	4500	3100	2800	3000	2100	3000	3100	3200*
Hot Modulus of Rupture—psi ASTM C-583									
@1000F	1250	2000	1600	1500	1400	1300	2000	1700	1100
@1500F	1750	2400	2000	1900	2000	2400	2000	1900	1300
@2000F	900	1200	1200	900	1000	1800	1200	900	1300
@2500F	600	1100	1100	600	750	500	400	500	700
Cold Crushing Strength—psi ASTM C-133									
@ 230F	1200	1900	2000	1900	2000	2200	2000	2000	1700
@1500F	300	6000	6000	600	7000	800	800	7500	3400
Abrasion Loss-cc's ASTM C-704 After 1500F	13	7	8	6	8	8	4	6	12
Thermal Conductivity btu . in/hr . ft² . °F									
@ 500F	4.8	8.9	8.9	13.0	13.0	16.5	18.1	18.1	72.0
@1000F	6.0	8.5	8.5	11.8	11.8	14.2	16.1	16.1	64.0
@1500F	6.8	8.5	8.5	10.9	10.9	13.0	14.6	14.6	55.0
@2000F	7.2	9.1	9.1	11.3	11.3	12.0	13.7	13.7	47.0
Bake Out Schedule	D	D	D	D	D	D	D	D	D
Applicable Specifications ASTM C-673	Super Duty	70% Alumina	70% Alumina	85% Alumina	85% Alumina	85% Alumina	90% Alumina	90% Alumina	—
Product Number	10011	10068	10037	10085	10035	10018	12011	10033	11075

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests; reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

HyRATE® SERIES
FOR PNEUMATIC APPLICATIONS

Plibrico®
PLASTIC REFRACTORY

	HyRATE SUPER F AIR BOND	HyRATE 60 AIR BOND	HyRATE 68-S	HyRATE 80 AIR BOND	HyRATE 85-S SPECIAL	HyRATE 90-S	HyRATE STR 65-14	HyRATE STR 75-14
Recommended Service Limit °F	2900	3200	3200	3300	3300	3400	3000	3100
Setting Characteristics	Air & Heat	Air & Heat	Chemical	Air & Heat	Chemical	Chemical	Chemical	Chemical
Packaging lbs/bloc or carton	55	55	58	75	60	65	45	62
Shelf Life—Months	3	3	3	3	3	3	3	3
Weight to Place lbs/ft³	153	157	160	174	180	188	175	184
Weight in Service lbs/ft³	142	148	152	165	170	176	165	172
Min. Time Before Firing	None	None	None	None	None	None	None	None
Typical Chemical Analysis—%								
Al_2O_3	43.9	58.6	69.3	77.9	84.5	88.9	67.7	74.9
SiO_2	48.6	34.5	23.8	17.0	8.5	6.1	12.2	7.5
Fe_2O_3	2.1	1.4	1.0	1.5	1.2	0.5	1.3	0.5
TiO_2	1.4	0.5	1.6	2.2	1.0	0.6	1.7	0.6
CaO	0.5	0.1	0.1	0.2	0.1	0.1	0.1	0.1
MgO	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Alk	0.4	0.3	0.2	0.2	0.2	0.2	0.1	0.2
P_2O_5	—	—	2.7	—	2.7	2.7	2.6	2.2
SiC	—	—	—	—	—	—	13.8	13.8
Permanent Linear Change—% ASTM C-179								
@ 230F	−0.5	−0.4	−0.5	−0.5	−0.5	−0.4	−0.5	−0.4
@1000F	−0.6	−0.4	−0.5	−0.5	−0.5	−0.4	−0.5	−0.4
@1500F	−0.7	−0.4	−0.6	−0.6	−0.4	−0.4	−0.5	−0.5
@2000F	−0.6	−0.7	−0.6	−0.6	−0.5	−0.3	−0.6	−0.4
@2500F	+0.6	+1.2	+0.1	−0.1	+0.6	+0.2	0.4	+0.2
@3000F	+1.1*	+2.0	−0.8	+1.8	+1.0	−0.1	0.2	−0.4
Cold Modulus of Rupture—psi ASTM C-491								
@ 230F	510	600	1200	550	1300	1500	1200	1400
@1000F	500	500	1700	400	1500	1600	1300	1400
@1500F	450	550	1300	400	1500	2000	1400	1700
@2000F	700	650	1400	650	2000	2100	1800	1800
@2500F	900	750	2000	700	2000	1870	1600	1600
@3000F	1600	1200	2400	900	1800	1400	1400	1000
Hot Modulus of Rupture—psi ASTM C-583								
@1000F	550	500	1550	500	1600	1800	1200	1400
@1500F	600	600	1900	700	2000	2000	1600	1700
@2000F	900	900	1550	1000	800	1400	700	1300
@2500F	150	200	800	400	800	1200	700	900
Cold Crushing Strength—psi ASTM C-133								
@ 230F	700	700	2000	700	2000	2400	2000	2200
@1500F	1000	1000	8000	1000	8000	9000	8000	8000
Abrasion Loss-cc's ASTM C-704								
After 1500F	—	—	12	—	10	10	12	12
Thermal Conductivity btu . in/hr . ft² . °F								
@ 500F	4.5	4.8	8.9	11.1	13.0	18.0	22.0	23.0
@1000F	5.5	6.0	8.5	10.7	11.8	16.1	20.0	21.0
@1500F	6.2	6.8	8.5	10.5	10.9	14.6	18.0	19.0
@2000F	6.7	7.2	9.1	10.3	11.3	13.7	16.0	17.0
Bake Out Schedule	A	A	B	A	B	D	D	D
Applicable Specifications ASTM C-673	Super Duty	60% Alumina	70% Alumina	80% Alumina	70% Alumina	90% Alumina	70% Alumina	75% Alumina
Product Number	10041	10048	10047	10080	10046	11090	10115	11091

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests on laboratory pressed specimens. reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

Plibrico

PLASTIC REFRACTORY

FerREZIST SERIES — PliRam RAM MIXES

	FerREZIST Super	FerREZIST 55	FerREZIST 68	FerREZIST 85	PLIRAM 80 AIR BOND	PLIRAM 95-S
Recommended Service Limit °F	2900	3000	3100	3200	3300	3400
Setting Characteristics	Heat	Chemical	Chemical	Chemical	Air & Heat	Chemical
Packaging lbs/ctn	100	100	100	100	100/Pail	100/Pail
Shelf Life—Months	12	4	4	4	12	3
Weight to Place lbs/ft³	134	147	155	175	175	180
Weight in Service lbs/ft³	120	132	145	162	166	173
Min. Time Before Firing	None	None	None	None	None	None
Typical Chemical Analysis—% (Calcined)	8.0 LOI**	5.0 LOI	5.0 LOI	4.7 LOI		
Al_2O_3	35.3	55.8	65.9	80.8	79.3	92.5
SiO_2	52.5	32.5	23.5	8.5	13.8	3.1
Fe_2O_3	1.0	0.9	0.9	1.2	1.8	0.1
TiO_2	1.7	1.0	1.4	1.8	2.6	0.1
CaO	0.3	0.4	0.1	0.1	0.1	—
MgO	0.2	0.2	0.2	0.1	0.1	—
Alk	0.9	0.3	0.2	0.1	0.2	0.1
P_2O_5	—	2.6	2.6	2.6	—	4.0
Permanent Linear Change—% ASTM C-179						
@ 230F	−0.4	−0.6	−0.4	−0.5	−0.3	−0.2
@1000F	−0.4	−0.7	−0.4	−0.6	−0.3	−0.2
@1500F	−0.6	−0.7	−0.5	−0.7	−0.3	−0.2
@2000F	−0.7	−0.8	−0.5	−0.5	−0.4	+0.1
@2500F	+1.6	+0.4	−0.1	0.6	+1.4	+0.2
@3000F	+1.0*	+1.0	0.7	0.3	+1.9	−1.0
Cold Modulus of Rupture—psi ASTM C-491						
@ 230F	250	700	700	1000	400	1800
@1000F	250	800	800	1200	450	1850
@1500F	300	800	900	1300	400	2200
@2000F	400	900	1000	1300	850	1900
@2500F	550	1000	1200	1400	1550	1700
@3000F	750	1100	1400	1500	1800	2000
Hot Modulus of Rupture—psi ASTM C-583						
@1000F	300	1000	1100	1300	450	2000
@1500F	300	1100	1300	1500	600	1800
@2000F	400	600	650	1000	1000	1200
@2500F	100	350	600	500	300	500
Cold Crushing Strength—psi ASTM C-133						
@ 230F	450	1000	1200	1200	1500	3300
@1500F	800	3000	4000	5000	2200	5000
Thermal Conductivity btu . in/hr . ft² . °F						
@ 500F					9.0	18.1
@1000F					8.7	16.1
@1500F					8.9	15.0
@2000F					9.5	14.0
Bake Out Schedule	A	D	D	D	A	D
Applicable Specifications ASTM C-673	Super Duty	Super Duty	70% Alumina	85% Alumina	80% Alumina	90% Alumina
Product Number	11002	11006	11068	11007	10016	12004

*At Service Limit

**Loss On Ignition

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLICAST®
DENSE CASTABLE REFRACTORY

	PLICAST 15	PLICAST TROWL MIX	PLICAST 27	PLICAST 27C	PLICAST TUFF MIX
Recommended Service Limit °F	1500	2400	2500	2500	2500
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	100	100	100	100	100
Required Water U.S. qts./100 lbs	7.5	10	7	6	6
Shelf Life—Months	12	12	12	12	12
Weight to Place lbs/ft³	122	110	124	130	130
Weight in Service lbs/ft³	122	110	124	130	130
Min. Time Before Firing	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%					
Al_2O_3	30.9	37.9	41.1	42.6	43.6
SiO_2	46.2	44.2	42.2	36.8	37.5
Fe_2O_3	2.3	3.0	4.1	5.0	2.6
TiO_2	1.8	1.2	1.2	1.0	2.0
CaO	16.4	10.9	9.4	13.1	10.0
MgO	1.1	0.8	0.3	0.3	0.4
Alk	0.9	1.2	0.1	0.8	1.2
Permanent Linear Change—% ASTM C-113					
@ 230F	−0.2	−0.3	−0.2	−0.1	−0.2
@1000F	−0.3	−0.6	−0.2	−0.2	−0.2
@1500F	−0.6	−0.8	−0.3	−0.3	−0.3
@2000F	—	−1.1	−0.4	−0.4	−0.4
@2500F	—	−1.3*	−0.8	−0.6	−0.8
@3000F	—	—	—	—	—
Cold Modulus of Rupture—psi ASTM C-133					
@ 230F	900	400	600	1000	1000
@1000F	450	300	250	300	700
@1500F	150	300	350	400	700
@2000F	—	250	400	400	500
@2500F	—	650*	1500	1700	2300
@3000F	—	—	—	—	—
Hot Modulus of Rupture—psi ASTM C-583					
@1000F	—	300	250	300	400
@1500F	—	350	250	400	450
@2000F	—	300	300	325	450
@2500F	—	—	100	125	125
Cold Crushing Strength—psi ASTM C-133					
@ 230F	2500	1250	3000	5000	4750
@1500F	800	1000	2000	2500	3000
Thermal Conductivity btu . in/hr . ft² . °F					
@ 500F	3.6	3.3	3.9	3.9	3.9
@1000F	4.2	3.9	4.7	4.7	4.7
@1500F	—	4.9	5.7	5.7	5.7
@2000F	—	6.4	7.4	7.4	7.4
Bake Out Schedule	B	B	B	B	B
Applicable Specifications ASTM C-401	—	B	C	C	C
Product Number	14001	14016	14003	14004	14007

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLICAST®

DENSE CASTABLE REFRACTORY

	PLICAST STEEL MIX	PLICAST 31	PLICAST KL MIX	PLICAST 3000	PLICAST 36	PLICAST 40
Recommended Service Limit °F	2700	2800	3000	3000	3100	3300
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	100	100	100	100	100	100
Required Water U.S. qts/100 lbs	6.25	7	5.25	5.5	4.25	4.25
Shelf Life—Months	12	12	9	9	9	9
Weight to Place lbs/ft³	135	130	132	142	155	165
Weight in Service lbs/ft³	135	130	132	142	155	165
Min. Time Before Firing	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%						
Al_2O_3	59.9	47.2	53.3	55.6	63.2	95.7
SiO_2	33.0	42.2	39.2	38.8	29.9	0.1
Fe_2O_3	0.9	1.4	1.1	1.0	1.1	0.1
TiO_2	0.2	1.9	1.2	1.5	1.6	—
CaO	5.0	5.5	4.0	3.9	3.7	3.6
MgO	0.2	0.5	0.2	0.2	0.1	0.1
Alk	0.5	1.1	0.4	0.6	0.1	0.3
Permanent Linear Change—% ASTM C-113						
@ 230F	−0.1	−0.2	−0.2	−0.1	−0.1	−0.1
@1000F	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2
@1500F	−0.3	−0.2	−0.2	−0.2	−0.2	−0.2
@2000F	−0.3	−0.3	−0.2	−0.2	−0.2	−0.2
@2500F	−1.0	−0.3	−0.1	−0.1	+0.2	−0.3
@3000F	+1.1*	+1.5*	+0.2	−0.4	+2.0	−0.8
Cold Modulus of Rupture—psi ASTM C-133						
@ 230F	1000	700	900	1050	1100	1200
@1000F	550	300	400	600	900	1100
@1500F	500	350	450	750	1000	1100
@2000F	500	300	450	700	600	1000
@2500F	1200	1200	1250	1300	900	1800
@3000F	2500*	2300*	2500	2600	2700	2300
Hot Modulus of Rupture—psi ASTM C-583						
@1000F	400	300	350	600	1000	1200
@1500F	500	400	700	800	1000	1200
@2000F	400	400	500	600	800	1000
@2500F	125	200	300	350	400	1200
Cold Crushing Strength—psi ASTM C-133						
@ 230F	4500	2000	3400	3500	4000	5000
@1500F	3000	2000	3400	3500	3000	4200
Thermal Conductivity btu . in/hr . ft² . °F						
@ 500F	4.4	3.9	4.4	4.8	5.9	12.0
@1000F	5.3	4.7	5.3	5.7	7.1	11.0
@1500F	6.5	5.7	6.5	6.9	8.7	10.5
@2000F	8.3	7.4	8.3	8.7	11.3	11.0
Bake Out Schedule	B	B	B	B	B	B
Applicable Specifications ASTM C-401	C	D	E	E	F	G
Product Number	14018	14006	14019	14053	14008	14010

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLICAST®
DENSE CASTABLE REFRACTORY

HYREZIST* SERIES

	HyREZIST T.S. MIX	HyREZIST 2700	HyREZIST 3000	HyREZIST SUPER E.R.	HyREZIST SIC
Recommended Service Limit °F	2500	2700	3000	2900	2700
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	100	100	100	100	100
Required Water U.S. qts/100 lbs	4.5	4.0	4.5	3.75	4.5
Shelf Life—Months	6	6	6	6	6
Weight to Place lbs/ft³	128	140	140	165	140
Weight in Service lbs/ft³	128	140	140	165	140
Min. Time Before Firing	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%					
Al_2O_3	32.5	47.9	54.7	86.8	24.4
SiO_2	61.0	40.1	36.5	8.1	9.2
Fe_2O_3	0.3	1.3	1.0	0.2	0.2
TiO_2	0.1	0.3	0.3	0.2	0.1
CaO	0.1	1.9	1.4	0.1	0.1
MgO	5.2	7.2	4.7	3.9	3.5
Alk	0.3	0.8	0.9	0.2	0.2
SIC	—	—	—	—	61.9
Permanent Linear Change—% ASTM C-113					
@ 230F	−0.2	−0.1	−0.1	−0.1	−0.2
@1000F	−0.2	−0.2	−0.2	−0.2	−0.2
@1500F	−0.3	−0.3	−0.3	−0.3	−0.3
@2000F	−0.3	−0.3	−0.3	−0.4	−0.3
@2500F	+0.3	−0.6	−0.7	−0.3	−0.1
@3000F	—	−0.3*	+0.8	−1.0*	−0.8*
Cold Modulus of Rupture—psi ASTM C-133					
@ 230F	1150	1500	2000	2500	1200
@1000F	1050	1400	1500	2200	1150
@1500F	1200	1200	1950	2200	1300
@2000F	850	1150	1600	2100	1350
@2500F	550	2500	2100	2300	1700
@3000F	—	3200	3500	3000*	2800*
Hot Modulus of Rupture—psi ASTM C-583					
@1000F	1000	1500	1500	1600	1000
@1500F	1150	1800	2250	1950	1100
@2000F	1250	1500	1600	1800	970
@2500F	—	250	500	1100	300
Cold Crushing Strength—psi ASTM C-133					
@ 230F	7000	6000	9000	8000	4000
@1500F	7000	8000	9000	8700	5000
Abrasion Loss-cc's ASTM C-704					
After 1500F	13	13.5	8	5.5	13
Thermal Conductivity btu . in/hr . ft² . °F					
@ 500F	6.5	7.0	7.3	10.3	50.4
@1000F	7.1	7.6	7.9	9.8	45.0
@1500F	7.5	8.0	8.3	9.7	38.0
@2000F	7.8	8.3	8.6	10.8	30.0
Bake Out Schedule	C	C	C	C	C
Applicable Specifications ASTM C-401	C	C	E	D	C
Product Number	2495	2508	14072	14073	2544

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment Data should not be used for specification purposes.

PLICAST' DENSE CASTABLE REFRACTORY

HyMOR' SERIES

	PLICAST HyMOR 2800	PLICAST HyMOR 3000	PLICAST HyMOR 3000 VIBE CAST	PLICAST HyMOR 3100	PLICAST HyMOR 3100 VIBE CAST	PLICAST HyMOR 3100 SPECIAL	PLICAST HyMOR 3100 SPECIAL VIBE CAST	PLICAST HyMOR TSR PLUS	PLICAST SUPER HyMOR. 93
Recommended Service Limit °F	2800	3000	3000	3100	3100	3100	3100	2500	3000
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	100	100	100	100	100	100	100	100	100
Required Water U.S. qts/100 lbs	4.25	3.75	3.0	3.5	2.75	3.25	2.5	4.25	2.2
Shelf Life—Months	6	6	6	6	6	6	6	6	6
Weight to Place lbs/ft³	140	145	150	165	172	160	167	125	190
Weight in Service lbs/ft³	140	145	150	165	172	160	167	125	190
Min. Time Before Firing	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%									
Al_2O_3	46.8	49.5	49.5	70.9	70.9	62.6	62.6	28.4	93.0
SiO_2	46.1	43.6	43.6	15.9	15.9	32.7	32.7	66.5	4.1
Fe_2O_3	1.3	1.0	1.0	1.2	1.2	0.9	0.9	0.3	0.3
TiO_2	1.5	1.6	1.6	1.9	1.9	1.5	1.5	0.2	0.6
CaO	3.6	2.5	2.5	1.4	1.4	1.4	1.4	3.9	1.2
MgO	0.2	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Alk	0.3	0.6	0.6	0.2	0.2	0.2	0.2	0.2	0.1
Permanent Linear Change—% ASTM C-113									
@ 230F	−0.1	−0.1	0.0	−0.1	0.0	−0.1	0.0	−0.1	0.0
@1000F	−0.2	−0.1	−0.1	−0.2	−0.1	−0.2	−0.1	−0.2	−0.1
@1500F	−0.3	−0.2	−0.2	−0.2	−0.2	−0.3	−0.2	−0.2	−0.2
@2000F	−0.5	−0.3	−0.2	−0.2	−0.2	−0.3	−0.2	−0.4	−0.3
@2500F	+0.2	0.3	−0.4	+0.3	+0.4	+0.4	+0.5	−1.2	−0.3
@3000F	+0.4*	−0.6	−0.5	+0.7	+0.8	−0.1	−0.1	—	−1.5
Cold Modulus of Rupture—psi ASTM C-133									
@ 230F	1100	1300	1600	1900	2100	2000	2300	1300	2300
@1000F	1150	1300	1600	1500	1700	1750	2050	1100	2900
@1500F	1150	1500	1900	2000	2250	2000	2350	1200	3800
@2000F	1200	1800	2200	2200	2500	2500	2950	1000	4500
@2500F	1500	2200	2700	2300	2600	3000	3500	500	5000
@3000F	1800*	2700	3400	2900	3200	3800	4300	—	6500
Hot Modulus of Rupture—psi ASTM C-583									
@1000F	1000	1500	1800	1500	1700	2000	2300	1000	2500
@1500F	1200	2000	2400	2700	3000	3000	3500	1600	3000
@2000F	1400	2200	2700	2000	2300	2300	2700	1400	4000
@2500F	250	400	450	900	950	1100	1200	—	—
Cold Crushing Strength—psi ASTM C-133									
@ 230F	4500	5000	6000	5000	7000	5000	7000	4000	8000
@1500F	6000	8000	9000	9000	10000	9000	10000	6000	10000
Abrasion Loss-cc's ASTM C-704									
After 1500F	15	10	8	12	8	9	6	15	4
Thermal Conductivity btu . in/hr . ft² . °F									
@ 500F	9.3	9.7	9.7	13.8	13.8	11.5	11.5	9.3	18.5
@1000F	10.1	10.5	10.5	13.1	13.1	11.7	11.7	10.1	15.0
@1500F	10.7	11.1	11.1	13.0	13.0	12.3	12.3	10.7	14.2
@2000F	11.1	11.5	11.5	14.4	14.4	13.4	13.4	11.1	14.0
Bake Out Schedule	C	C	C	C	C	C	C	C	C-2
Applicable Specifications ASTM C-401	D	E	E	F	F	F	F	C	E
Product Number	2209	2104		2128		2359		2339	2284

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLICAST®

INSULATING CASTABLE REFRACTORY

	PLICAST AIRLITE	PLICAST VERILITE	PLICAST LWI-20	PLICAST LWI-20 TROWL MIX	PLICAST LWI-22	PLICAST LWI-24	PLICAST LWI-26	PLICAST LWI-28
Rec. Service Limit °F—Exposed	1500	1500	2000	2000	2200	2450	2600	2800
Rec. Service Limit °F—Backup	1800	1800	—	—	—	—	—	—
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	40	50	50	50	50	100	100	50
Required Water U.S. qts/100 lbs	24	22	11.5	12	10	14.5	14.5	6
Shelf Life—Months	12	12	12	12	12	12	9	9
Weight to Place lbs/ft³	27	37	55	60	65	80	80	80
Weight in Service lbs/ft³	27	37	55	60	65	80	80	80
Min. Time Before Firing	48 hrs	48 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%								
Al_2O_3	14.0	15.5	39.6	39.8	41.0	42.6	51.3	54.2
SiO_2	33.3	38.7	31.5	33.4	34.0	39.0	36.9	36.3
Fe_2O_3	5.3	5.8	5.4	4.8	4.4	4.6	1.0	0.8
TiO_2	0.1	0.3	1.5	0.4	0.8	1.5	1.3	0.5
CaO	35.4	30.6	19.5	18.8	17.2	9.3	7.1	5.7
MgO	8.8	6.9	0.8	0.8	0.7	0.6	0.3	0.2
Alk	2.9	1.9	1.4	1.8	1.7	1.7	1.3	1.5
Permanent Linear Change—% ASTM C-113								
@ 230F	−0.3	−0.3	−0.3	−0.5	−0.3	−0.2	−0.2	−0.2
@1000F	−0.9	−0.9	−0.8	−1.0	−0.7	−0.4	−0.3	−0.3
@1500F	−1.6	−1.7	−1.0	−1.3	−0.8	−0.6	−0.3	−0.3
@2000F	—	—	−1.2	−1.5	−1.0	−0.7	−0.4	−0.5
@2500F	—	—	—	—	−1.3*	−1.3*	+1.2	+1.6
@3000F	—	—	—	—	—	—	+0.5*	−0.2*
Cold Modulus of Rupture—psi ASTM C-133								
@ 230F	90	150	175	150	200	225	320	350
@1000F	50	70	125	100	150	175	200	250
@1500F	50	70	125	100	150	175	200	300
@2000F	—	—	125	100	150	150	130	300
@2500F	—	—	—	—	175*	300*	350	400
@3000F	—	—	—	—	—	—	480*	600*
Hot Modulus of Rupture—psi ASTM C-583								
@1000F	—	—	90	75	150	150	200	200
@1500F	—	—	100	75	1500	160	220	250
@2000F	—	—	75	50	75	150	160	200
@2500F	—	—	—	—	—	—	80	80
Cold Crushing Strength—psi ASTM C-133								
@ 230F	200	200	600	500	600	700	1000	1100
@1500F	100	125	400	300	500	600	750	750
Thermal Conductivity btu . in/hr . ft² . °F								
@ 500F	0.6	1.0	1.2	1.3	1.8	2.3	2.3	2.5
@1000F	0.7	1.2	1.3	1.4	2.1	2.5	2.5	2.7
@1500F	1.0	1.5	1.7	1.8	2.5	2.8	2.8	3.0
@2000F	—	—	—	—	3.0	3.7	3.7	4.0
Bake Out Schedule	B	B	B	B	B	B	B	B
Applicable Specifications ASTM C-401	—	—	O	O	P	Q	R	S
Product Number	16001	16002	16005	16012	16015	16007	16008	16009

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLIGUN

DENSE GUNNING MIXES

	PLIGUN HYDRO MIX	PLIGUN TUFF MIX	PLIGUN 2800	PLIGUN 48	PLIGUN 3000	PLIGUN TURBO MIX	PLIGUN 3100 SPECIAL	PLIGUN SIC 80	PLIGUN HyREZIST
Recommended Service Limit °F	2400	2500	2800	2900	3000	3000	3100	2700	2700
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs / bag	80	80	80	80	80	80	80	80	80
Shelf Life—Months	12	12	12	12	9	9	9	9	9
Weight to Place lbs / ft³	116	120	120	125	130	145	135	136	130
Weight in Service lbs / ft³	116	120	120	125	130	145	135	136	130
Min. Time Before Firing	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%									
Al_2O_3	41.7	49.5	44.7	45.5	50.6	78.7	59.1	13.6	57.8
SiO_2	44.9	38.8	46.6	47.6	40.5	13.4	35.3	4.8	33.1
Fe_2O_3	2.2	1.4	1.3	1.4	1.2	1.4	1.2	0.3	1.0
TiO_2	1.6	1.8	1.2	1.7	1.2	2.1	1.5	0.1	1.3
CaO	7.2	7.1	4.0	1.4	2.7	3.7	2.3	3.9	5.8
MgO	0.5	0.2	0.3	0.4	0.2	0.1	0.2	0.1	0.2
Alk	1.2	0.9	1.3	1.2	0.4	0.2	0.3	0.2	0.6
SiC	—	—	—	—	—	—	—	77.5	—
Permanent Linear Change—% ASTM C-113									
@ 230F	−0.3	−0.3	−0.2	−0.2	−0.2	−0.2	−0.2	−0.2	−0.1
@1000F	−0.3	−0.3	−0.3	−0.3	−0.2	−0.3	−0.3	−0.3	−0.2
@1500F	−0.4	−0.4	−0.4	−0.4	−0.3	−0.3	−0.3	−0.3	−0.2
@2000F	−0.6	−0.3	−0.5	−0.[illegible]	−0.4	−0.2	−0.2	−0.2	−0.3
@2500F	−1.5*	+1.1	−0.9	−0.9	+1.2	−0.6	+0.3	−0.7	−0.3
@3000F	—	—	−0.1*	−0.1*	−0.4	−1.4	+0.2	—	−0.9
Cold Modulus of Rupture—psi ASTM C-133									
@ 230F	700	1000	600	100	800	1050	600	1000	1200
@1000F	400	700	400	100	500	750	400	450	1000
@1500F	400	750	350	110	550	700	470	600	800
@2000F	350	650	450	200	430	550	500	600	900
@2500F	1800*	1950	1600	500	750	1300	1000	2700	1500
@3000F	—	—	2000*	1700*	1700	2700	1600	—	1800
Hot Modulus of Rupture—psi ASTM C-583									
@1000F	400	650	400	80	600	650	400	400	600
@1500F	450	800	400	150	750	730	550	650	1000
@2000F	400	500	500	150	650	600	650	1000	700
@2500F	—	100	100	50	110	200	150	100	200
Cold Crushing Strength—psi ASTM C-133									
@ 230F	1800	2200	1600	300	2200	2400	1600	2500	4000
@1500F	1600	1850	1200	300	2000	2000	1500	2000	3500
Thermal Conductivity btu . in/hr . ft² . °F									
@ 500F	3.9	3.9	3.9	3.9	4.4	5.9	4.7	72.0	4.4
@1000F	4.7	4.7	4.7	4.7	5.3	7.1	5.6	64.0	5.3
@1500F	5.7	5.7	5.7	5.7	6.5	8.7	6.8	55.0	6.5
@2000F	7.4	7.4	7.4	7.4	8.3	11.3	8.6	47.0	8.3
Bake Out Schedule	B	B	B	B	B	B	B	B	B
Applicable Specifications ASTM C-401	B	C	D	E	E	E	F	D	D
Product Number	14015	14033	13028	13003	2336	13014	14031	13030	13041

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests on gunned samples: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLIGUN®

INSULATING GUNNING MIXES

	PLIGUN VERILITE	PLIGUN LWI-106	PLIGUN LWI-22	PLIGUN LWI-24	PLIGUN LWI-26	PLIGUN LWI-28
Rec. Service Limit °F—Exposed	1500	2000	2200	2450	2600	2800*
Rec. Service Limit °F—Backup	1800	—	—	—	—	—
Setting Characteristics	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Packaging lbs/bag	50	50	50	80	80	50
Shelf Life—Months	12	12	12	12	9	9
Weight to Place lbs/ft³	38	38	65	82	85	90
Weight in Service lbs/ft³	38	38	65	82	85	90
Min. Time Before Firing	48 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Typical Chemical Analysis—%						
Al_2O_3	16.4	30.9	44.0	44.9	57.4	53.1
SiO_2	36.7	21.9	34.[illegible]	41.7	37.6	36.0
Fe_2O_3	6.7	9.6	2.7	1.4	0.9	0.9
TiO_2	0.4	1.5	0.3	1.3	0.8	0.5
CaO	27.5	21.6	16.0	8.5	7.2	7.1
MgO	9.3	8.2	0.3	0.2	0.2	0.3
Alk	2.6	2.7	2.1	1.5	1.5	1.6
Permanent Linear Change—% ASTM C-113						
@ 230F	−0.3	−0.3	−0.2	−0.2	−0.2	−0.2
@1000F	−0.6	−0.4	−0.5	−0.3	−0.3	−0.3
@1500F	−1.4	−0.7	−0.8	−0.6	−0.4	−0.4
@2000F	—	−1.8	−1.2	−0.8	−0.5	−0.4
@2500F	—	—	−1.5*	−1.2*	+0.6	+1.3
@3000F	—	—	—	—	+1.4*	+0.7*
Cold Modulus of Rupture—psi ASTM C-133						
@ 230F	120	120	150	250	500	500
@1000F	100	100	125	220	280	300
@1500F	80	110	150	250	320	400
@2000F	—	210	150	270	460	400
@2500F	—	—	150*	520*	500	550
@3000F	—	—	—	—	1250*	1200*
Hot Modulus of Rupture—psi ASTM C-583						
@1000F	100	140	150	200	300	320
@1500F	50	110	100	230	360	400
@2000F	—	—	100	140	180	220
@2500F	—	—	—	—	—	100
Cold Crushing Strength—psi ASTM C-133						
@ 230F	250	300	400	800	1300	1300
@1500F	250	250	300	750	1100	1200
Thermal Conductivity btu in/hr . ft² . °F						
@ 500F	1.0	1.0	1.9	2.5	2.5	3.0
@1000F	1.2	1.2	2.2	2.7	2.7	3.4
@1500F	1.5	1.5	2.6	3.0	3.0	3.7
@2000F	—	—	3.1	3.9	3.9	4.3
Bake Out Schedule	B	B	B	B	B	B
Applicable Specifications ASTM C-401	—	O	P	Q	R	S
Product Number	16003	13018	16022	16014	16013	13016

*At Service Limit

Note: All figures are averaged results of laboratory ASTM tests on gunned samples reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes

PLISTIX® SERVICING MIXES

	PLISTIX SPRAYTITE B	PLISTIX SUPER	PLISTIX 900 F	PLISTIX SR-68	PLISTIX SR-90
Recommended Service Limit °F	2500	2700	3400	3100	3400
Setting Characteristics	Silicate	Silicate	Chemical	Chemical	Chemical
Packaging	80 lbs/bag	100 lbs/bag	50 lbs/pail	50 lbs/pail	50 lbs/pail
Shelf Life—Months	12	12	3	[illegible]	3
Weight to Place lbs/ft³	118	110	182	160	175
Weight in Service lbs/ft³	118	110	182	145	155
Min. Time Before Firing	None	None	None	None	None
Typical Chemical Analysis—%					
Al_2O_3	23.3	33.9	91.8	69.0	90.7
SiO_2	69.8	63.2	1.4	25.5	5.3
Fe_2O_3	0.8	1.1	0.7	0.9	0.2
TiO_2	1.2	1.7	—	1.0	0.1
CaO	0.5	0.4	0.02	0.1	0.1
MgO	0.4	0.3	0.07	0.1	0.1
Alk	2.3	4.3	0.21	0.2	0.2
P_2O_5	—	—	—	2.7	2.7
Product Number	17514	17504	17505	17704	12020

PLISTIX® INJEC-TITE® INJECTION MIXES

	PLISTIX INJEC-TITE LWI-2300	PLISTIX INJEC-TITE 80
Rec. Service Limit °F (exposed)	2300	3100
Setting Characteristics	Heat	Silicate
Packaging	50 lbs/pail	80 lbs/bag
Required Water U.S. qts/100 lbs	—	6.5
Shelf Life—Months	3	6
Weight to Place lbs/ft³	75	140
Weight in Service lbs/ft³	30	140
Permanent Linear Change—%		
2000°F	-3.5	-0.2
2300°F	-7.5	-0.4
2700°F	—	-2.0
Thermal Conductivity btu . in/hr . ft² . °F		
@ 500F	0.6	10.0
@1000F	0.7	9.2
@1500F	1.0	9.1
@2000F	—	9.4
Product Number	17618	17602

DEMON® MORTARS

	SUPER DEMON AIR.SET WET
Recommended Service Limit °F	2950
Setting Characteristics	Air
Coverage: lbs per 1000 Std. Fire Brick	350-400
Packaging lbs/drum	50 or 100
Shelf Life—Months	9
Typical Chemical Analysis—%	
Al_2O_3	46.2
SiO_2	48.4
Fe_2O_3	0.9
TiO_2	0.6
CaO	0.1
MgO	0.1
Alk	[illegible]
Product Number	[illegible]

Note:
All figures are averaged results of laboratory ASTM tests: reasonable variations can be expected. Thermal conductivity will vary depending upon installation technique and thermal treatment. Data should not be used for specification purposes.

PLIBRICO MONOLITHIC LININGS FOR
FLUID BED COMBUSTORS

A Fluid Approach To Combustor Refractory Selections . . .

Have it your way!

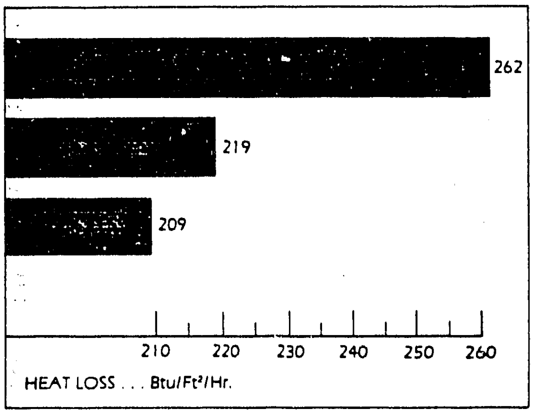
Plan a combustor lining that delivers all the inherent advantages of monolithic Plibrico construction . . . plus . . . all the individually selected benefit features you consider most important.

Choices . . . the choices available among the broad range of Plibrico refractories . . . enable you to select products with properties to precisely match your own operational requirements, to coordinate with your own parameters for cost-effective levels of service. That's the fluid approach, the Plibrico approach, to fluid bed combustor system linings.

You can select among formulations serving over a spectrum of service temperatures, offering varying alumina contents and densities, delivering varying levels of hot strength and abrasion resistance, providing varying degrees of thermal conductivity and insulation. And all of these choices are yours in materials for either casting or gunning in place, with plastics also available for selected combustor applications.

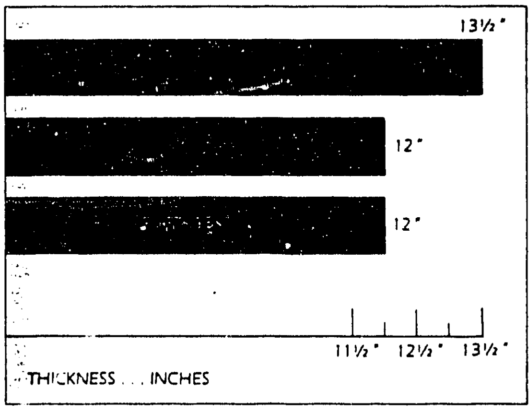
You can have it our way, if you choose. You'll see the Plibrico way in the following pages presenting three schematically illustrated combustor systems and the application of selected product combinations currently recommended by Plibrico in this still evolving technology. The significant advantages that are yours with those product combinations are highlighted at the right.

You get all these benefits . . . and more . . . with Plibrico's recommended lining designs



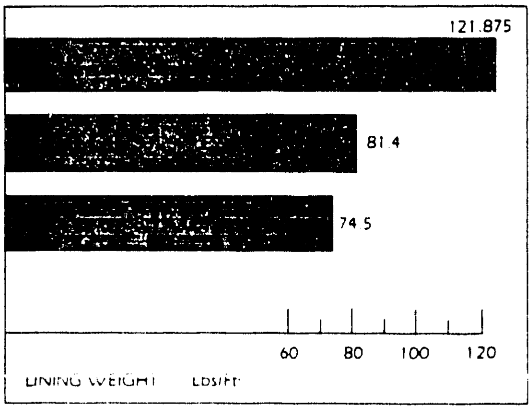
LOWER HEAT LOSS
. . . for high thermal efficiency

Look at the valuable reductions in heat loss Plibrico linings achieve compared to ordinary fire brick linings, a graphic demonstration of their superior thermal efficiency. Apply these percentages to your cost for the fuel needed with ordinary construction and you'll welcome the substantial dollar savings, savings that continue throughout the extended life of the Plibrico lining.



THINNER LININGS
. . . for reduced vessel size

Significant to new combustor system designers and buyers alike is the fact that the high thermal efficiencies depicted here result from linings that are 11% thinner than the fire brick linings. Thus, while maintaining the same internal dimensions to provide the same combustion volumes and gas velocities, external vessel dimensions can be reduced appreciably, yielding desirable companion reductions in steel quantities and weights, as well as fabricating and erection costs.



LIGHTER LININGS
. . . for less structural support

Clearly shown here are the pronounced weight differences that set Plibrico linings far apart from fire brick linings: they're from 33.2% to 38.9% lighter. Consider the synergistic effect of linings that are both lighter and thinner, linings that not only contribute to more compact vessel sizing, but also trim down the need for structural support. Plibrico linings are distinctive, giving you high thermal efficiency plus cost-effective construction.

9" Super Duty Firebrick / 4" Insulating Firebrick — 5" Plicast HyMOR 3000 / 7" Pligun LWI-106 Special — 5" Pligun 3000 / 7" Pligun LWI-106 Special

Consider these Additional Lining Features

Fully Monolithic . . .

Every Plibrico lining forms one continuous, tightly knit unit. It's completely free of the countless joints that make a fire brick lining so vulnerable, joints that open with expansion and contraction, allowing excess air infiltration to retard combustion efficiency, leading to costly and premature repairs.

Totally Anchored . . .

Strategically placed anchors embedded throughout the Plibrico lining provide a positive support system to enhance the lining's structural integrity. Engineered to application temperatures, they serve as shock-absorbers, allowing for free natural movement while tenaciously holding the lining securely in place.

Rapidly Installed . . .

You'll note from the drawings that gunning refractories predominate, ensuring high speed placement at rates that outstrip those of laid up construction, especially where configurations would require special shapes. Pligun refractories flow freely, quickly building up a lining that molds to any contour, compensating on the spot for any shell irregularities. Even in severe wear zones where its unique properties are so advantageous, Plicast HyMOR 3000 can be rapidly cast.

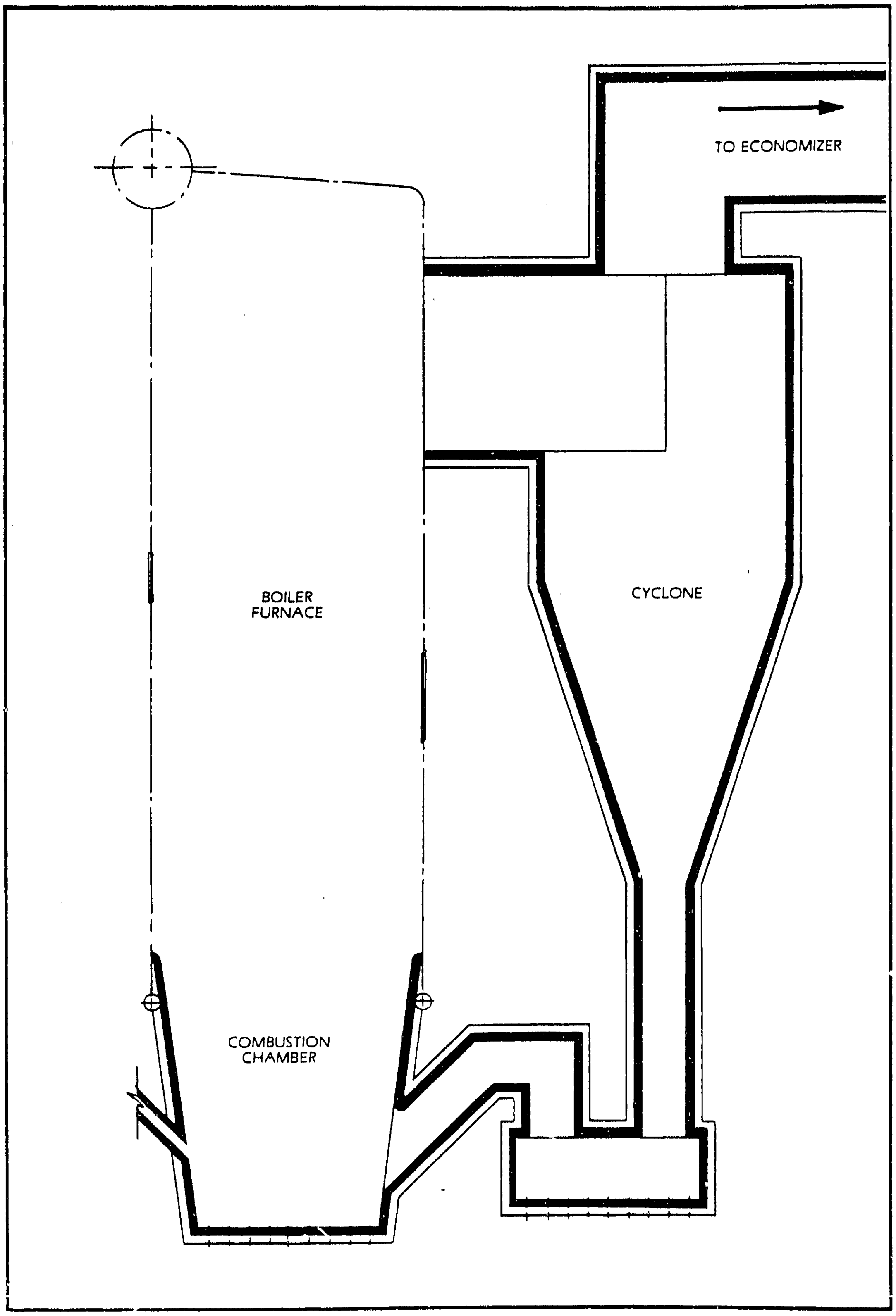
Unmatched Abrasion Resistance . . .

No conventional castable in its class can withstand abrasion as well as Plicast HyMOR 3000. It's twice as effective! It's ideally suited to the turbulent, high wear conditions of fluidized beds.

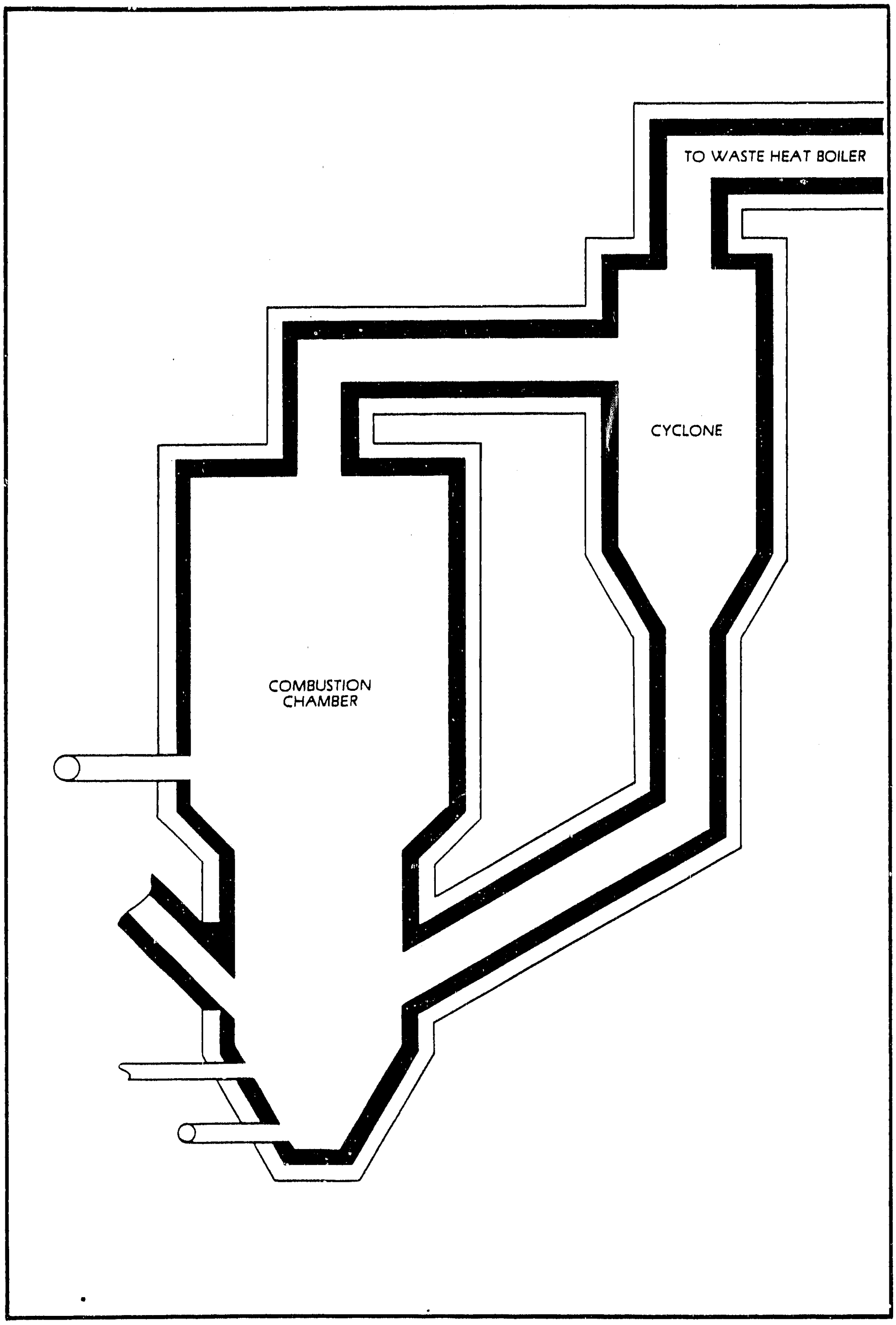
Superb Hot Strength . . .

High temperature testing reveals that Plibrico hot face refractory selections achieve excellent in-service strengths, making them more resistant to hot load deformation, and prolonging their service life. For example, Plicast HyMOR 3000 has three times the hot strength, one-third the hot load deformation of conventional castables.

For a Direct Fired Boiler Combustor



For a Waste Heat Boiler Combustor



. . . and these Refractory Properties

Plicast HyMOR 3000

This super duty class castable, a 50% alumina formulation with the relatively low iron content of 1.10%, serves the full temperature range from 200 °F to 3000 °F. It weighs 145 lb/ft³ in service and offers high load bearing capacity for it has three times the hot strength of conventional super duty castables. In the standard abrasion test its loss is a mere 6cc, half that of its conventional counterparts.

Pligun 3000

Constituents of this formulation are carefully sized and blended, providing a uniform mix with excellent flow characteristics to assure consistent gunnability. It's a super duty material with a 50% alumina content and the relatively low iron content of 1.16%. In service it weighs 129 lb/ft³. Across its full service temperature range, extending from 200 °F to 3000 °F, it achieves uniformly high hot strengths. It's distinguished by the moderate thermal conductivity that contributes to lower heat loss, and it provides good abrasion resistance, ample to withstand the wear of those areas where it's employed.

Pligun LWI-106 Special

Formulated for service in the intermediate duty temperature range from 200 °F to 2000 °F, this is a smooth-gunning mix that's very light in weight, only 36 lb/ft³. For its weight it delivers uniform strength over its entire service range. Its key characteristic lies in its remarkable insulating efficiency, reflecting its markedly low heat storage capacity, its minimal thermal conductivity.

For an Incinerator/Process Combustor

A Rugged Plastic Lining . . . Gunned at High Speed

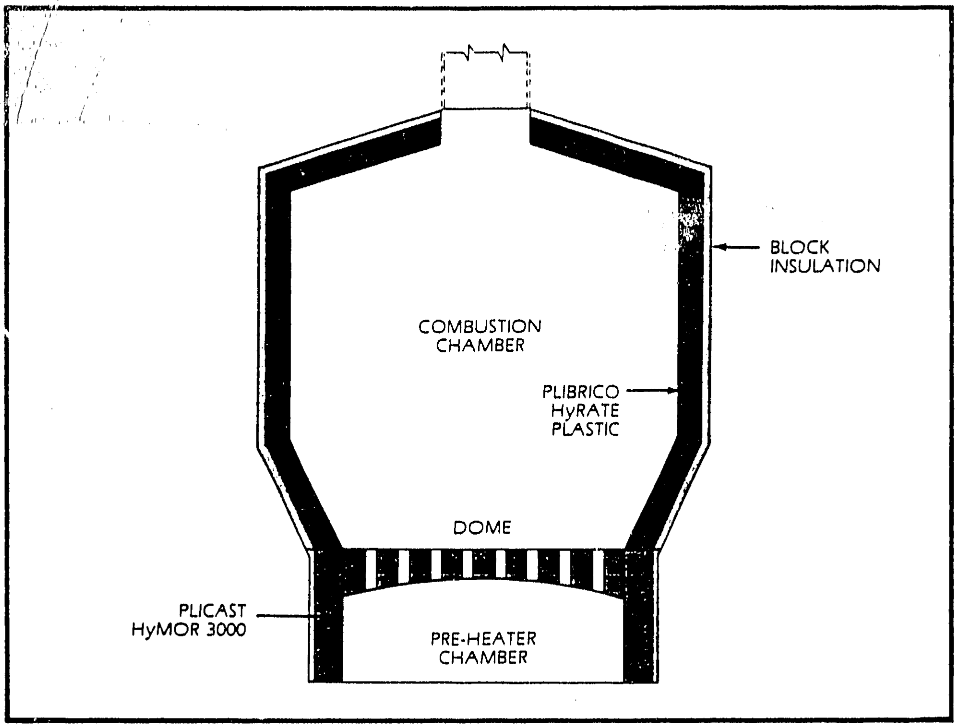
High performance Plibrico plastics excel in this service because they so capably combat chemical attack, repelling the adverse reactions generated by wastes and many process products. They not only develop high strengths at operating temperatures, but they're also volume stable, ruggedly resisting thermal shock.

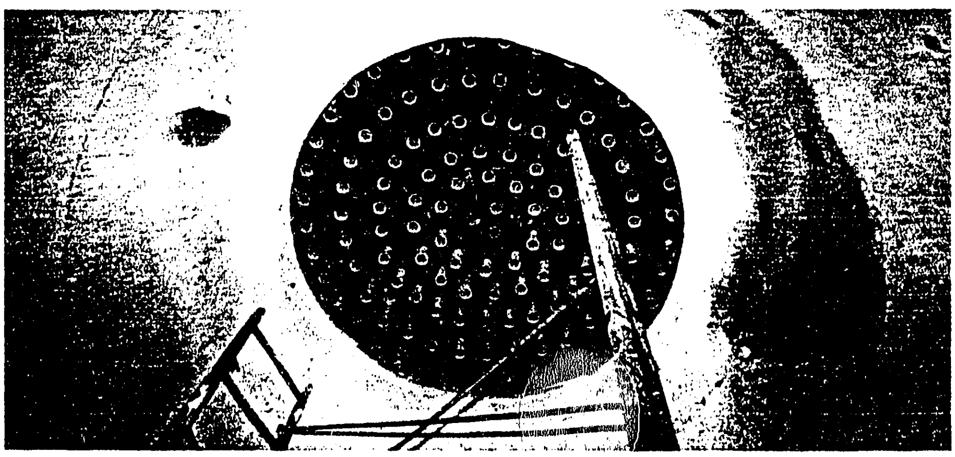
Now, thanks to the unique HyRATE Process, plastics can be gunned at speeds 250% faster than conventional ramming, and often more. Both installation time and labor expense are effectively reduced. Specially formulated for gunning, Plibrico HyRATE plastics are available in a selection for any service condition.

A Joint-Free Dome . . . Cast as a Single Entity

What could more vividly illustrate the impeccable integrity of Plicast castable construction than these two photos of a one-piece combustor dome, one view taken from below and the other from above. Here you see the unified expanse of a monolith, readily formed and cast as one integrated structure. Eliminated is the tedious process of installing costly special shapes.

With its own powerful properties, Plicast HyMOR 3000 further enhances the inherent integrity of this dome's monolithic structure. Superb strength distinguishes Plicast HyMOR 3000 from conventional castables for it attains three times greater hot strengths, withstands hot load deformation three times more effectively. And it's 100% more resistant to abrasion.





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Refractory Experience in Circulating Fluidized Bed Combustors, Task 7

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