POWER-GEN International '96 Conference
December 4-6, 1996
Orlando, Florida

CONF-961232--6

AFBC - Operation of Small Scale Demonstration for Greenhouse Heating

Robert A. Ashworth, Manager Advanced Systems
Duane A. Plessinger, Senior I & C Specialist
Energy and Environmental Research Corporation

Rodney L. Webner, Senior Product Manager
Will-Burt Company

Thomas Machamer, President
Cedar Lane Farms Corporation

Abstract

A 2.2 million Btu/hr unit prototype AFBC system was installed in 1995 at Cedar Lane Farms, a commercial nursery in Ohio. The AFBC is in operation and is heating hot water for greenhouse temperature control. A team consisting of the Energy and Environmental Research Corporation, the Ohio Agricultural Research and Development Center of Ohio State University and the Will-Burt Company developed this technology with funding support from the Ohio Coal Development Office and the U.S. Department of Energy.

The system is fully automated with little operator attention being required. Operating experience at Cedar Lane Farms has shown that only 2 hours per day of operator attention is required for the system. The system includes flyash/sorbent reinjection and underbed coal/limestone feed. These features provide for good limestone utilization; a Ca/S (in coal) ratio of 2.5 will maintain an SO_2 emissions level of 1.2 lb/10^6 Btu when burning high sulfur (3.2%) Ohio coal. A baghouse is used to control particulate emissions. Based on the success of the prototype unit, a design has been recently completed for a commercial size 10×10^6 Btu/hr unit. This environmentally acceptable and cost effective coal-fired AFBC system is targeted for industrial-commercial-institutional space and process heat applications in the 5×10^6 to 10×10^6 Btu/hr capacity range. Multiple AFBC units can be used to provide larger heat outputs. Potential coal-fired AFBC users include institutions (schools, hospitals, prisons, government), light industry (agriculture, food processing), commercial users (shopping centers), and large residential users (apartment complexes).

Introduction

Currently, oil and gas are the fuels of choice for the space and process heat requirements of commercial and small industrial applications. This is because of the convenience and cleanliness offered by these fuels compared to coal. However, there are social and strategic pressures to provide technologies which will enhance the acceptability of coal for these applications. Commercial/small industrial boilers, i.e., those in the range of 1.5 to 10 million Btu/hr size are large oil and gas users. For example, assuming a 50% capacity factor, these boilers consume about 3.5×10^{15} Btu/year. It is estimated that if only 25% of oil and gas-fired boilers in this size range were converted to coal, then coal consumption would be increased by some 35 million tons/year, an amount in 1995 of around twice the State of Ohio's annual coal production. Potential coal-fired AFBC users include institutions (schools, hospitals, prisons, government), light industry (agriculture, food processing), commercial users (shopping centers), and large residential users (apartment complexes).

DISCLAIMER

Fluidized bed combustion offers several potential advantages over conventional coal combustion systems for small scale applications:

Minimal Fuel Processing The combustion process is not overly sensitive to the physical characteristics of the coal feed. There is no need to pulverize the fuel. This greatly simplifies the design and operation of the fuel supply system.

Low Temperature Combustion. The fluidized bed operates at low temperatures. This avoids problems such as clinker formation and slagging which are major areas of concern with other coal fired systems.

SO_2 Emission Control. Limestone sorbent in the fluid bed reacts with SO_2 liberated during the combustion process to control SO_2 emissions. Emissions can be reduced in excess of 80 percent.

NO_x Emissions. Low temperature combustion results in low NO_x emissions compared to many other coal fired systems.

Process Description

The host site for this 2.2 million Btu/hr AFBC demonstration was Cedar Lane Farms, Inc., a nursery near Wooster, Ohio. Cedar Lane Farms grows/produces roses, perennials, flowering hanging baskets, potted flowering plants, blooming annual and vegetable flats, pansy and primrose baskets and poinsettias. The greenhouse area under glass and heated by Cedar Lane Farms totals some 200,000 ft^2. The AFBC provides heat to a portion of this greenhouse area. The AFBC ties into an existing hot water heating system, supplied from one coal-fired stoker and two natural gas fired hot water heaters.

The AFBC system installed at Cedar Lane Farms uses a fluid bed operating at 1500 to 1600°F, and at near atmospheric operating pressure, see the process flow diagram in Figure 1 and the equipment layout in Figure 2. Stoker coal (~2"×½" size) is unloaded using an existing belt conveyor that transports the coal to an existing coal storage bin. This bin provides the coal feed to both the coal-fired stoker and the AFBC. From the coal storage bin, the coal is augered to a jaw crusher that crushes the coal to a minus ½" size and the coal from the crusher feeds into a coal auger feed bin. For the prototype demonstration, coal feed rate is controlled automatically to maintain the desired bed temperature, and recycle flue gas is automatically controlled to respond to the thermal load. Fresh air feed into the system is controlled to maximize overall thermal efficiency and reduce NO_x emissions. The feed bin coal is augured into a standpipe that feeds a rotary lock feeder.

In parallel to the coal feed, limestone from a separate feed bin is also augured into the standpipe. From the rotary feeder, coal and limestone fall into a pneumatic transport line. A fresh air blower provides the air transport media. Coal and limestone are blown through a transport line that passes through the combustor wind box and then up through the center of the air distribution grid plate, into the bottom of the fluid bed. Graded sand is used as the inert fluid bed media. Coal combustion and sulfur dioxide capture take place in the fluid bed. The coal rate is set to provide the energy release to maintain the fluid bed temperature and the limestone:coal ratio is set to yield the SO_2 capture desired. The coal feed rate is controlled automatically to maintain the desired bed temperature, and recycle flue gas is automatically controlled to respond to thermal load. Fresh air feed into the system is controlled to maximize overall thermal efficiency and to reduce NO_x emissions.

The fluidized bed proper is designed with simplicity as the prime input, recognizing that small scale operators do not have the resources to maintain a large staff, with the diverse talents necessary, to operate and maintain a complex system. The combustor is a cylindrical, refractory lined vessel with no heat transfer surfaces or pressure parts. The only maintenance that needs to be done on the combustor is relegated to refractory and possible grid plate repair.

The hot flue gas exits the combustor and flows through a mechanical collector where large particles of coke and limestone are removed and pneumatically recycled back into the fluid bed. Recycled flue gas is also used here as the transport media. The purpose of this reinjection technique is to yield better calcium (limestone) utilization for SO_2 capture. Hot flue gas from the collector then enters a waste heat recovery hot water heater. The cooled flue gas from the hot water heater exits at a temperature of approximately 300°F and enters a bag house for particulate removal. Particulate is removed by an automatically actuated screw conveyor to a disposal bin. An induced draft fan on the exit of the bag house provides the motive force to draw the flue gas from the combustor, maintaining a slight negative pressure at the combustor flue gas outlet. The induced draft fan discharges into an atmospheric stack.

A unique design feature of this fluidized bed combustor, is the use of flue gas recycle plus fresh air for feed throughput control. The flue gas recycle technique improves the overall thermal efficiency of this AFBC system by some 3.5% to 5%. Further, by controlling the amount of fresh air being drawn into the system, the oxygen content at the exit of the fluid bed is controlled to maximize thermal efficiency and still provide for good combustion conditions within the fluid bed. Flue gas from the bag house is recycled back to the windbox of the combustor for temperature control and supply of combustion air. A controlled rate of fresh air is drawn into the suction of the recycle blower and is then mixed with the recycled flue gas. The rate of fresh air is controlled to maintain a set oxygen percentage in the flue gas exiting the fluid bed. The recycled flue gas-fresh air mix enters the windbox of the fluidized bed combustor and flows up through air distributor caps on the grid plate that supports the inert sand bed, providing the proper velocity to fluidize the bed.

Operations Assessment

The operation of the AFBC has been very successful in meeting the cyclical heating demand loads of the greenhouse. Because there are no heat exchanger tubes in the bed proper, it can be banked for five to six hours during the day when the heating demand is low and restarted with no auxiliary fuel. It requires very little operator attention; the system runs on automatic control and the only operator function normally required is to empty the flyash catch drum under the baghouse. Cedar Lane Farms (host site) intends to use the AFBC as a first on, last off hot water heater in lieu of running its natural gas fired boiler.

The CLF application requires that the AFBC meet the demand for hot water varied throughout the day. The AFBC control system is designed so that the unit will shutdown and start backup automatically. During the spring months when the heat load is very cyclical, on-off cycling could occur five or six times in a 24-hour period. A programmable logic control (PLC) system was installed to handle the sequential starting, stopping and banking as well as the modulating the control of the AFBC when operating. The combustor will stay in a banked condition without a need for fuel for some five to six hours, a feature very important in meeting the cyclical demand load for greenhouse heating and for that matter, other small industrial heating applications.

This particular AFBC uses a sand bed and has no internal heat transfer surfaces, and as a consequence there are no ash-calcium agglomerates formed in the bed. All of the ash and sorbent are blown from the combustor to a downstream baghouse. This feature reduces the risk of an operator being burned with hot ash and also reduces operating labor costs.

Testing

The testing program included the measurement of sulfur and nitrogen oxides emissions and thermal efficiency. Over the testing periods, one coal and two limestones were tested in the combustor. The coal and limestones tested are shown in Table 1.

Table 1. Coal and Limestones Tested

Wayne Mine, Ohio Coal and Ash Analyses:

Coal Delivered: Bituminous Coal, size 2" x 0" unwashed

Coal Analyses(as received):

Ultimate Analysis

Component	Wt %
Carbon	71.15
Hydrogen	4.44
Oxygen	8.13
Nitrogen	1.24
Sulfur	3.28
Moisture	5.68
Ash	6.08
Total	100.00

Higher Heating Value:
HHV = 12,640 Btu/lb
Coal Sulfur = 5.18 Lb SO_2/MM Btu
Calculated Ca/S ratio of ash = 0.04
where, Ca = Ca + Na_2 + K_2

Ash Analyses:

Major and Minor Elements as Oxides:

Component	Wt %
SiO_2	41.46
Al_2O_3	24.26
TiO_2	1.08
Fe_2O_3	26.95
CaO	2.00
MgO	0.82
Na_2O	0.46
K_2O	1.80
P_2O_5	0.28
SrO	0.06
BaO	0.00
MnO_2	0.13
Other	0.36
Total	100.00

Limestone:

National Lime and Stone Limestone - 80 wt% $CaCO_3$ Calcitic Limestone
Ohio Lime Company - 54.5 wt% $CaCO_3$ Dolomitic Limestone

Sulfur Dioxide Capture

The Ohio coal being fired during the testing of the Cedar Lane Farms system had a sulfur content of 3 wt% and a higher heating value of 12,650 Btu/lb which translates to 4.74 lb SO_2/MM Btu. Not unexpectedly, the best temperature for sulfur dioxide capture when using dolomitic limestone as a sorbent appears to be in the range of 1500 to 1550°F (see Figure 3).

Sulfur dioxide capture with a dolomitic limestone addition to yield a Ca/S ratio of 2.5 to the fluid bed yielded flue gas emission rates as low as 0.98 lb of SO_2 per million Btu of coal fired, see Figure 4. The data indicates that the regulated emission requirement of 1.2 lb of $SO_2/10^6$ Btu of coal fired can be met with a dolomitic limestone rate to yield a Ca/S ratio of ~2.0. The calcitic limestone performed better than dolomitic limestone, with sulfur dioxide capture at a Ca/S ratio of 2.5 yielding flue gas emission rates as low as 0.44 lb of SO_2 per million Btu of coal fired.

Thermal Efficiency

The thermal efficiency of hot water out to fuel in for the various run periods examined ranged from 43% to 75%. Theoretically, with better oxygen control in the system, the overall thermal efficiency should approach 85%. For some of the runs there was a buildup of sorbent/flyash in the boiler which could account for the low efficiency. The design for a 10 million Btu/hr commercial unit has separate air and flue gas recycle blowers that will provide for the oxygen control required to yield the higher thermal efficiency level.

NO_x Reduction

Generally the NOx emissions were lower than that observed during pilot plant operation, ranging from 0.41 to 1.07 lb NOx/MM Btu. In Figure 5, a correlation between carbon monoxide in the flue gas and NOx emissions is shown. The trend, like the pilot plant operations, shows NOx emissions reducing with increased CO levels. During the use of the dolomitic limestone, the levels of NOx were lower when feeding limestone at the higher rate to achieve a Ca/S ratio of 2.5. It appears that the limestone may be capturing some NOx as calcium nitrate.

Economics

The prototype unit at the Cedar Lane Farms facility is not an economic size that could compete with the firing of natural gas in a package hot water heater or boiler; however, based on the current cost differential between coal and natural gas. However, with a four-fold increase in size the AFBC does start being competitive with natural gas fired heaters/boilers. This is due to the capital cost economy of scale. At larger sizes than a four-fold increase over pilot plant scale, the AFBC becomes even more cost competitive. The design scaleup considerations for larger commercial AFBC units are as follows:

- The outside diameter of the combustor proper, will be limited based on over-the-road travel clearance considerations. For economic reasons, it is desirable to shop fabricate rather than field fabricate the combustor.
- For large units, multiple coal-limestone feed points may be desirable. However, multiple units of the auger system that is to be tested could be used to satisfy this need.
- Combustion/recycle gas distribution through grid plate distributors has been proved for large fluidized bed combustors. This is not considered a problem for scale-up.
- The rest of the system, waste heat recovery, baghouse, blowers, and pumps are units that are commercially available in both small and large sizes.
- The controls to be used are applicable, no matter the size of the system.

Capital and operating costs were developed to compare the cost of producing hot water using a natural gas fired boiler with that for producing hot water with an AFBC system. The capital cost for an identical size hot water heater as that used for the AFBC system (7.84 million Btu/hr of hot water produced with 9.8 million Btu/hr of fuel consumed) was developed for the natural gas system. The total installed cost was estimated at $206,163. This compares to the $568,000 required for the AFBC system. Based on coal being purchased at $30/ton ($1.18/million Btu) and natural gas at $4.50, whereas the capital cost for the AFBC system is some 2½ times that of the natural gas fired system, the AFBC system because of the lower fuel cost will produce hot water at some $2.00/million Btu less than that for a natural gas.

When evaluating the economics for a specific AFBC system application, two factors are very important, the price differential between coal and gas or oil, and the onstream capacity factor for the heating system. The AFBC system will be more economically competitive with higher price differentials and higher capacity factors. A cost comparison based on 250 day per year operation for natural gas and the coal-fired AFBC was made based on varying natural gas cost. In Figure 6, the comparison is shown. It can be seen that when using a purchased coal price of $1.18/MM Btu that the AFBC unit is cost competitive with natural gas when the cost of gas is $2.85/MM Btu or greater. Most small consumers will probably be paying between $3.50 to $5.00/million Btu for natural gas, so the AFBC at the 10 million Btu/hr size should be the economical choice for new heating systems.

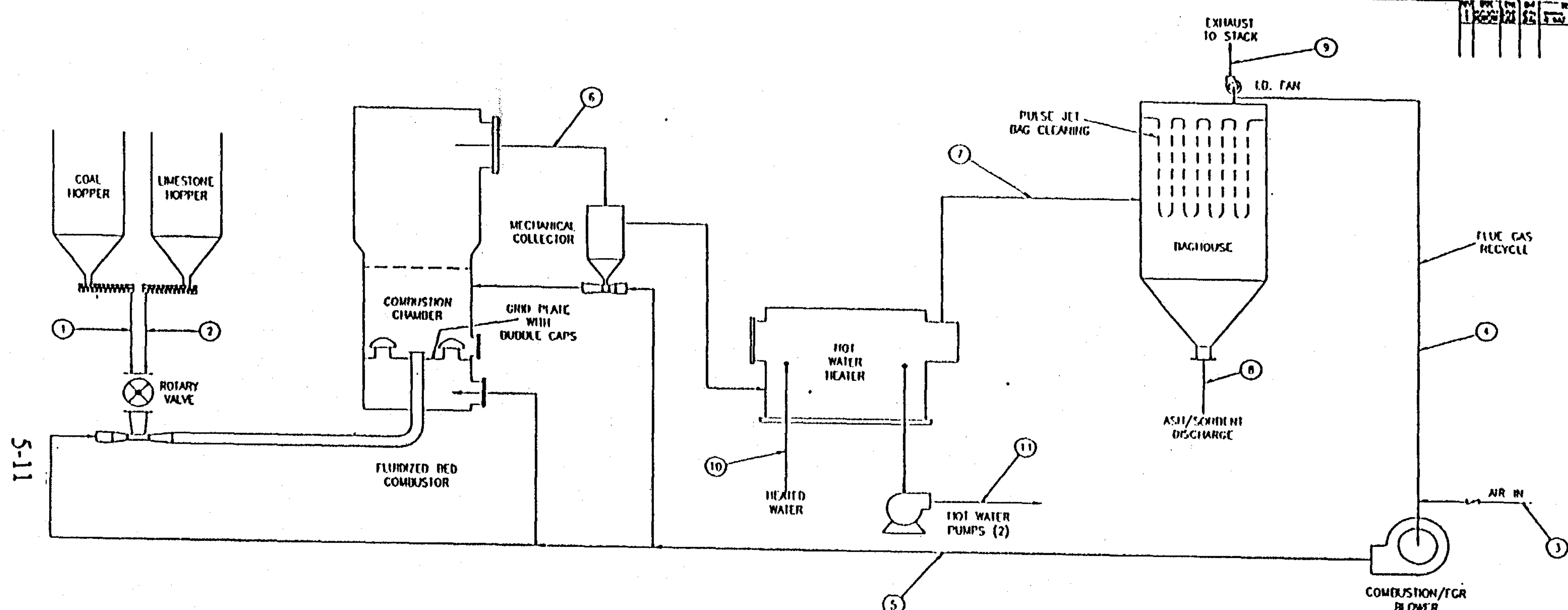
Markets

The coal industry in all states that have high sulfur coal reserves, has seen a dramatic drop in coal consumption because of the ever increasing environmental constraints imposed on the industries burning these coals. This negative impact has been very dramatic in the industrial /commercial marketplace. For instance, according to the 1991 *State Energy Data Report*, from 1960 to 1991, annual coal use in Ohio by commercial and industrial entities dropped from 27,730 tons in 1960 to 8,822 tons in 1991, a 68% decrease. To reverse this trend and place coal once again as the fuel of choice, low cost environmentally acceptable technologies must be developed.

The AFBC system currently under is one system that has the potential to reverse this trend toward ever increasing use of natural gas at the expense of the coal industry. The AFBC is of simple design and easy to operate that lends itself to modular construction, allowing for lower cost shop fabrication as opposed to field fabrication. This AFBC system can process run of mine coal of any ash, moisture or sulfur content. It is amenable for use with all types of coal. It uses low cost limestone as a sorbent to meet the regulatory limits on SO_2 emissions. Whereas for coal-fired units under 100 MM Btu/hr there are no Federal limits for NO_x emissions, the AFBC incorporates a flue gas recycle technique which not only can be used to reduce NO_x emissions, but also increases the overall thermal efficiency of the system.

The successful development and widespread implementation of this system, could well start to reverse the trend of decreasing coal use by the commercial, industrial, and institutional market sectors. With the widespread use of this technology, other benefits will arise in the form of increased business revenues from the sale of indigenous limestone, the reduction in fuel costs for the end user which will make its products more cost competitive, and the development of a new technology that will be fabricated and marketed in the United States.

In addition to the use of the AFBC for production of hot water and steam; EER is evaluating its use for co-generating electrical power. The team has developed a power generation design based on the use of a hot air Brayton cycle which can yield 20-25% thermal efficiency (fuel in to electric power out). This compares with small scale steam Rankine cycles with efficiencies of 10 to 12%. When including waste heat recovery for heating use, the overall system thermal efficiency of an electric power/district heating system increases to 50 to 55% efficiency. The coal-fired AFBC Brayton cycle will be cost competitive with diesel fired electrical generators. Under an agreement between EER and the Will-Burt Company, Will-Burt will fabricate the AFBC systems and market the technology. Will-Burt is currently marketing and fabricating small scale coal fired stokers for industrial, commercial, and institutional use. The AFBC system will be added to its market line as a replacement for the stoker technology for those size units which must meet SO_2 emission limits.



NOTE: HEAT INPUT = 2.3 X 10^6 BTU/HR

STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11
STREAM NAME	COAL FEED	LIMESTONE FEED	COMBUSTION AIR	FLUE GAS RECYC.	COMBUSTION AIR + FGR	AFBC FLUE GAS	B.H. INLET FLUE GAS	B.H. ASH	STACK GAS	C.W. INLET	H.W. OUTLET
UNITS	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr	lbs/hr
C	121.3					1.2	1.2	1.2	0.0		
H	7.8										
O	13.?										
N	2.?										
S	3.7										
ASH	10.8	11.2				21.8	21.8	21.8	0.0		
H2O(l)	8.3									17481.3	17481.3
O2			818.3	133	710.1	381.8	381.8		381.8		
N2			2695.1	1100.5	3205.8	3205.8	3205.8		3205.8		
H2O(v)			31.5	83.1	99.6	179.1	179.1		179.1		
CO2				270.1	270.1	311.1	311.1		311.1		
SO2				1.4	1.4	3.8	3.8		3.8		
NOx AS NO2											
CO				0.8	0.8	1.8	1.8		1.8		
[illegible]				0.3	0.3	0.1	0.1		0.1		
CaCO3		33.7									
CaSO4						18.3	18.3	18.1			
CaO						17.3	17.3	17.2			
TOTAL	173.0	55.1	2888.2	1839.1	3325.3	3558.2	3558.2	53.3	4186.8	17481.3	17481.3
FLOW RATE, GPM										35	35
PRESSURE, PSIA	14.7	14.7	14.7	14.7					14.7	30	30
PRESSURE, in. H2O					30	-0.3	-0.2	-1			
TEMPERATURE, F	50	50	70	250	100	1550	355	250	250	102	137

Coal HHV (13,040 Btu/lb)

Fuel to Hot Water Thermal Efficiency = 83.0%

AS BUILT

CEDAR LANE FARMS

Energy and Environmental Research Corporation

ATMOSPHERIC FLUIDIZED BED COMBUSTOR SIMPLIFIED PFD W/FGR HOT WATER SYSTEM

DRAWN: GDP | CHECKED | ENGINEER: RAA | PROJ. MGR: RAA | DATE: 01 AUG 95 | SCALE: NONE | JOB NO. 8808 | DWG P88080-001

Figure 1.

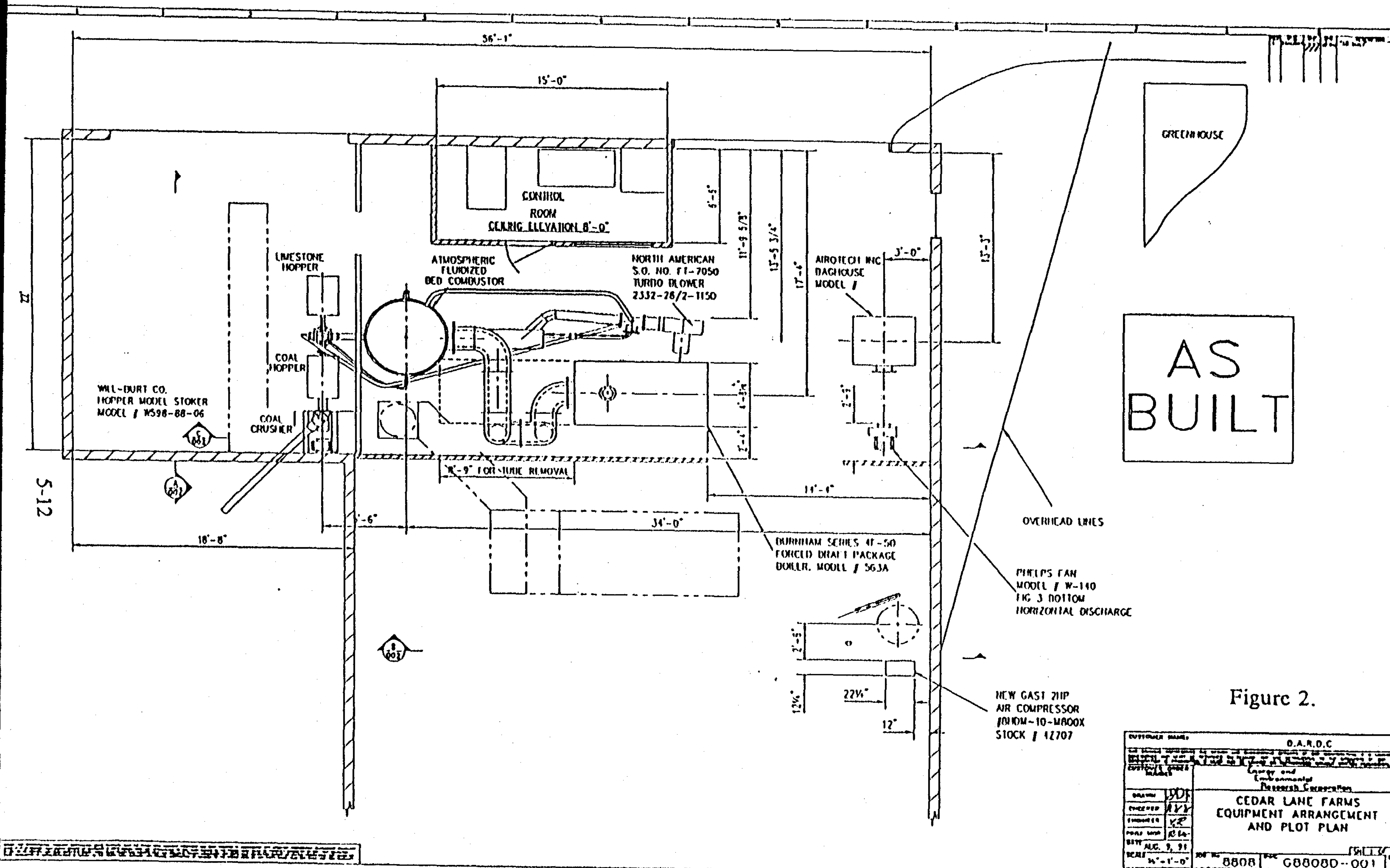

56'-1"
15'-0"
CONTROL
ROOM
CEILING ELEVATION 8'-0"
LIMESTONE HOPPER
COAL HOPPER
COAL CRUSHER
WILL-BURT CO.
HOPPER MODEL STOKER
MODEL # W598-88-06
ATMOSPHERIC
FLUIDIZED
BED COMBUSTOR
NORTH AMERICAN
S.O. NO. F1-7050
TURBO BLOWER
2332-28/2-1150
AIROTECH INC
BAGHOUSE
MODEL #
3'-0"
6'-5"
11'-9 5/8"
13'-5 3/4"
17'-4"
13'-3"
8'-9" FOR TUBE REMOVAL
34'-0"
14'-4"
18'-8"
BURNHAM SERIES 4F-50
FORCED DRAFT PACKAGE
BOILER. MODEL # 563A
PHELPS FAN
MODEL # W-140
FIG 3 BOTTOM
HORIZONTAL DISCHARGE
OVERHEAD LINES
GREENHOUSE
AS
BUILT
NEW GAST 2HP
AIR COMPRESSOR
#1HOM-10-M800X
STOCK # 12707
22½"
12"
12¾"
D.A.R.D.C
Energy and
Environmental
Research Corporation
CEDAR LANE FARMS
EQUIPMENT ARRANGEMENT
AND PLOT PLAN
AUG. 9, 91
¼"=1'-0"
8808
G8808D--001

Figure 2.

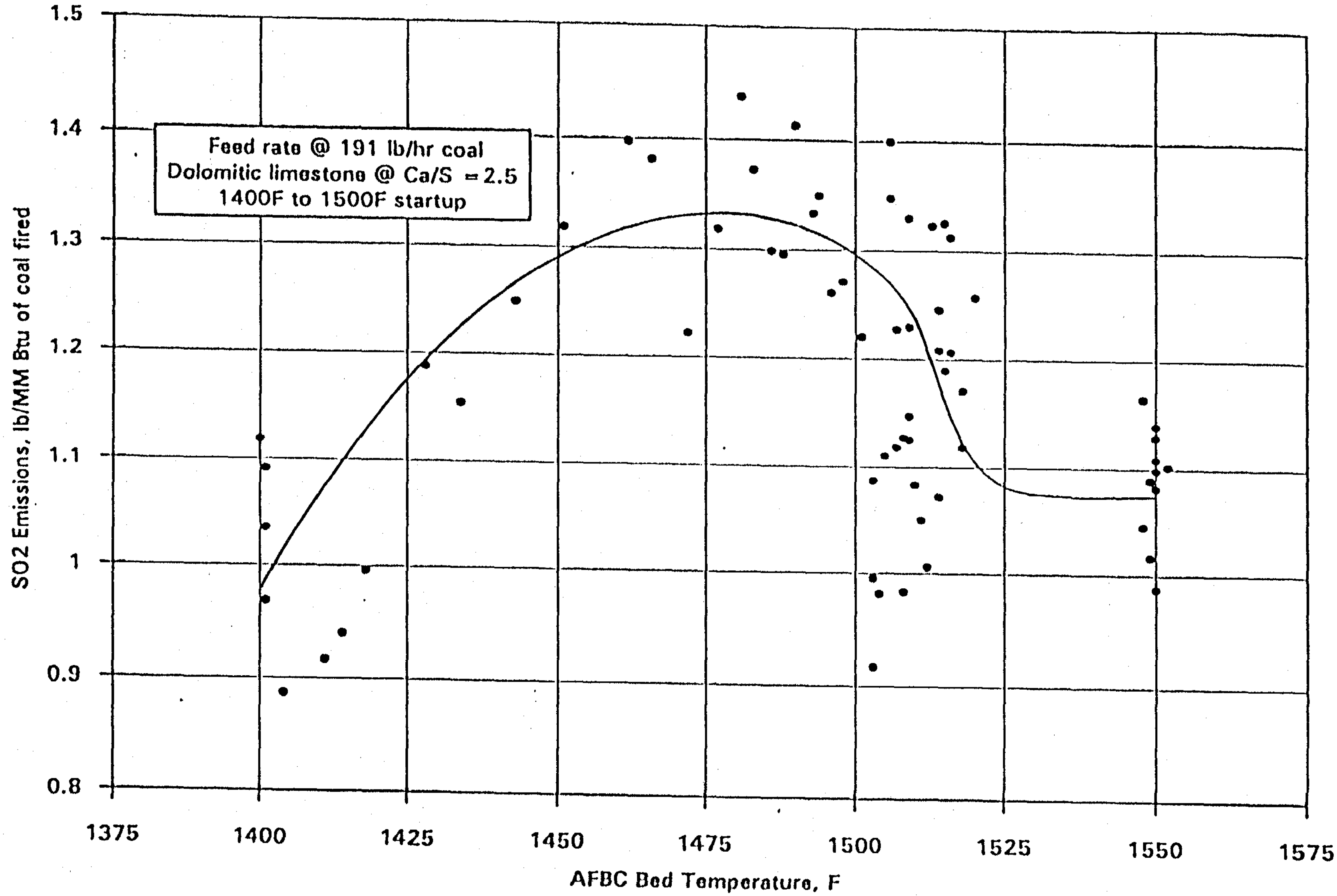


Figure 3. SO_2 emissions versus bed temperature

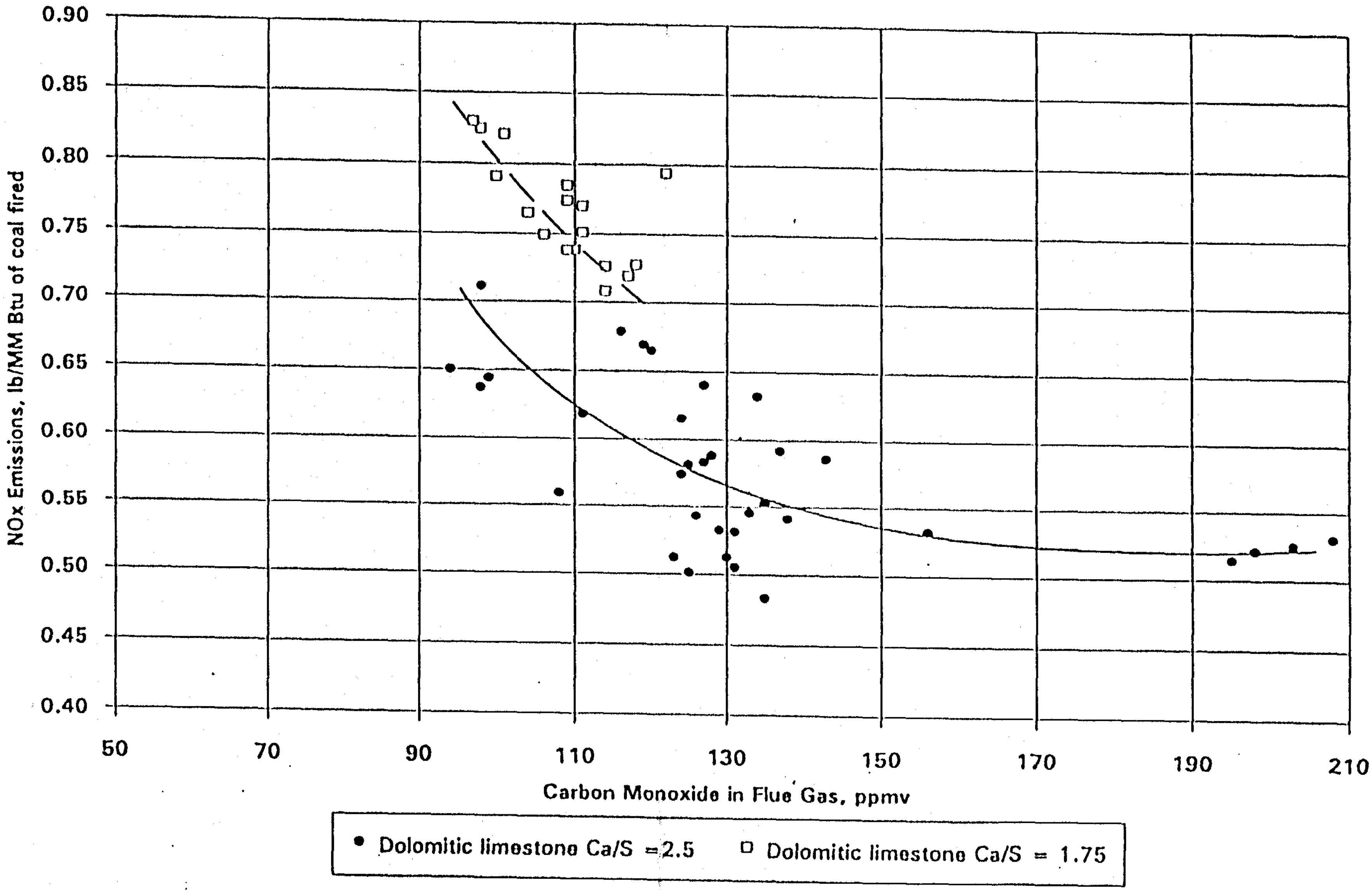


Figure 5. NO_x emissions versus flue gas CO concentration

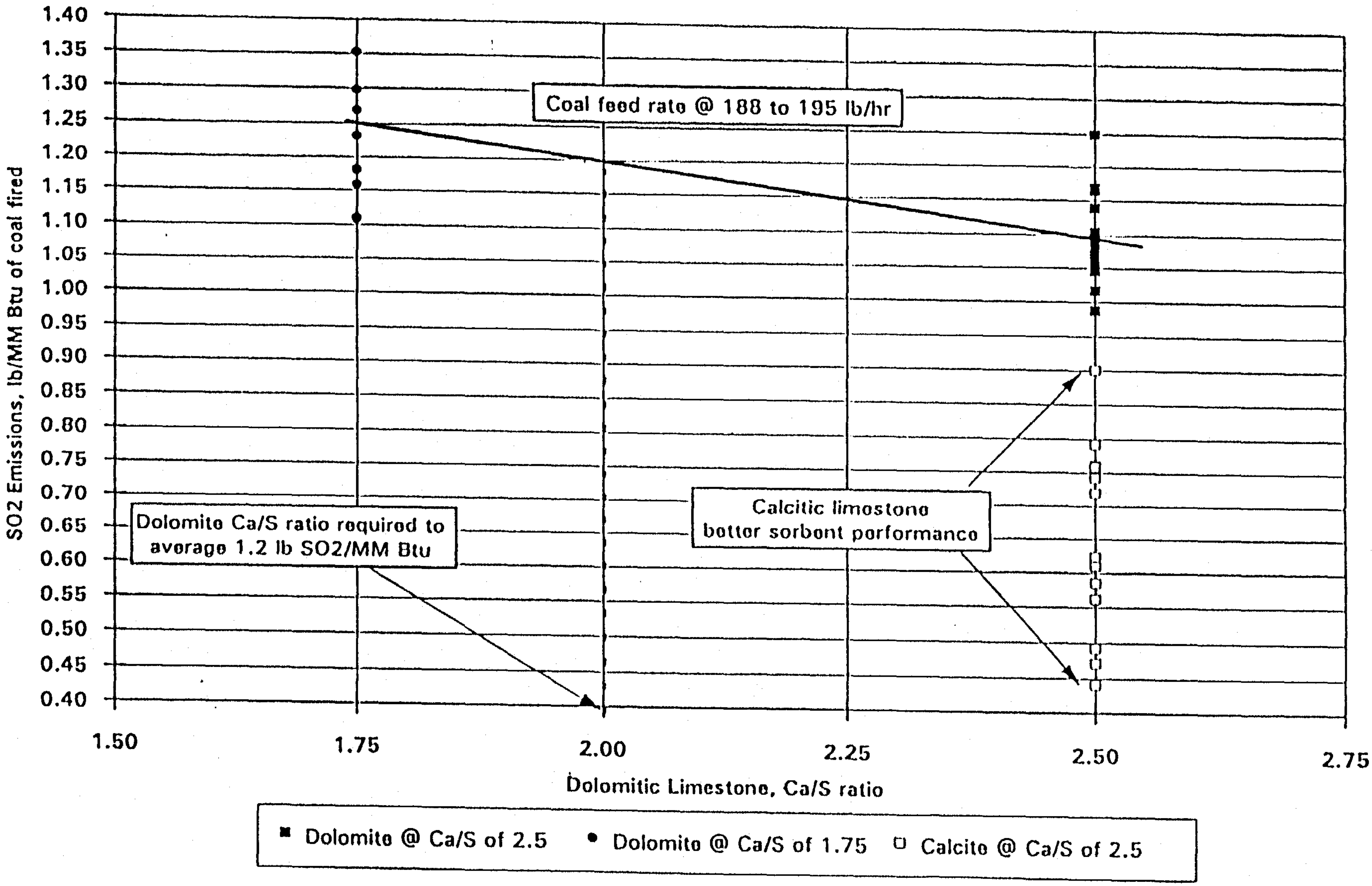


Figure 4. SO_2 capture versus Ca/S ratios

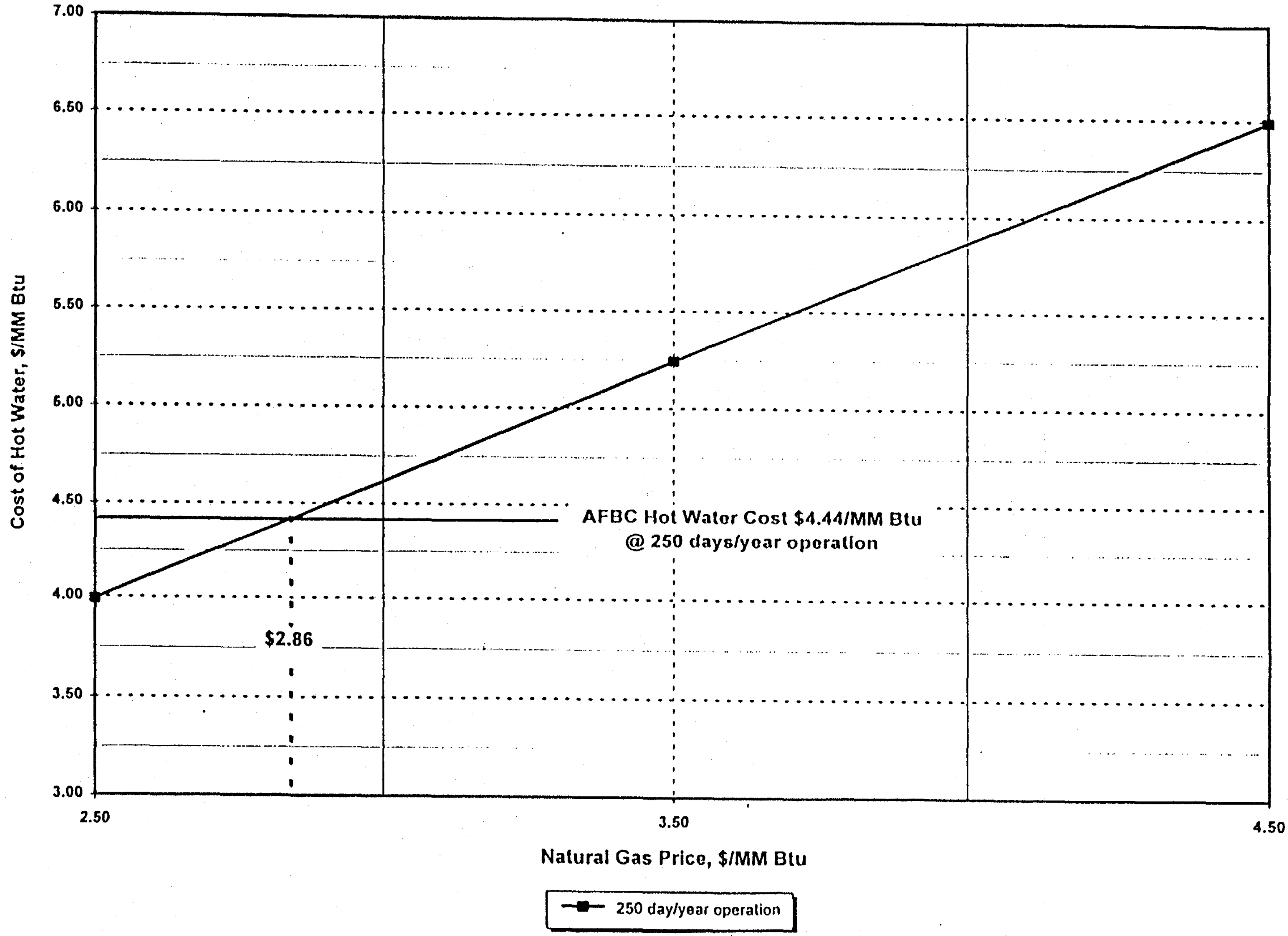


Figure 6. Hot water cost, AFBC versus natural gas