Conf-9410316--1

DOE/METC/C-95/7174

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Conference Title:
Mechanical Engineering Symposium

Conference Location:
Prairie View, Texas

Conference Dates:
October 27 -28, 1994

Conference Sponsor:
Prairie View A&M University College of Engineering and Architecture, Department of Mechanical Engineering

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INTRODUCTION

The Morgantown Energy Technology Center (METC) is a Government-owned and Government-operated research center located in Morgantown, West Virginia. Since its opening in 1955, METC has been a Fossil Energy research laboratory focused on the development of advanced Fossil Energy technologies. METC is currently an organizational unit of Fossil Energy which is, in turn, a part of the U.S. Department of Energy.

METC pursues the development of fossil energy technologies through contracts with industrial/commercial partners, through Cooperative Research and Development Agreements, and through a relatively small in-house hands-on research program which is coordinated with customer/program needs associated with the major technologies. The purpose of this paper is to introduce the Integrated Gasification Combined Cycle (IGCC) concept for power generation and to review the METC in-house activities related to this concept.

The IGCC System

Figure 1 illustrates a basic IGCC system. Gas from the gasifier is routed successively through hot particulate and sulfur removal systems before entering a turbine combustor. Hot combustion products from the combustor are expanded through a gas turbine which provides power to drive an air compressor and an electrical generator. The turbine exhaust is routed through a heat recovery steam generator which powers a steam turbine to drive a second electrical power generator. High-pressure combustion air and gasification air are supplied by the turbo compressor driven by the gas turbine. The combined cycle title denotes that power is derived from a combination of steam and gas turbines.

Hot gas cleanup as illustrated in Figure 1 is still in the developmental stages with hot particulate removal and hot desulfurization being the focus of most current research programs. The METC in-house gasification/cleanup program, which is the subject of this paper, is focused primarily on hot gas desulfurization.

Program Organization

The METC in-house gasification program includes projects ranging from small laboratory projects to larger process development units (PDU's). The approach is to investigate and screen basic concepts using small- to intermediate-scale units, and to utilize this information for the design of the larger PDU-scale units. The basic process understanding is obtained using the larger units. Information, theories, etc., developed at the PDU scale are then shared with customers in the commercial/industrial markets as they move the products towards the larger demonstration scale and eventually commercialization. Figure 2 illustrates the major elements of our in-house program and how the priority is changing from the smaller projects in the 1993-1994 timeframe to the larger more mature projects in the 1995-1996 timeframe. Each of these major activities will be described in the subsequent sections.

Gasification

A coal gasifier is the heart of any IGCC system. The most common types of gasifiers, arranged according to increasing throughput per unit cross sectional area, are illustrated in Figure 3. The three basic types are fixed bed, fluid beds, and entrained reactors. Fixed Bed Gasifiers are typified by the Lurgi, Fluid Bed Gasifiers are typified by the IGT and KRW concepts, while the Entrained Reactors are typified by Shell and Texaco gasifiers.

The Fixed Bed concept involves the passing of steam and air or oxygen mixtures in an upward direction over a "fixed" or downward flowing bed of coal. The coal charge is introduced into the top of the gasifier and settles slowly through the gasifier, counter to the upward flowing gases. In the upper zones, the coal dries and devolatilizes. It then progresses downward sequentially through gasification and combustion zones. Char produced in the gasification zone is combusted in the lower combustion zone to provide heat to drive the gasification process. Ash remaining from this counterflow process is then removed via the grate assembly in the bottom of the gasifier. These gasifiers are relatively simple and cheap, use run-of-mine coal, efficiently utilize the feedstock, and can produce a low- to high-Btu gas depending on the oxidant employed and the conditions. They are forgiving and can be banked for days, but generally produce a dust- and tar-laden gas.

The Fluid Bed Gasifier concept utilizes a pulverized/ground coal generally with a 0.64-cm (1/4-inch) top size and reacts the coal in a bubbling Fluid Bed Gasifier which exhibits a uniform mixture temperature. In the most popular versions, the coal and oxidants or just the oxidants are introduced through a center jet at the bottom of the gasifier to create a combustion jet which supports a bubbling gasification bed above the jet and a recirculation zone adjacent to the jet. The recirculation zone allows larger char particles formed in the combustion jet to recycle to extinction.

Entrained Gasifiers operate at even higher throughputs per unit cross sectional area and utilize even smaller size feedstocks. The entrained units can be either dry bottom or slagging types fed with either air or oxygen respectively.

A more recent development utilizes transport reactors. These are simply nonslagging entrained reactors with higher throughputs and large solid recycle rates to achieve acceptably high carbon conversion rates.

METC's in-house activities are now focused on systems to be coupled with advanced Fluid Bed Gasifiers or advanced hybrid concepts such as the PYGAS (a CRS Sirrine Gasifier) gasifier to be tested in the METC Gasifier Product Improvement Facility (GPIF).

The GPIF will be built near METC at a local power station and will accommodate gasifiers rated at up to 6 tons/hour coal feed. It is being built at the power station to make use of many of the stations facilities such as coal supply and ash disposal and to introduce a utility to the IGCC concept.

Figure 4 depicts the PYGAS concept. Coal and the oxidant are introduced axially into a central pyrolyzer in a manner similar to most Fluid Bed Gasifiers. The char and gaseous products produced in the pyrolyzer are exhausted at 871 °C (1600 °F) to the upper combustor where additional air can be introduced for cracking tars and elevating the temperature to the 1260 °C (2300 °F) range. The char and gaseous products from this zone are then processed in a downward co-flowing moving bed zone. In this zone, the char is further gasified until the temperature drops to the 800-871 °C (15-1600 °F) range. The gases from this zone mix with gases flowing up from the lower fixed bed zone and flow up to the gasifier exhaust while the solids continue their downward travel towards the conventional counterflow fixed bed zone. In this fixed bed zone, the char reacts with steam and air flowing upwards from the rotating grate as in a conventional Fixed Bed Gasifier. Ash from the process is expelled by the rotating grate.

It is anticipated that this advanced concept gasifier will exhibit a higher through-put than other designs, will be able to process the high swelling bituminous coals, and will produce a tar-free gas.

Phase I of this project involves testing of the gasifier while an anticipated Phase II involves testing of a fully integrated hot gas desulfurization system. Testing viable systems in a fully integrated mode with real gases from a 6-ton/hr gasifier would represent the last step in the developmental path for the in-house program.

METC's Process Development Unit

Before testing in a fully integrated mode with a real gasifier, suitable desulfurizer systems must be developed and considerable design and operational experience must be gained at an intermediate scale. Figure 1 depicts the sulfur removal system as a single block, while, in reality, it is more complex. Figure 5 schematically illustrates the system METC is currently designing and constructing.

Basically, the system consists of an absorber and a regenerator with several interconnecting transport pipes for circulating the sorbent between the absorber and the regenerator. Lockhoppers are also provided for removing sorbent for sampling and/or adding fresh sorbent to make up for attrition. A regenerator is required since the sorbents are generally expensive and must be re-used for several cycles. The absorber and regenerator can be fixed, fluid, or transport reactors just as with the gasifiers; however, METC has chosen to focus on the fluid bed and the transport reactor concepts primarily because they offer control flexibility and because they exhibit a continuous noncyclic operation.

In Figure 5, the larger vessels are the Fluid Bed absorber and regenerator with the connecting pipes serving as transport and isolation lines. Larger lift pipes are provided to test the transport reactor concepts, and, in these cases, the Fluid Bed vessels will serve as knock-out or separation devices.

Due to the cost and complexity of gasifier operations, this unit will be operated on a syn-gas supplied from a partial methane combustor. The supply gases can be doped to provide the proper composition and contaminants.

An isometric view of the structure and equipment arrangement of this facility is shown in Figure 6.

Operation of this unit will provide invaluable process design as well as operation and control data needed for the design of larger demo or commercial units. Isolation of the reducing absorber circuit from the oxidizing regenerator circuit, pressure balance, reaction kinetics, sorbent attrition, etc., are typical problems to be studied with this unit.

Table 1 gives the operating capabilities of this unit. It will be operated at 28 atm (450 psia) and is sized to simulate operation with a 0.5-1.0-ton/hour gasifier.

The Modular Gas Cleanup Rig (MGCR)

METC's efforts to design the PDU system are supported by one intermediate-scale project (the MGCR) fed by real gases from a Fluid Bed gasifier. A schematic of the system is shown in Figure 7. This facility includes a hot particulate vessel for testing particulate cleanup devices such as candle filters and a single absorption vessel for batch Fixed Bed or batch Fluid Bed testing of sorbents on real gases. Table 2 gives the design capabilities of this facility.

While the MGCR batch Fluid Bed does not provide data from an integrated continuous operation such as the PDU, it does supply data using real gasifier product gases at realistic temperatures. Data from this facility and from the smaller laboratory units associated with our sorbent development projects must be used together to form a design basis for the larger PDU and GPIF projects.

Sorbent Development Activities

METC's sorbent development program includes both a sorbent formulation activity and a small-scale testing activity. The salient activities in each of these areas will be briefly described.

It is clear that any desulfurization system will subject the sorbent to severe physical and chemical environments. Therefore, to be practical in the desulfurization process, sorbents must demonstrate the physical and chemical characteristics listed in Table 3.

Spalling is a cracking or flaking away of the sorbent due to chemical and/or thermal phenomenon resulting from the absorption and regeneration cycles. Figure 8 depicts a fresh and a spalled sorbent pellet. Spalling is a more serious problem for fixed bed reactors but is not expected to be so severe for fluid or transport systems because these systems do not require that the sorbent be loaded so heavily with sulfur in the absorption process and are not so likely to form sulfate compounds during the regeneration process. Sorbent swelling due to the formation of sulfates is thought to be the cause of spalling.

Likewise, due to the high sorbent circulation rates, these systems do not require that the sorbents have such high capacities. Capacities in the range of 15-30 wt % are required for fixed bed reactors while 1-5 wt % will suffice for fluid and transport reactors.

High mechanical strength (crushing) and low attrition (wear) rates are required for the sorbent to withstand the physical abuse of circulating between an absorber and a regenerator. Catalysts used in the petroleum catalytic cracker industry provide a baseline reference for comparison and several sulfur sorbents being developed today exhibit equal or better attrition resistance.

Current IGCC systems with hot gas cleanup require a gas inlet temperature to the absorber of approximately 537 °C (1000 °F); however, some activity is being directed toward lower temperatures in the range of 426 °C (800 °F) as well. Sorbents are generally tailored for a specific temperature but the ability to operate over a range of temperatures adds flexibility to the process.

Since large inventories of sorbent are required for these systems and since the sorbents are not disposable, low cost also becomes a priority. Costs are currently running in the $8/pound range; however, costs in the $3/pound range are required for these systems to be competitive in the commercial market according to current systems analyses.

Some kind of diluent, generally steam, is normally required to prevent overheating of the sorbent during the highly exothermic regeneration process. Since most IGCC systems have steam available, it is highly desirable for a sorbent to be compatible with steam diluents during regeneration. Some systems with air separation units can provide nitrogen as a diluent, but these systems can be prohibitively expensive.

Other contaminants besides sulfur are in a typical gasification process stream so it is important that the sorbent either be resistant to these contaminants or be able to absorb them in a dual function. Chlorine is one known trace contaminant and resistance to chlorine is being addressed by the METC program. In the future, it is expected that either multi-purpose sorbents which absorb more than one contaminant or a series of sorbent systems to absorb various contaminants will be required.

To date, METC has been surprisingly successful in coming up with sorbents which meet most of the criteria and have the potential for meeting them all. Table 4 lists the sorbents formulated and the testing accomplished to date at METC. The sorbents are screened in a low-pressure, 2.54-cm (1-inch) diameter reactor or in a 5.08-cm (2-inch) diameter high-pressure reactor in the Fixed Bed mode, with steam or dry regeneration as stated under the testing column. The METC 2 and METC 6 sorbents are the main candidates to date with a focus being on the METC 6 Fluid Bed Gasifier sorbent. A patent application has been made to cover the METC 2 sorbent and an application to cover the METC 6 sorbent is in the process.

Figures 9 and 10 compare the performance of the METC 2 sorbent, in terms of hydrogen sulfide absorption (PPM in exhaust stream) plotted as a function of hours on stream, to the performance of two leading sorbent candidates. Figure 9 compares the METC 2 sorbent to a popular zinc titanate sorbent tested by General Electric and conveys two messages. First, it can be seen by comparing the S1 curve to the S5 and S6 curves that the METC sorbent performance improves between the first and fifth cycles and then equilibrates. Secondly, after the fifth cycle, the METC sorbent performs better than the General Electric sorbent. Figure 10 compares the METC 2 sorbent to a proprietary Phillips Petroleum sorbent referred to as Z-Sorb. From Figure 10, it can be noted that the METC sorbent performs comparably to the Z-Sorb sorbent after the fifth cycle.

Similar tests have shown the METC 2 sorbent to be tolerant to steam during regeneration and attrition tests have shown it to be very hard and resistant to crushing, actually getting harder after sulfidation.

Figure 11 is a schematic of the high-pressure test rig used to qualify or screen candidate sorbents. Other rigs such as a 1-inch diameter low-pressure unit are used also, but the 2-inch diameter unit is the workhorse. This high-pressure unit uses bottled gases mixed through mass flow meters to obtain the desired input gas composition. It utilizes guard heaters to maintain the desired absorber temperature due to the small vessel size. Most testing to date has been in the Fixed Bed mode; however, the rig is being modified to allow batch Fluid Bed operation.

Summary

METC has a well coordinated in-house program to formulate and test sorbents in facilities ranging from small-scale screening tests on make gases to larger pilot (GPIF) scale tests on real gases. The small-scale to intermediate-scale elements are in place and operating while the larger PDU and pilot-scale experiments are in the design and construction phases.

METC has had considerable success in formulating new sorbents which appear to be very promising according to preliminary testing. The larger PDU and GPIF facilities promise to provide the larger scale process integration and control experience which will be crucial to the success of hot gas cleanup. The success of these efforts will contribute to the success of clean coal technologies and will directly contribute to the efficient use of the nation's abundant coal resource.

Integrated Gasification Combined Cycle (IGCC)

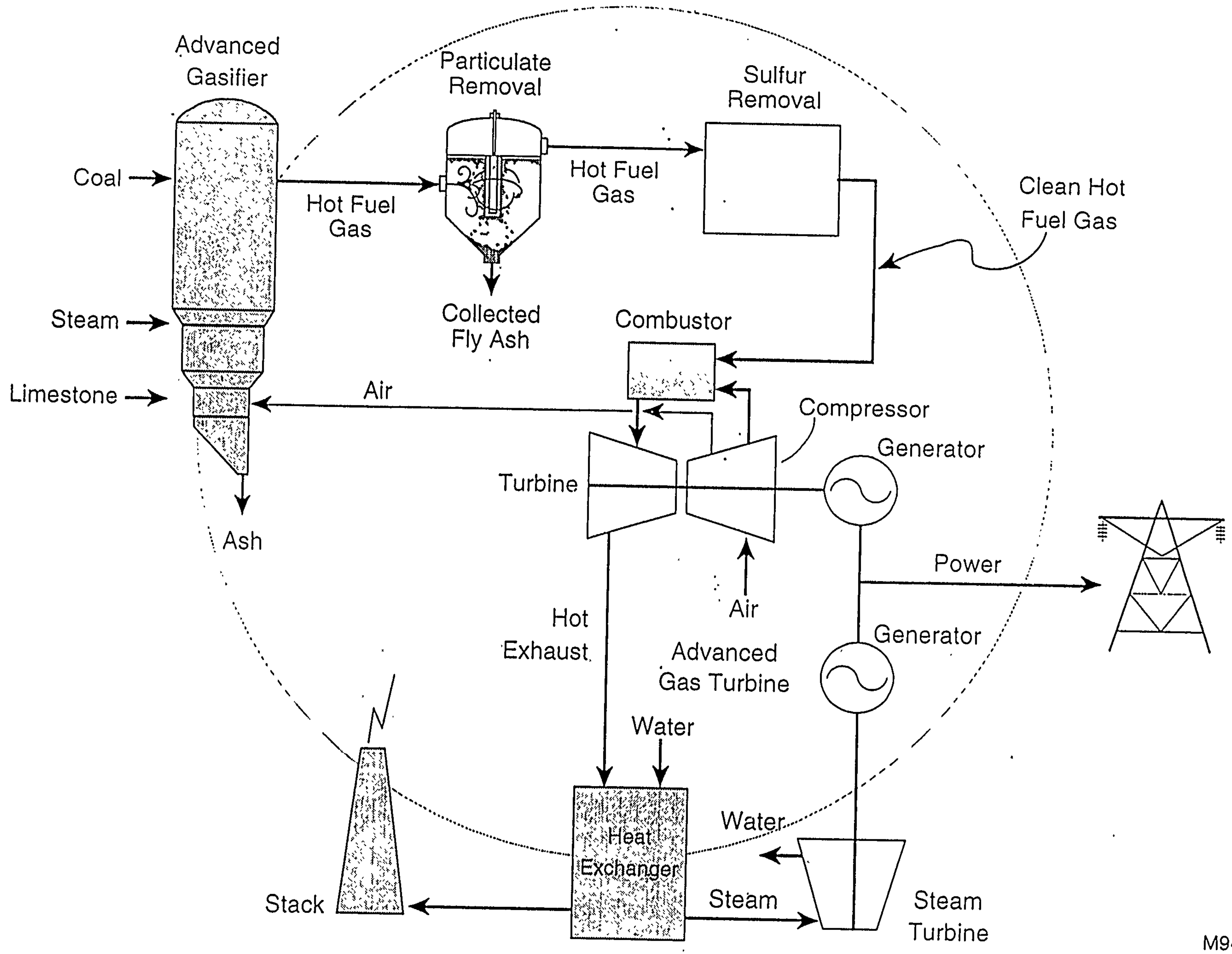

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Figure 1

Technology Development Path

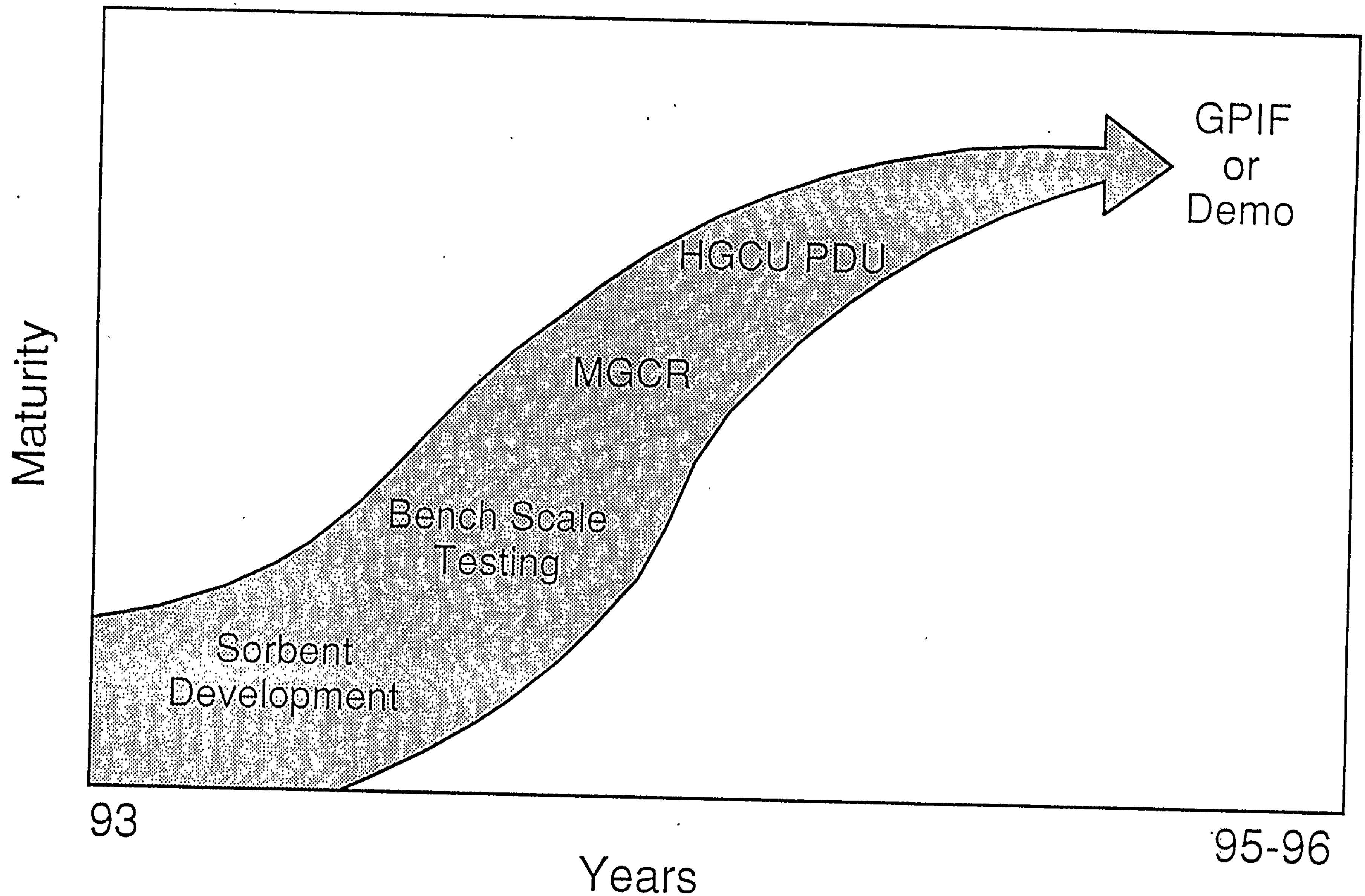

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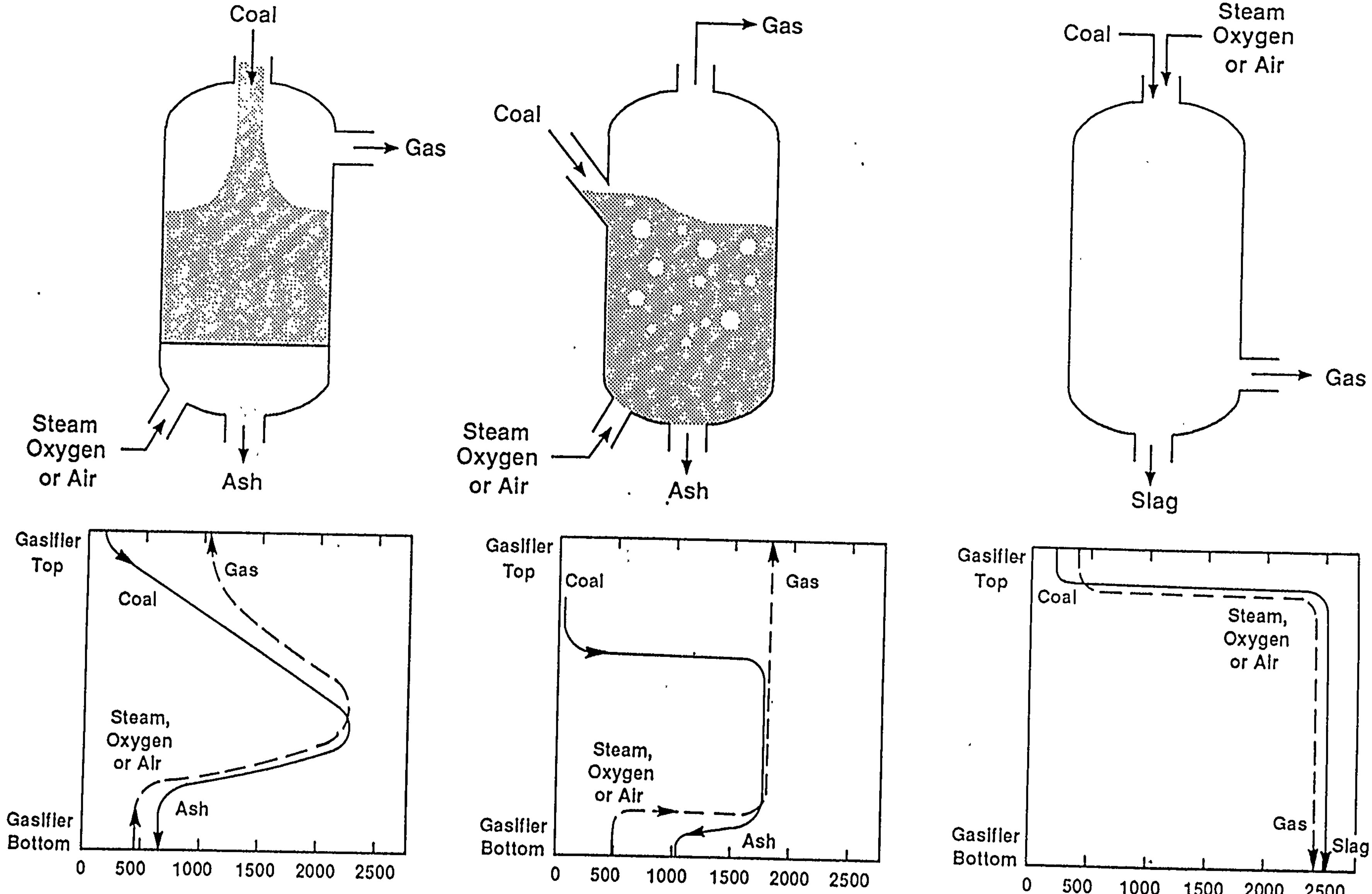
Figure 2

Generic Coal Gasification Reactors



Moving-Bed Gasifier (Dry Ash)

Fluidized-Bed Gasifier

Entrained-Flow Gasifier

C89-0553-D TC3

Figure 3

PYGAS Gasifier

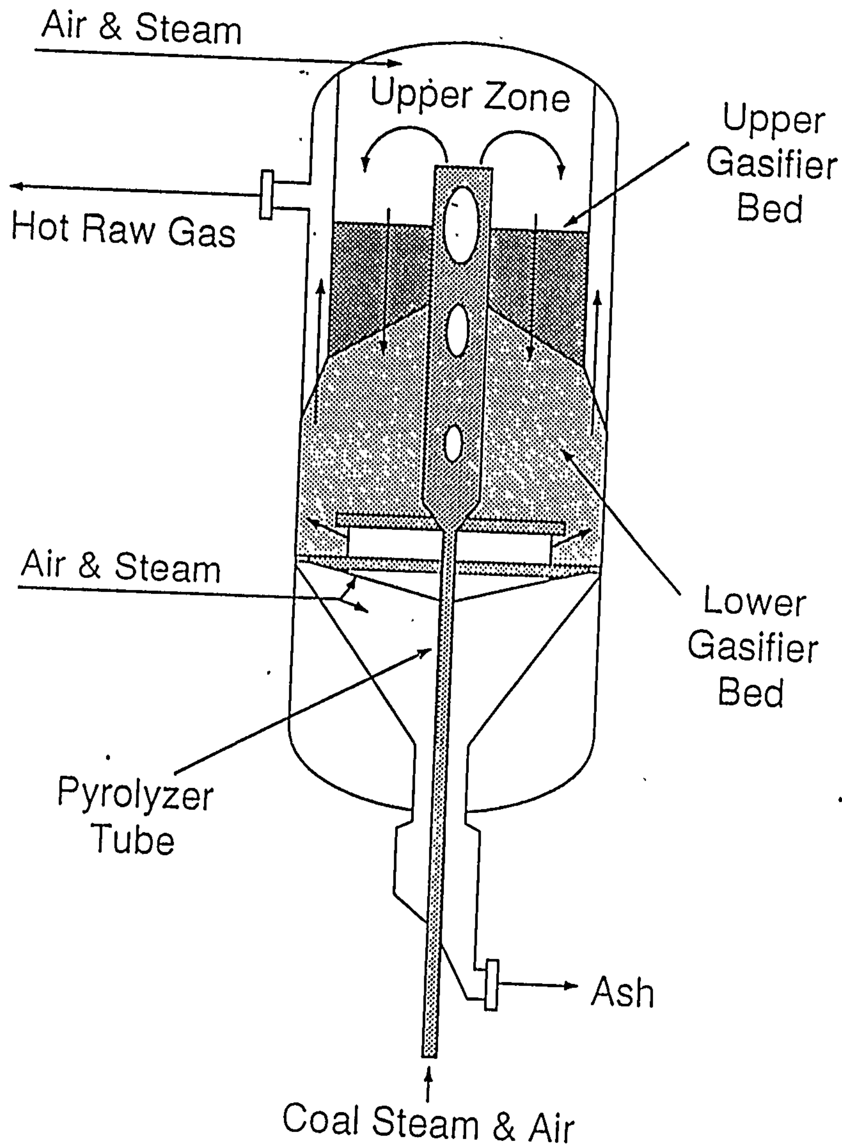


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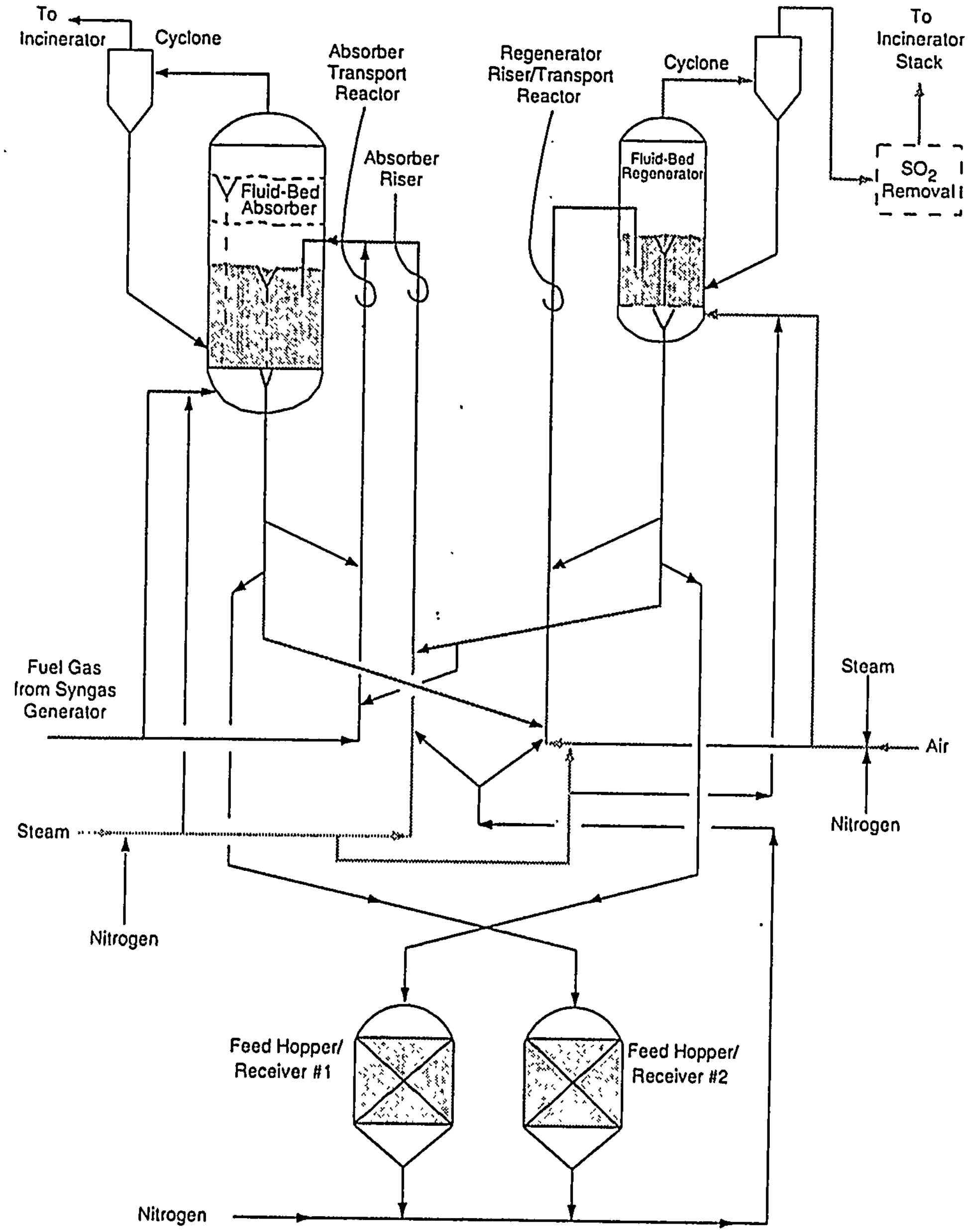
Figure 4

11

Simplified Flow Diagram of HGD PDU

Coupled Fluid-Bed Mode



Note: Only major interconnections shown

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Figure 5

HGD/PDU Isometric

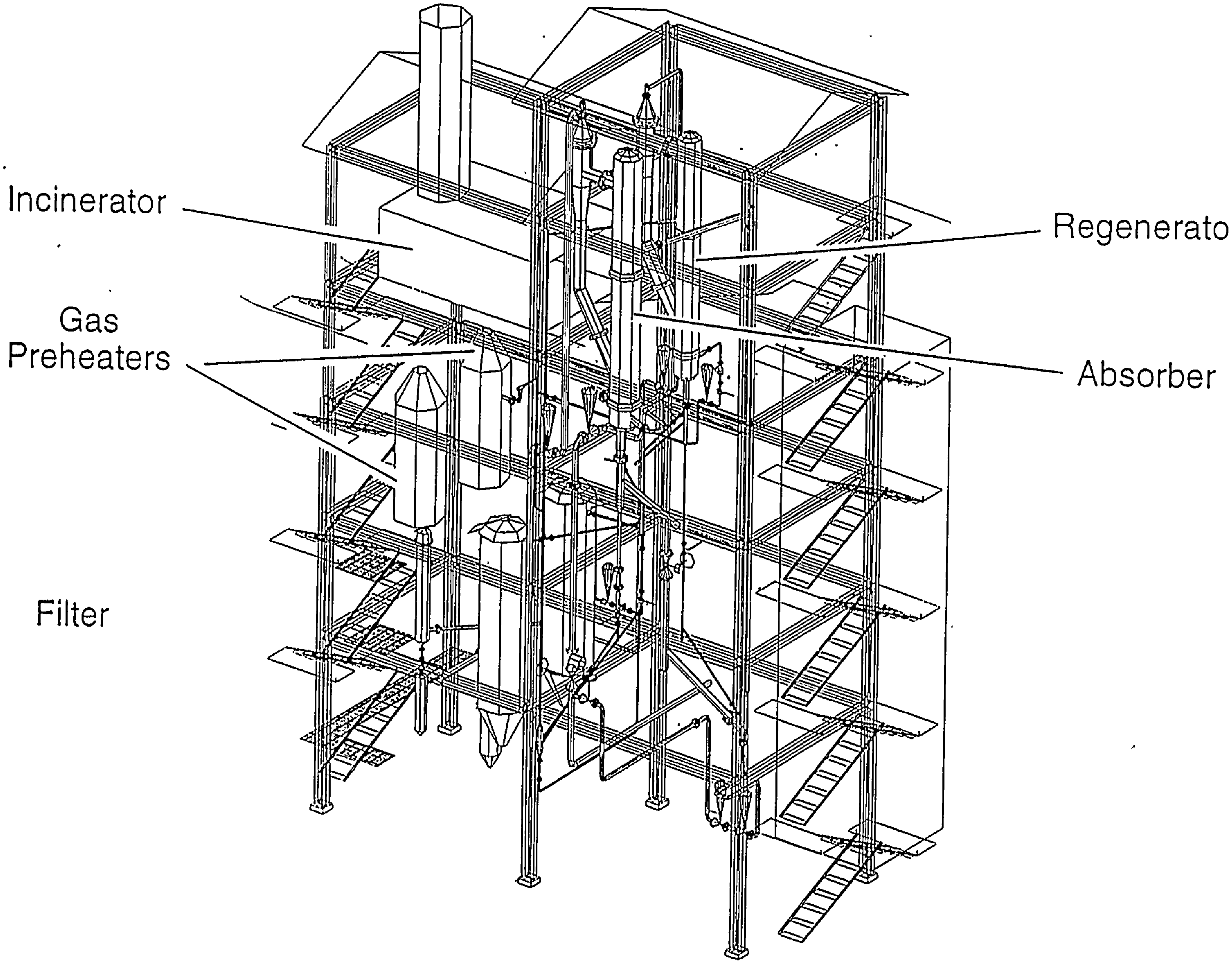

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Figure 6

B-12 Fluid Bed Gasifier & Clean up Rig Simplified Vessel & Piping Layout

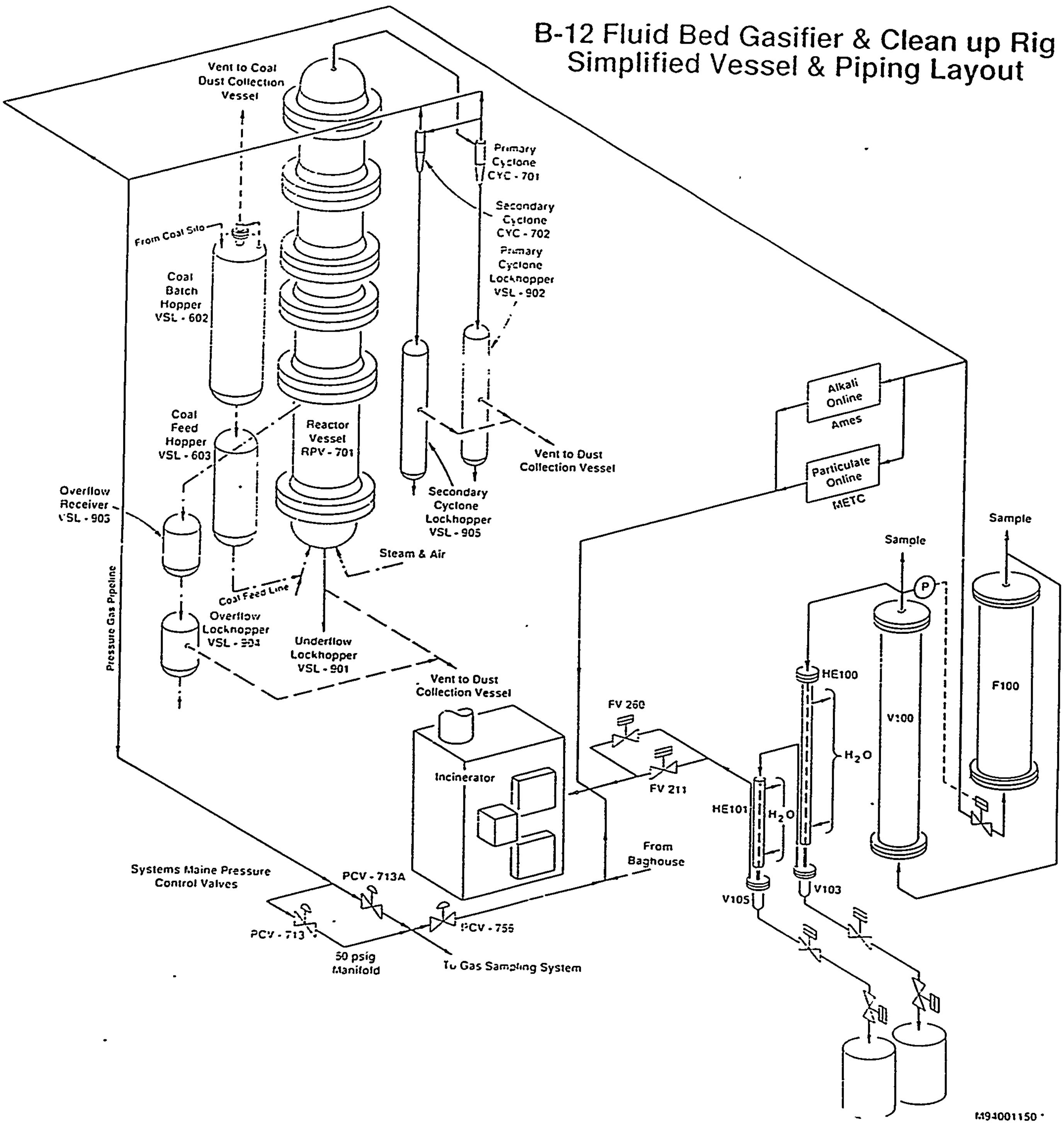

Figure 7

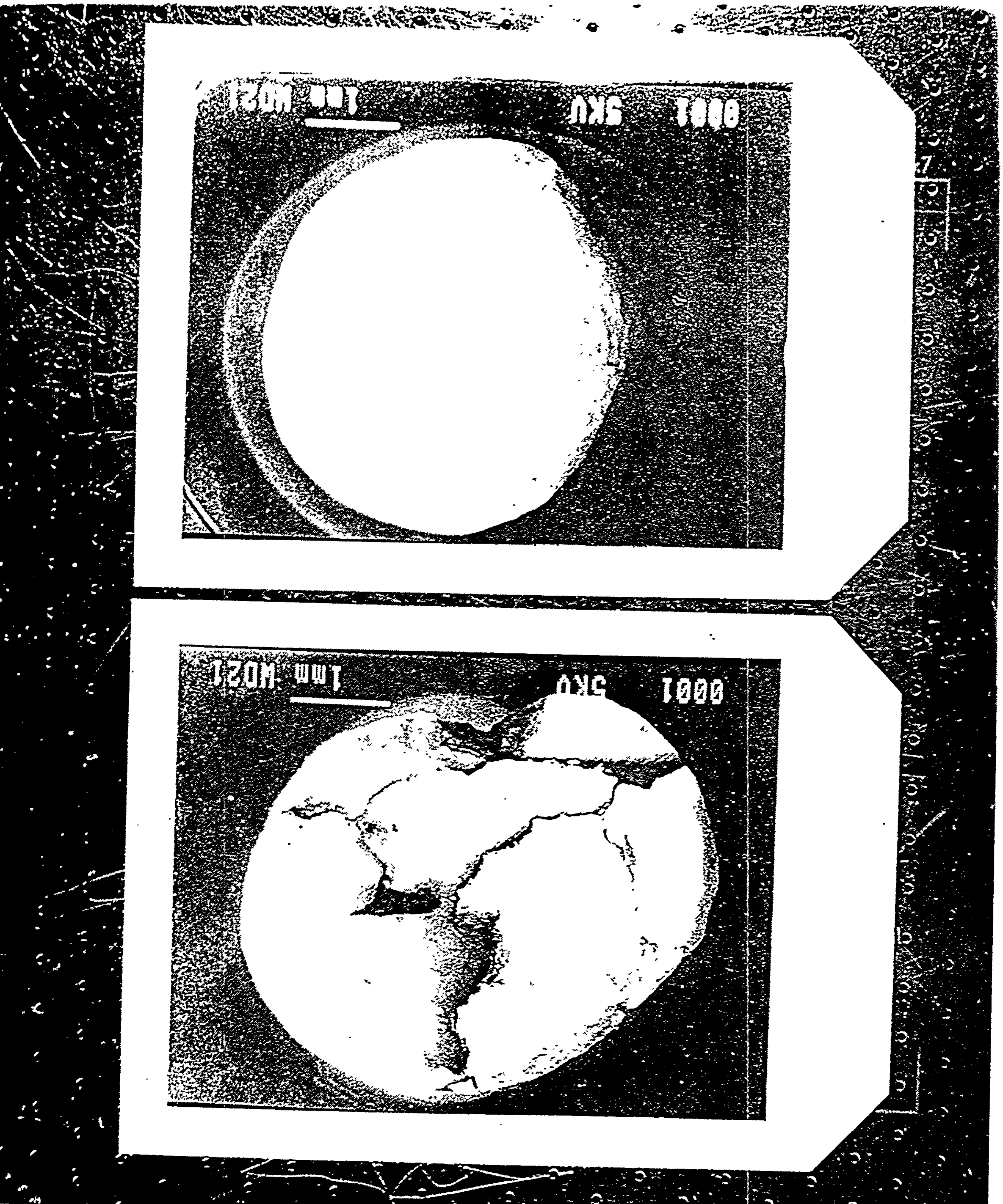

Figure 8

Comparison of METC2 Sorbent and GE Zinc Titanate

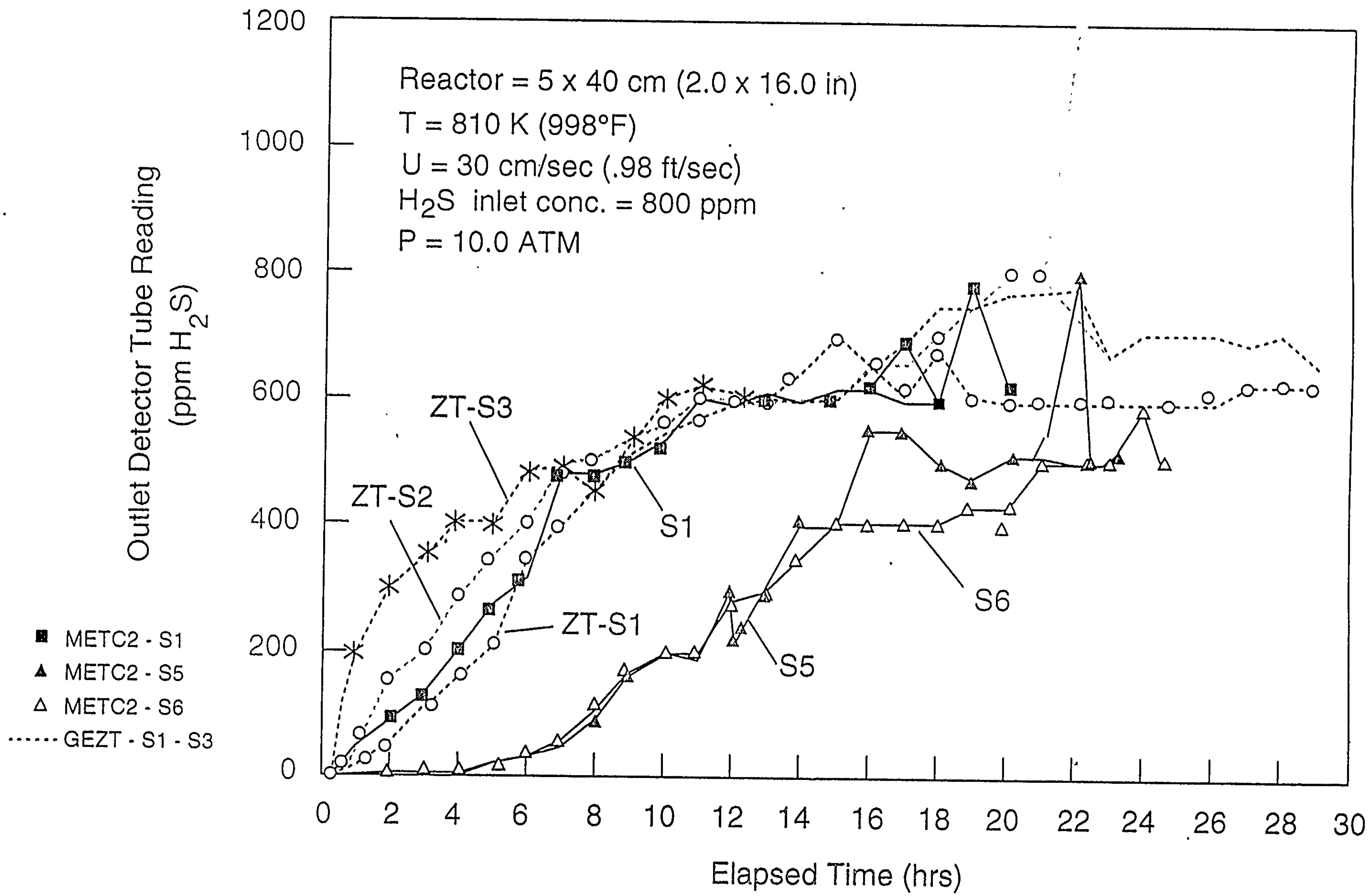

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Figure 9

Comparison of METC2 Sorbent and Z-Sorb

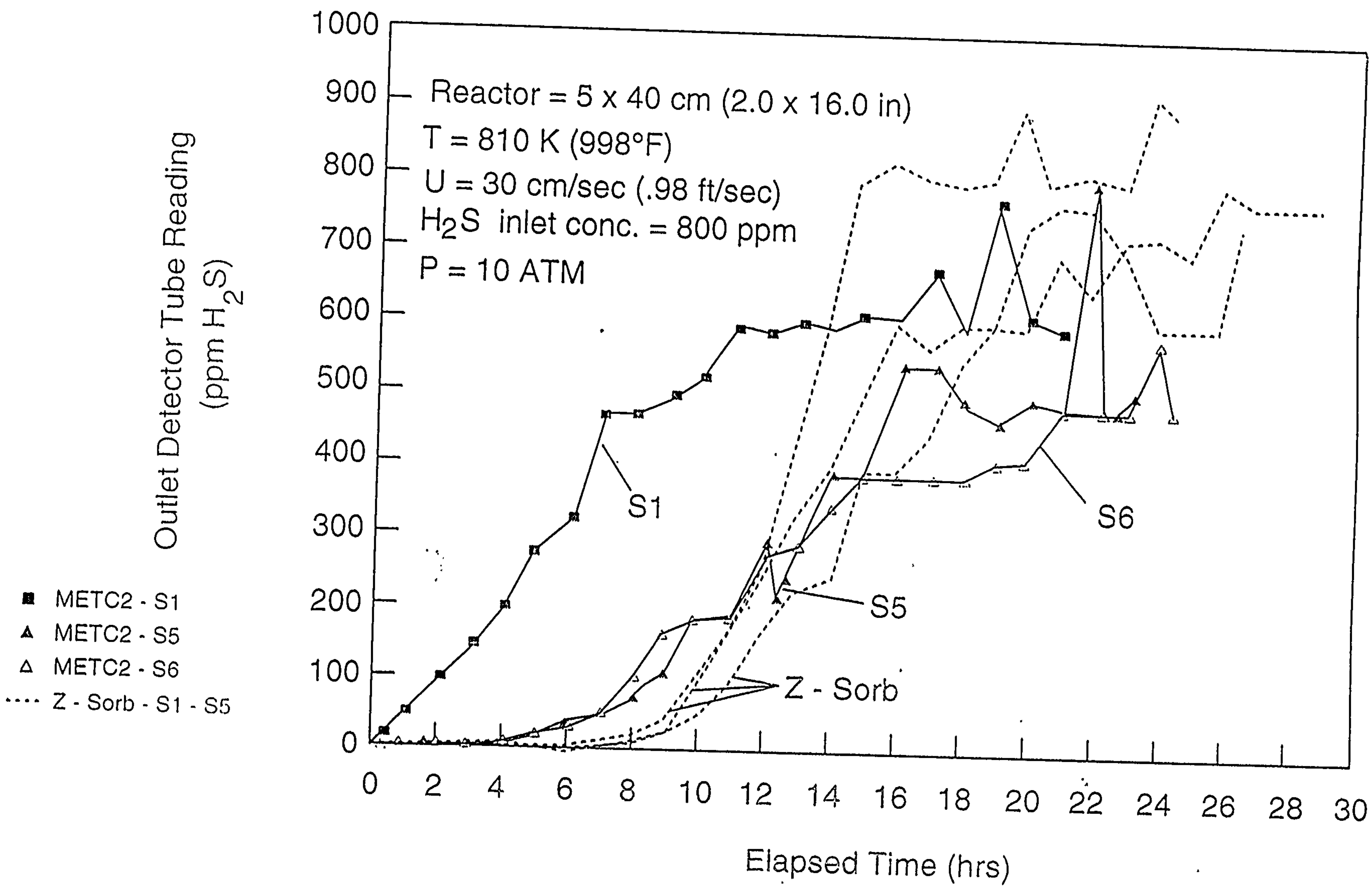

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Figure 10

High Pressure Bench-Scale Hot Gas Desulfurization Unit

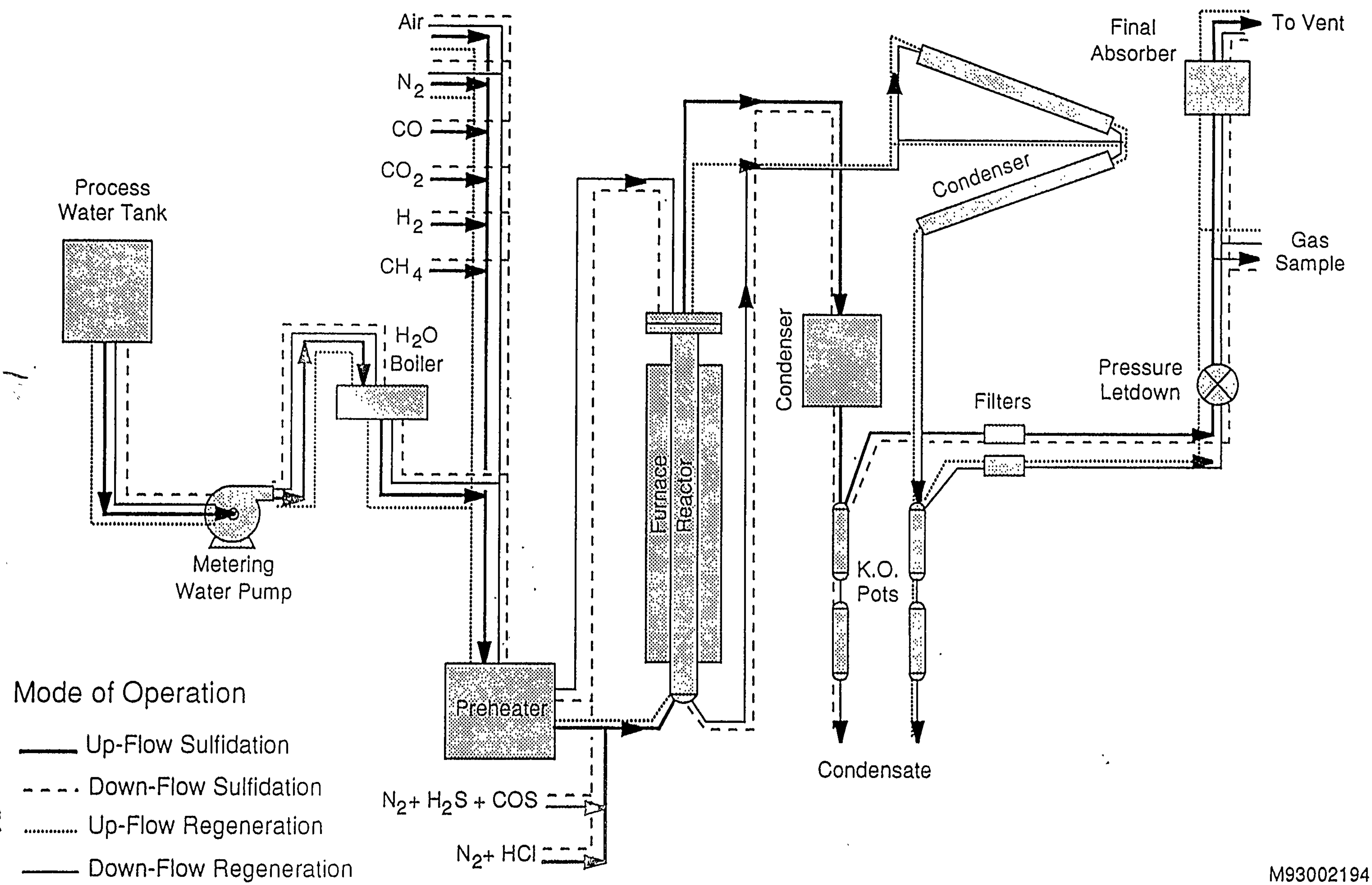

Figure 11

Capabilities of METC PDU

Sulfidation temperature	425 - 650°C (797 - 1,202°F)
Regeneration temperature	up to 760°C (1,400°F)
Pressure	up to 2.8 MPa (28 ATM)
Syngas flow	up to 4,000 cu m/hr (NTP) (14,200 SCFH)
Circulation	900 - 2,300 kg/hr (1,980 - 5,060 lb/hr)
Absorber recirculation	up to 23,000 kg/hr (50,000 lb/hr)
Regenerator recirculation	up to 2,300 kg/hr (5,060 lb/hr)

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Table I

FBG/MGCR Capabilities

	FBG	Batch MGCR
• Solids Flow Rate	Coal	Sorbent
(kg/hr)	36.3 - 45.4	13.6 kg batch
(lb/hr)	80 - 100	30 (lb)
• Particle Size Range (µm)	<1,400	200 - 300
• Air Flow Rate (kg/hr)	36.3 - 45.4	NA
(lb/hr)	80 - 100	
• Steam Flow Rate (kg/hr)	22.7 - 36.3	NA
(lb/hr)	50 - 80	
• Gas Throughput (kg/hr)	147 - 245	68.0 - 99.8
(lb/hr)	323 - 539	150 - 200
(schf)	5,000 - 8,000	2,300 - 3,300
• Bed Velocity (m/s)	0.11 - 0.18	0.15 - 0.23
(ft/sec)	0.36 - 0.59	0.49 - 0.75
• Reactor Temperature (°C)	840	620
(°F)	1544	1,150
• Reactor Pressure (kPa)	2,900	2,000 - 2,100
(atm)	29	20 - 21

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Table II

Desired Sorbent Characteristics

- Spalling Resistance
- Good capacity
- High mechanical strength
- Operational at 538°C (1000°F)
- Attrition resistant
- Low Cost
- Resistance to steam regeneration
- Resistance to hydrogen chloride

METC

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Table III

METC Sorbent Development

Sorbent	Description	Testing
METC 1	- Hand made - Low strength	10 cycles in low P unit - no spalling
* METC 2	- Increased strength - Fixed bed sorbent	Low P - 10 cycle /dry regen. High P - 20 cycles 6 dry/14 steam
METC 3	- High temperature	Not tested
METC 4	- Modification of METC 2 - Fluid bed sorbent	Not tested
METC 5	- Modification of METC 2 - Fluid bed sorbent	Not tested
* METC 6	- Modification of METC 2/ add new reagents - Fluid bed sorbent	Low P - 5 cycles steam reg.

Table IV

METC

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