Section 20

PRESSURIZED ENTRAINED FLOW GASIFICATION AND ITS APPLICATION TO COMBINED-CYCLE POWER PLANTS

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Introduction

GKT is convinced that coal gasification will play a most important role in future energy generation: Slide 1 shows the distribution of world coal deposits, arranged over the costs at which these deposits are presently available. There are territories with large deposits and low coal costs. Here, obviously, energy production on the basis of coal is attractive. Economic attractiveness can be expressed by the costs of a product as based on oil related to the costs based on coal.

Electric power generation on the basis of coal is an established technology of a high degree of maturity. Utility companies and their personnel are familiar with the conventional systems, involving power generation equipment, boilers, coal handling etc. For environmental reasons, some chemistry has been added; this is expensive but still does not dominate power plant operation.

Obviously the potential to increase net efficiency of the conversion of coal into electrical energy using conventional power plant technology with flue gas desulfurization is limited. The desulfurization of flue gas is a compromise, as desulfurization costs grow exponentially with the percentage of SO_2 removal, which is an important aspect, as in future the S-content of the available coals is expected to rise.

The combined cycle (CC) power generation concept based on coal gasification solves the SO_2 problem radically, at the same time minimizing the NO_x emission and offering the potential to increase the net efficiency of power generation considerably, but involves more chemistry with its acceptance problems with power plant operators.

Therefore, the efficiency gains of the new Integrated Coal Gasification Combined Cycle power generation (IGCC)-process as compared to the conventional power plant process must outweigh acceptance problems. Consequently the utility plant supplier must

- select the coal gasification process with the highest potential for rendering best efficiency in the process,

- determine the most effective distribution of energy streams between the gas-turbine and steam-turbine process,

- develop and install the most suitable connecting system,

and integrate all units in order to achieve the highest total net efficiency.

Obviously, a major component is the gasification process itself. It should suit the CC process, involve no restrictions as to the type of coal and should have a high availability.

I should like to

- report on the PRENFLO process, which is one process to meet the demands listed above, and

- give some typical performance data for cold gas efficiencies and total net efficiencies of an integrated PRENFLO combined cycle power generation system for some well known types of coal. Also, I wish to show the performance potential of dry-feed entrained-flow gasification for various types of coal, taking different ash contents as examples. Finally, I would like to give some information as to the status of the PRENFLO project and as to when PRENFLO will be ready for the market.

1 The PRENFLO Process

1.1 Origin of the PRENFLO Reactor and Process

The PRENFLO reactor and the SCG-reactor have common roots: the Koppers-Totzek (KT) atmospheric entrained-flow gasifier, Slide 2. This type was commercialized 35 years ago, and has in the meantime been operated and developed to high availability and capacity.

In the KT-process, Slide 3, predried pulverized coal is fed to pairs of opposed burners. It is gasified with oxygen and steam in partial oxidation at temperatures well above the ash fusion point. Part of the molten slag leaves the reactor at the bottom, part of it is carried along with the hot raw gas as fly ash, which leaves the reactor at its top end. The raw gas stream is quenched to solidify the fly ash particles before they enter the heat recovery boiler system.

The KT-process, together with the Winkler-, and Lurgi-processes, is one of the classical coal gasification processes. With respect to the number of customers (not the total erected capacities), it even is the most successful coal gasification process as far as we could find out.

The characteristics:
Pulverized coal, molten slag, high temperatures and consequently a raw gas containing mainly 2- or 3-atomic molecules make this process the favourite in synthesis gas production.

A total of 78 gasifiers have been constructed or are on order, the capacity of the four-burner reactor is about 650 mt of coal per day, this is more than 700 st/d if properly maintained, the availability is better than 95 %. In an ammonia plant (Slide 4) with a rated annual capacity of 300,000 mt production across the last few years has typically been 105 %.

Koppers-Totzek gasification is still a competitive process with reactive coal, especially with lignite. As it functions at atmosperic pressure, the system permits easy access; it is therefore also applicable in territories with limited technical infra-structure.

From a technical point of view, this type of gasification reactor is the most versatile, gives excellent results for young (reactive) coals, but lacks the benefit of pressurized gasification, which adds high C-conversion rates for coals of low reactivity to the advantages of KT gasification.

The effect of pressure in dry-feed entrained-flow gasification is shown in Slide 5.

GKT has accumulated a profound fund of experience with the KT-process, that can also be transferred to the new pressurized entrained-flow gasification process, also using dry fuel feed.

Therefore, when GKT and Shell cooperated on the development of pressurized entrained-flow gasification between 1976 and 1981, GKT put forward a KT-design reactor of a size appropriate to the pressure ratio, which concept was subsequently adopted. This way, most of the operational and technical experience could be transferred to the new pressurized process, which is one of the reasons why this system worked so well in the Shell-Koppers' project.

After the termination of the cooperation GKT continued the development of their process under the name PRENFLO.

1.2 Typical Features: Reactor and Process

One remarkable feature of this reactor design is the separation of two different types of stress (Slide 6):

Thermal impact is dealt with by the inner reactor casing without any load resulting from the operating pressure, whereas the pressure vessel has to deal with the stresses originating from pressure only without superimposed thermal stresses. That is to say, the reactor's inner vessel is completely designed for long life of the inner lining and the capability of running the gasifier at precisely those temperatures, that the ash viscosity and coal reactivity demand.

The main aspects of the design are shown in Slide 6. As you will realize, most of the information on the PRENFLO gasification was disclosed in the papers already read by Shell Corporation. The relationship to GKT's PRENFLO will be still more evident if the process flow diagram, Slide 7, is considered:

Coal supply is through a lock-hopper system and a flow control unit. Oxygen is added in the burner.

The temperature of the reaction is locally 2000 °C = 3,630 °F locally. The average temperature of the gas at the reactor outlet is about 1450 °C (2640 °F), however, the precise temperature varies according to the individual coal.

Part of the coal ash melts and leaves the reactor as a fluid at the bottom tap; the other part of the ash is entrained with the raw gas. The ratio between both types of ash is called the ash split; the ash split varies for different coals.

Next, we have a quench to solidify the ash particles in order to avoid fouling. The quench section is followed by the heat recovery steam generator. Some aspects of the quenching method and consequences for the heat recovery steam boiler will be discussed later.

Next comes a cyclone or battery of cyclones to remove 95 % of the fly ash, followed by some heat exchangers and saturators to bring the temperature down to the operating temperature of the venturi scrubbers, where the raw gas is completely dedusted. The raw gas is now ready for desulfurization.

As you will have established, this flow scheme is familiar to you from the Shell papers. The reason is, that this flow sheet shows a typical entrained-flow gasification concept, which GKT has been pursuing with unerring and logical continuity:

- during the development of KT atmospheric coal gasification,

- during the performance studies for pressurized entrained flow gasification in the early 70's,

- during our 4-years' cooperation with Shell, where Shell contributed considerable experience from their oil gasification under pressure,

- and later, while we improved associated components.

We are continuing on this course

- because we are convinced, that pressurized entrained-flow gasification is the most versatile concept with the highest potential for application (especially for combined cycle power generation), and the highest potential for total net efficiency, and

- because in addition to the design and operational experience from the Shell-Koppers project, GKT has 35 years of Koppers-Totzek experience, practical experience with the gasification characteristics of some 35 types of coal and laboratory results for more than 150 specimens. Correlation of this information pool allows very precise prediction of the gasification performance of numerous types of coal in the PRENFLO gasifier, and permits highly reliable plant layout.

2 Performance Data relevant for Combined Cycle Integration

2.1 Advantages of Pressurized Entrained-flow Gasifiers

Like all high temperature gasification processes, the PRENFLO process releases a gas of simple composition, consisting mainly of CO, H_2, CO_2, which provides a good synthesis gas as well as a medium BTU combined cycle fuel gas. Medium BTU gas is welcome, because at low combustion chamber temperatures NO_x emissions are low. Table 1 (Slide 8) shows the composition of a PRENFLO gas for CC-application. The purity of the oxygen was 85 %, nitrogen was used as coal dust conveying medium.

Substance	% WT (wf)	Substance	% Vol (dry)
C	69.80	CO_2	1.32
H	4.70	CO	62.13
O	9.00	H_2	26.74
N	1.40	N_2	7.65
S	3.28	AR	1.00
Cl	0.09	H_2S	1.01
AR	0.00	COS	0.11
Ash	11.73	CH_4	0.01
		HCl	0.03
		CO + H_2	88.87

TABLE 1: Typical PRENFLO Raw Gas Composition for Illinois No. 6 Coal, with Oxygen purity 85 %, Nitrogen as Coal Dust Conveying Gas.

Pollutant-content in the raw gas depends on the feed coal, but is always equal to or even smaller than that of other gasification processes.

Because of the high gasification temperatures, the slag is acceptable from an environmental point of view. Fly dust produces problems only if its disposal cannot be conveniently solved. With small ash content, recycle of fly dust can be considered, in order to minimize the ash output at the cost of increased slag production.

The dynamic performance is very promising. Some typical figures are shown in Table 2 (Slide 9). The confirmation of those figures, and possibly their improvement, is among the investigations for which a semi-technical plant is being erected at Fürstenhausen, West Germany.

- heating up from cold state	8 h
- heating from stand-by	2 h
- load/time gradient	5 %/min
- turn down ratio for a four burner gasifier	> 5 : 1

TABLE 2: PRENFLO Gasification. Dynamic Performance Data for CC Application.

The four burner arrangement also offers excellent safety and reliability. Failure of one burner does not trip the gasifier (Slide 10).

2.2 Versatility of the PRENFLO Process, Examples

The PRENFLO process is most versatile with respect to feedstock quality. The range is from lignite to anthracite, and ash contents up to 40 %. To demonstrate this flexibility, we have calculated cold gas efficiencies, thermal efficiencies of gasification including waste heat recovery, and system efficiency for a PRENFLO gasification unit integrated in a combined cycle power plant for different coal ash contents.

The Block-Flow Diagram is given in Slide 11. It was simulated using the ASPEN PLUS Simulator from ASPEN TECHNOLOGY, in conjunction with user's own models for the simulation of multi-stage steam circuits. We used Ensdorf Coal, which has 12 % ash. For reasons of consistency, the ash content of this coal was increased to 25 % and 35 %, with the remaining components adjusted accordingly. The objective was not so much the achievement of high figures but determination of the influence of ash content.

We used the Ensdorf coal to illustrate the effect of ash content on cold gas efficiencies (Slide 12). For reference reasons, we plotted the cold gas efficency for Illinois No. 6 coal gasified under the same conditions; we can assume that the drop in efficiency as a consequence of ash content would be similar.

The right hand side of Slide 12 shows the effect, that the ash content would have on the total net system efficiency of a combined cycle installation.

There is a loss in efficiency of between 39.13 % and 37.21 % when the ash content of the coal is changed from 12.5 % to 35 %, an ash content fluctuation range which we are obliged to take into account (GKT supplied KT gasifiers to Turkey for lignite with 38 % of ash, in South Africa the ash content of some hard coals is in the range of 22 %).

There are some reasons for efficiency losses:
With increasing ash content, the compression work for air, oxygen and nitrogen is increased and the ratio steam turbine output / total turbine output is increased.

For comparison, the relevant figures for Illinois No. 6 coal are indicated in both slides; also for comparison, theoretical efficiency results for other gasification systems are given for certain premises (Slide 13).

3 Present Status of the PRENFLO Project

In 1981, Shell and GKT decided to continue development separately. To be ready for commercial-size demonstration plants, GKT undertook the following steps simultaneously (Slide 14):

- component development, including improvement of associated processes (like coal dust feeding),

- PRENFLO 48 mt/d to prove long time availability of all components and confirm the operational flexibility necessary for combined cycle integration,

- preparation of the complete engineering and detailed design for a standard 1000 mt/d PRENFLO module.

Slide 14 gives a bar time schedule, that shows how these topics fit into the complete PRENFLO project.

So far we have reached the following results:

3.1 Component Development

A reliable and precise coal dust feeding system of high availability including a mass flow measuring method has been developed. It had been felt that reproducibility and uniformity of mass flow were still to be improved. As the coal dust particle residence time in the center of reaction is very short (fractions of a second), mass flow fluctuations of greater duration would change the momentary gasifier conditions to poor or rich oxygen content.

So precise measurement of coal dust flow and coal/ oxygen ratio control are essential for good gasification efficiency. The following improvements were worked out (Slide 15):

The coal dust outlet hopper underwent special design work to reduce the coal dust wall friction, and a special geometry was developed together with a university institute to improve the conditions for coal dust flow.

The coal dust is fluidized by a conveyor gas (N_2, CO_2, possibly raw gas) in a dense phase flow. It passes a density measuring device (absorption of radiation intensity), followed by a venturi type nozzle, that gives a differential pressure as an analog of flow velocity of the fluid-like dense phase. The product of density, flow velocity and the cross sectional area of the pipe gives the mass flow.

In addition, the changes of weight of the feed bunker are recorded over time. Comparison of mass flow measurement results with the results of the recorded weight-changes allows the calculation of a correlation factor for mass flow measurement. This calculation is continuously performed in a small computing device; the measurement is self-adjusting and allows control of oxygen and steam flow.

The average flow velocity is low ($<$ 8 m/s $\hat{=}$ 25 ft/s), so that the wear is negligible. The turn down ratio is 4 : 1. The flow density corresponds to 80 % of the bulk density. The typical range of operation is at a density between 400 : 480 kg/m³ (see Slide 16).

This mass flow measurement method is being commercialized to solve dust conveying problems outside the coal gasification too.

3.2 The PRENFLO 48 mt/d Plant

Thermodynamic efficiency and plant availability are decisive and equivalent factors for the economy of a process. It is well known that newly developed technologies sometimes fail to fulfil the economic expectations of the investors. For integration into a combined cycle power plant, an availability corresponding to typical availabilities of the rest of the equipment is compulsory. Consequently GKT's policy is to minimize the risks connected with PRENFLO. (Here we mean the risk of unexpected delay during the commissioning period, as well as reliability risks).

It is the purpose of the 48 mt/d plant in Fürstenhausen (West Germany) to run a PRENFLO module for 3 years at 4,000 h/a to establish availability data for all connected equipment, as a basis for commercial plant layout.

For important parts, a service-life wear history will be recorded and a data collection system will allow the correlation of observations with the relevant operational conditions that induced the wear observed.

In parallel, all product, waste, and effluent data will be collected and analyzed. The results will be used to optimize the efficiency of the module.

Special experimental work is provided for the waste heat recovery system, that contributes considerably to the overall efficiency of a combined cycle plant. The problems of superheating-temperatures at high steam pressure in corrosive raw gas atmospheres will be studied for the selection of materials.

Several options for heat exchanger arrangements will be studied to minimize cleaning expenditure at high average heat transfer conditions.

Operational work such as start up, load changes, load change velocity, emergency shut down, normal shut down, particularly under combined cycle aspects will always be superimposed.

Also in the Fürstenhausen plant we plan - in cooperation with the big power plant supplier KWU - to run an installation for turbine blade tests and special gas-gas heat exchangers.

As indicated in the time schedule (Slide 14), the Fürstenhausen plant (Slide 17) is under construction now, start-up operation will begin by November of this year; tests to solve problems connected with the integration of PRENFLO into the combined cycle process will be finished by the end of 1987.

The plant will also be used to study further applications such as syn-gas production, using direct quench.

The plant will be available for economical "large scale tests" of customer's coals in case of projects.

3.3 1000 mt/d PRENFLO Module
Preparation of the Engineering for a Standard Module

The pressure vessel of the PRENFLO 1000 mt/d reactor is approximately 7 m high and has a diameter of about 6 m. Inside the reactor chamber local temperatures of 2,200 °C occur, the internal pressure is 30 to 60 bar. The reactor chamber is made up of a reactor vessel, the face being protected by a ceramic lining.

It was impossible to design this type of reactor without previous study of limitations. Therefore, the feasibility of the concept was thoroughly investigated. Main topics were:

- limitation of flange rigidity for large diameters (which leads to welded pressure vessels), only relative small flange diameters are acceptable,

- the reactor vessel is to be inserted into the pressure vessel prefabricated, final assembly is inside the pressure vessel,

- access for maintenance and inspection of the boiler tubes,

- consequences for the pressure shell in case of boiler failure and consequent direct radiation striking the pressure shell inside,

- preparation of methods for calculation and approval of these methods for authority clearances.

Questions like these needed to be answered before a conceptual design for the reactor could be put forward.

To permit utilization of the operating results from the PRENFLO 48 mt/d reactor for the design of the 1000 mt/d reactor, both of them must be built to the same concept.

The basic and detailed design for the PRENFLO 1000 mt/d reactor has been started. We are in position to integrate results from the test unit into the reactor design, and, conversely to test certain new elements, which design work might produce, in the 48 mt/d plant.

In this context, I would like to state that the Fürstenhausen plant is not aimed at the development of a new gasification process. The PRENFLO process already exists! Instead the plant will serve to supply availability data to confirm the design concept and performance data.

The detailed engineering for a 1000 mt/d PRENFLO standard module will be finished by summer 1988.

Returning to the doctrine of minimizing risks of newly developed processes the preparation of the 1000 mt/d module puts GKT in a position to handle even the first order for a commercial PRENFLO plant on the basis of secure technology, authorities' approval and a safe price basis at minimum risk for all partners.

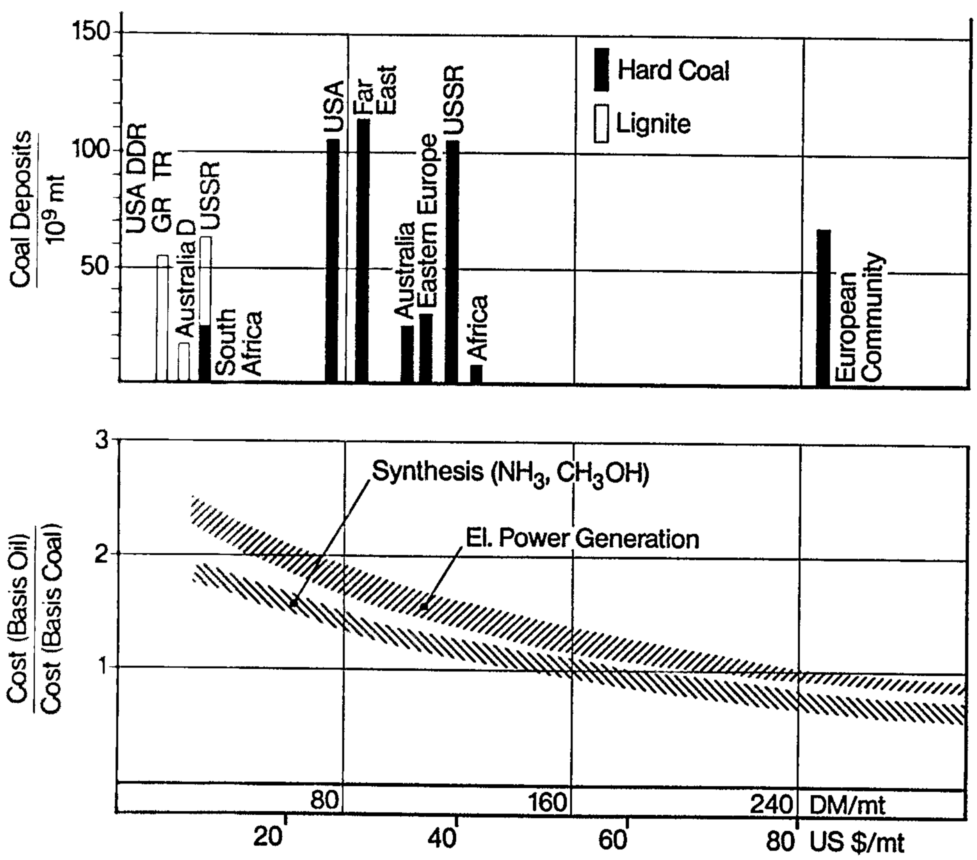
It should be mentioned that GKT, for the application of PRENFLO gasification in combined cycle power generation is in close contact with KWU of West Germany. Much work has been done together to make the combined cycle power generation with integrated PRENFLO gasification a highly efficient concept.

Conclusion

It is part of GKT's policy to go public only after a programme has been firmly established. This is one reason why PRENFLO has not up to now been widely publicized.

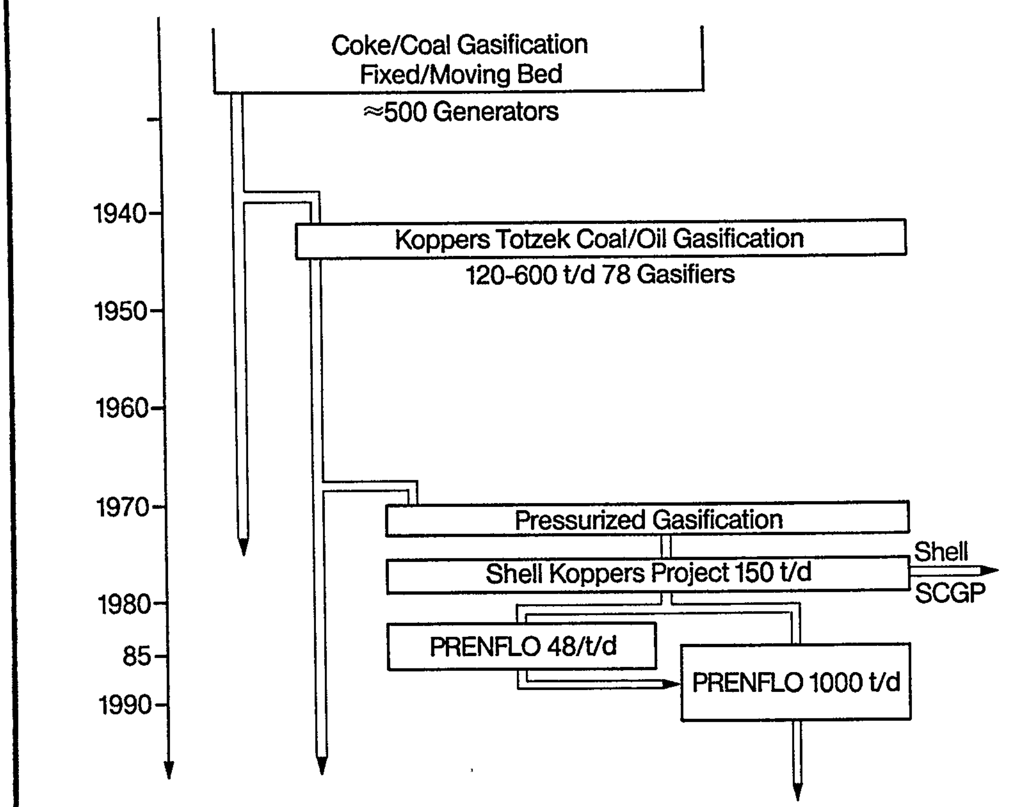
GKT will follow a strict strategy to bring the PRENFLO process into the market; it will be ready for commercial demonstration in 1988. We are convinced that this process will find its market, because its technical and economical standard is high, and because no company in the world has the entrained-flow gasification experience of GKT.

The PRENFLO project is being financially supported both by the West German Ministry of Development and Technology (BMFT) and by the commission of the European Communities.

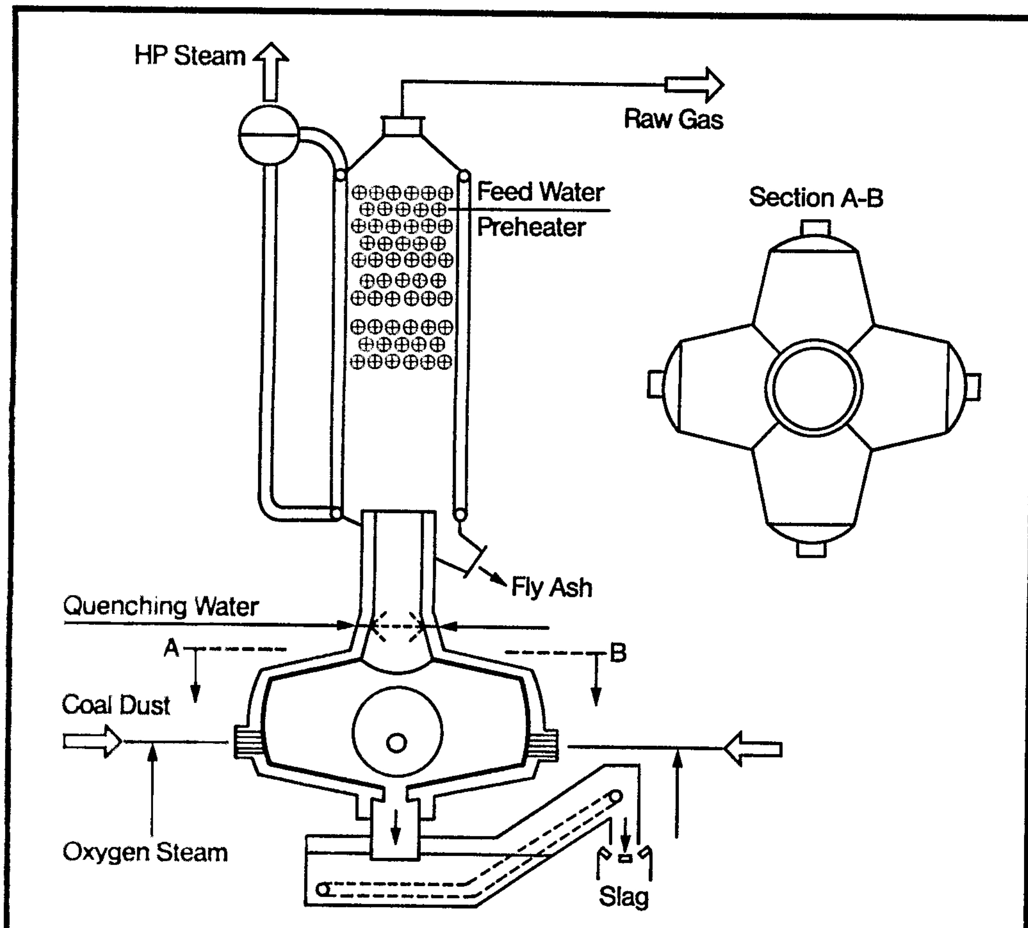


PRENFLO – Chances for Coal Gasification Based Processes

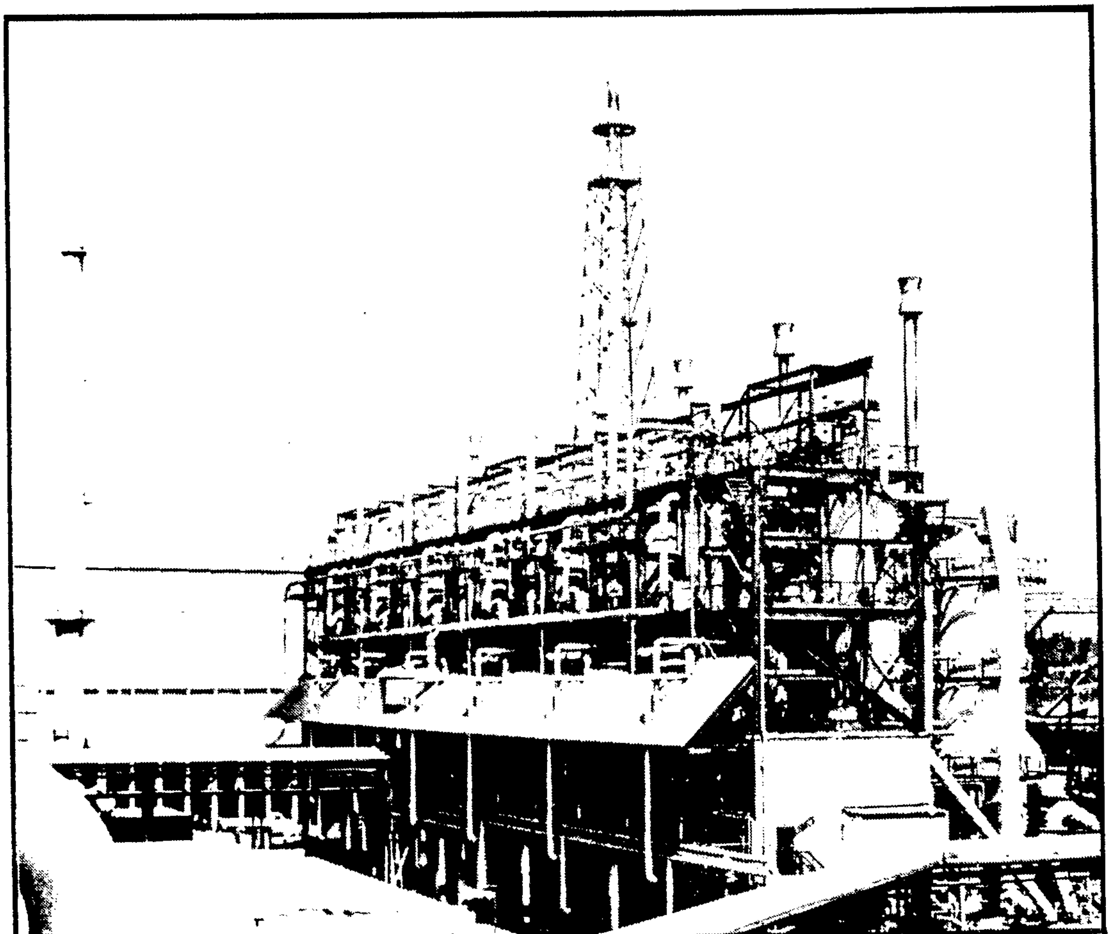
1



	KK Gasification-History	2



	KOPPERS-TOTZEK Gasifier	3



Koppers-Totzek Coal Gasification Plant at Modderfontein, South Africa | 4

Process		Koppers Totzek	PRENFLO
CO_2	Vol. %	6.37	1.36
CO	Vol. %	64.93	67.44
H_2	Vol. %	26.49	29.21
INERTS	Vol. %	0.92	0.78
H_2S	Vol. %	1.16	1.09
COS	Vol. %	0.13	0.12
$CO + H_2$	Vol. %	91.42	96.65
Cold Gas Eff. *)	Vol. %	73.46	82.47

Coal: Illinois No. 6.
Oxygen: Purity 99.5 %

*) Basis HHV

PRENFLO – Effect of Pressure on Gasification of Hard Coal

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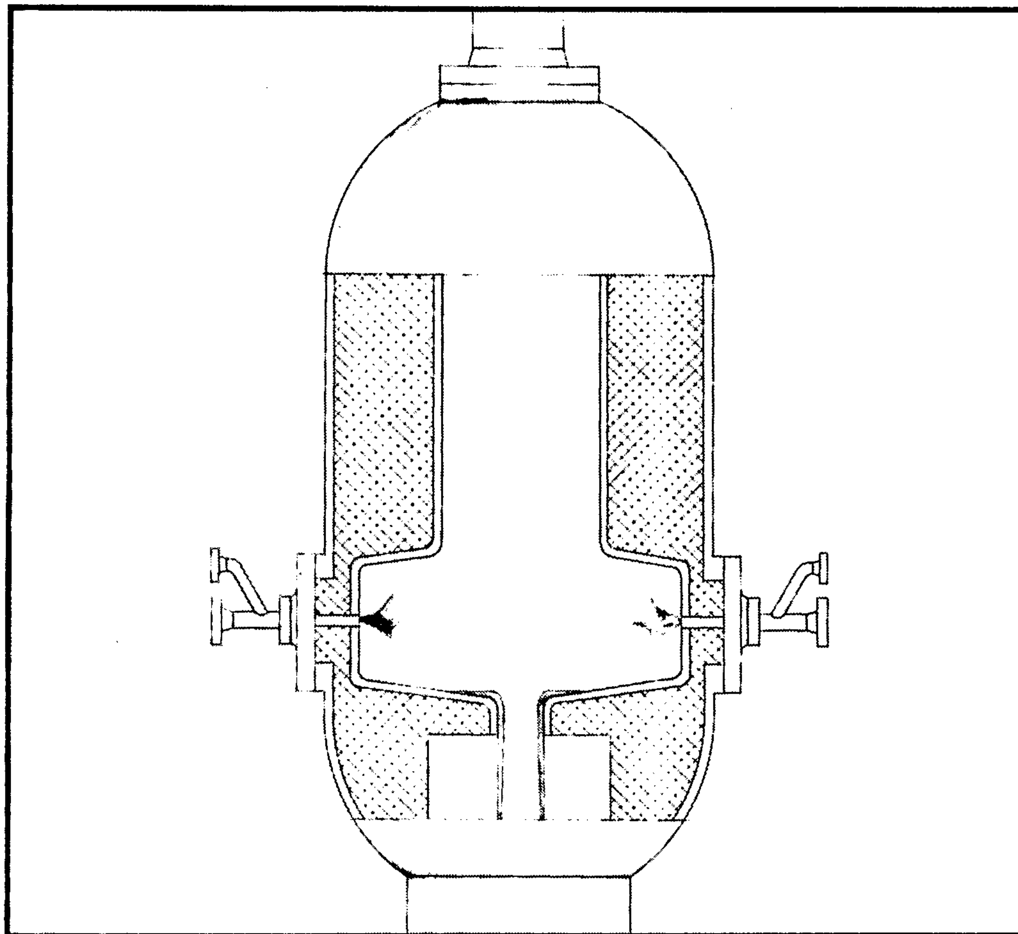
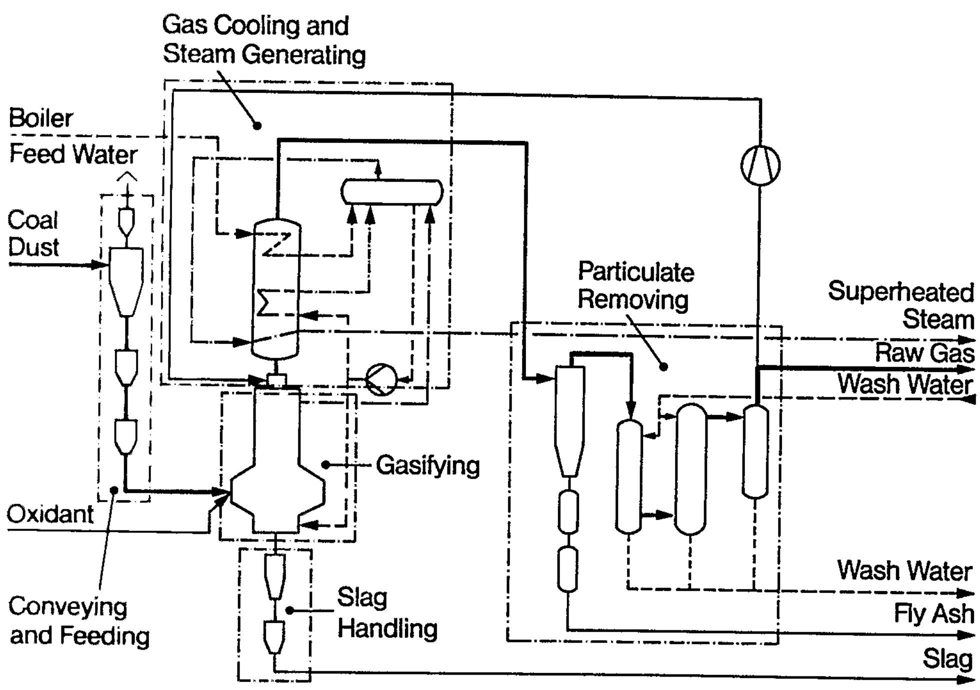


	PRENFLO Reactor	6



Flow Diagram of the PRENFLO Process | 7

Typical PRENFLO Raw Gas Composition
for Combined Cycle

Substance	% WT (mf)	Substance	% Vol. (dry)
C	69.80	CO_2	1.32
H	4.70	CO	62.13
O	9.00	H_2	26.74
N	1.40	N_2	7.65*
S	3.28	AR	1.00
CL	0.09	H_2S	1.01
AR	0.00	COS	0.11
Ash	11.73	CH_4	0.01
		HCL	0.03
		$CO + H_2$	88.87

Spec. Oxygen Consumption: 0.935 kg/kg Coal (maf)
*Purity of Oxygen: 85 % Vol.

	PRENFLO – 1.000 MT/D, Illinois No. 6	8

Heating up from Cold State	8 h
Heating from Idle Motion	2 h
Load/Time Gradient	5 %/min
Turn Down Ratio for a Four Burner Gasifier	>5 : 1

PRENFLO – Dynamic Perfomance Data for CC Application

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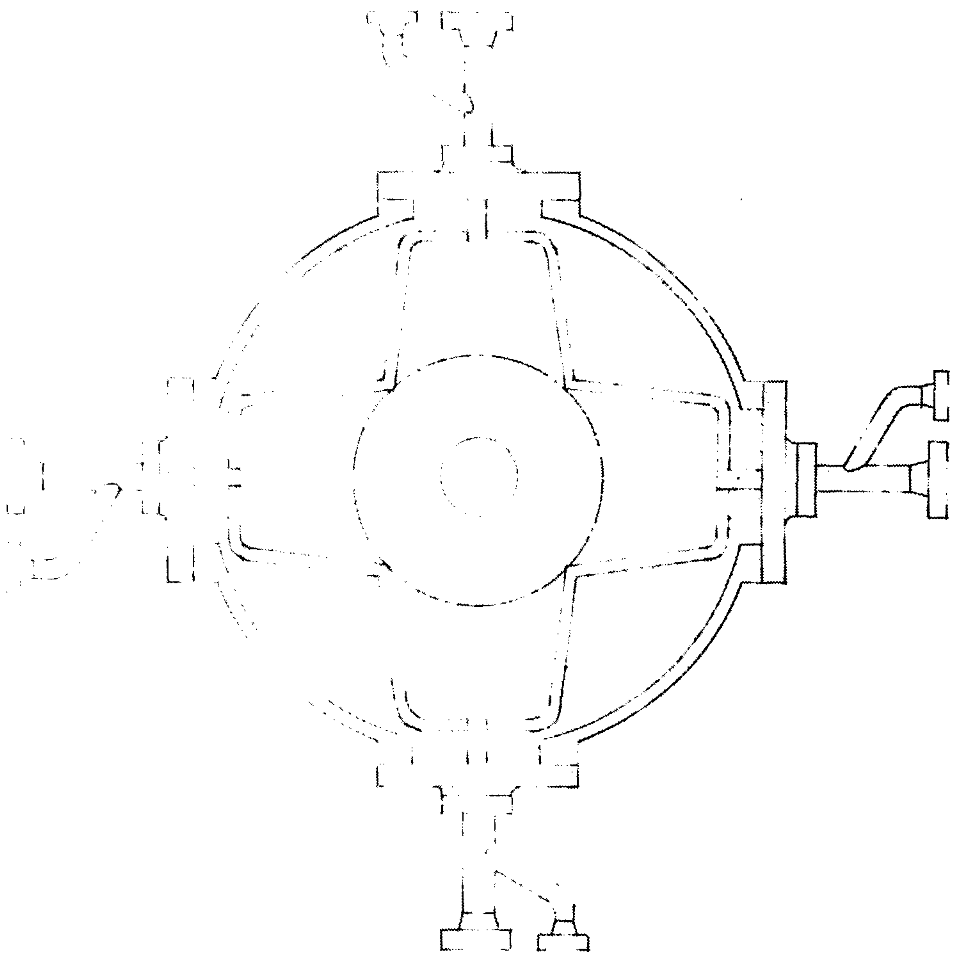
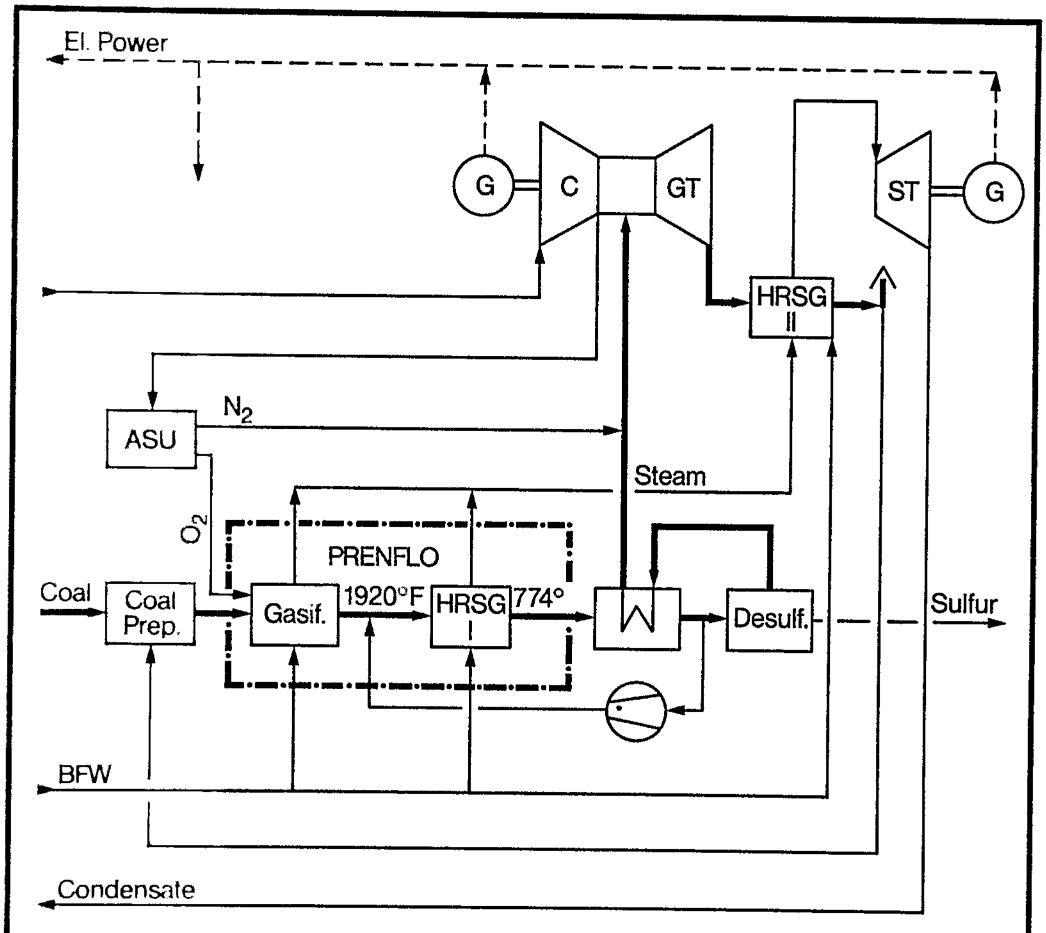
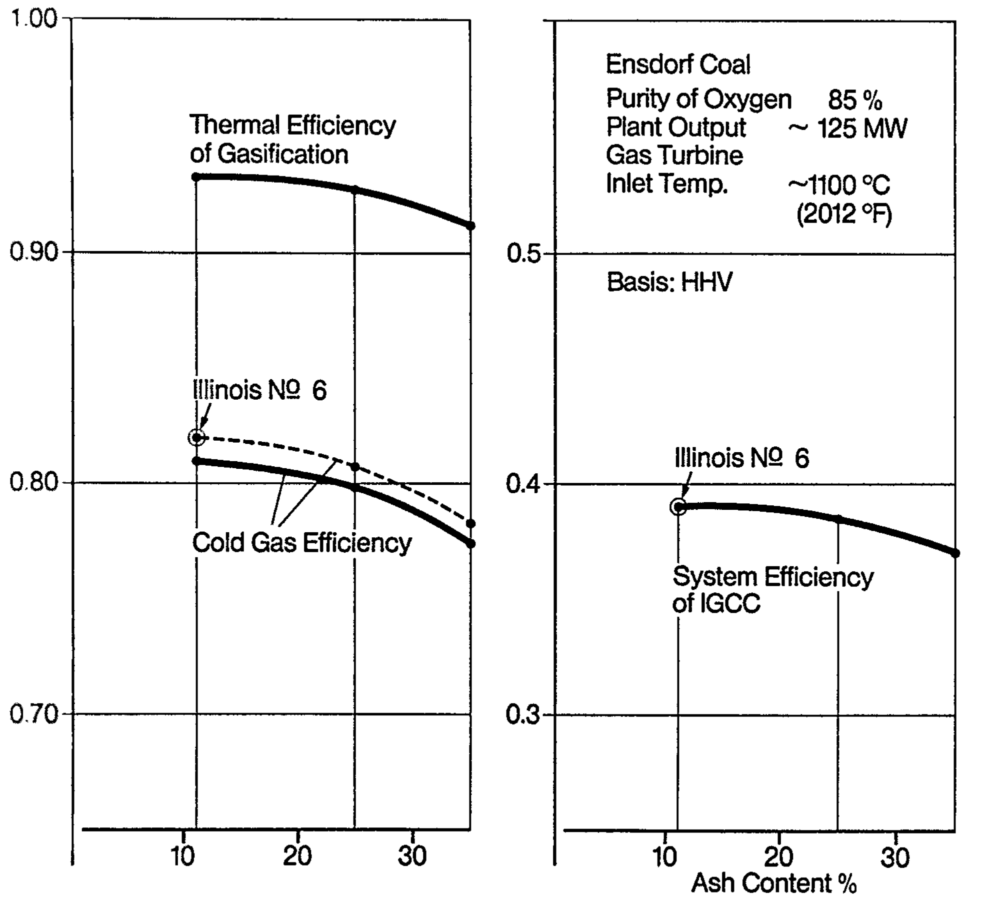


	PRENFLO Section through Burner Level	10



PRENFLO – IGCC-Block Flow Diagram | 11



PRENFLO – Effect of Ash Content on Efficiency of Gasification and IGCC-Power Plant

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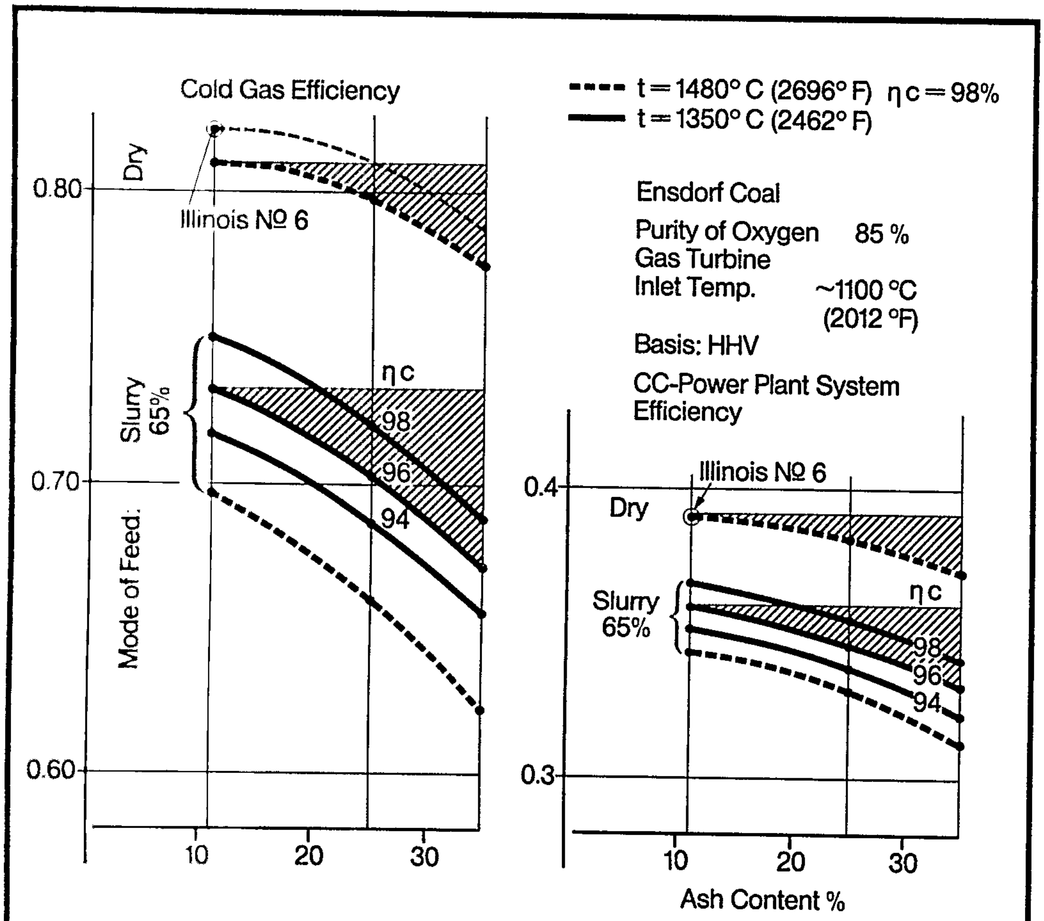

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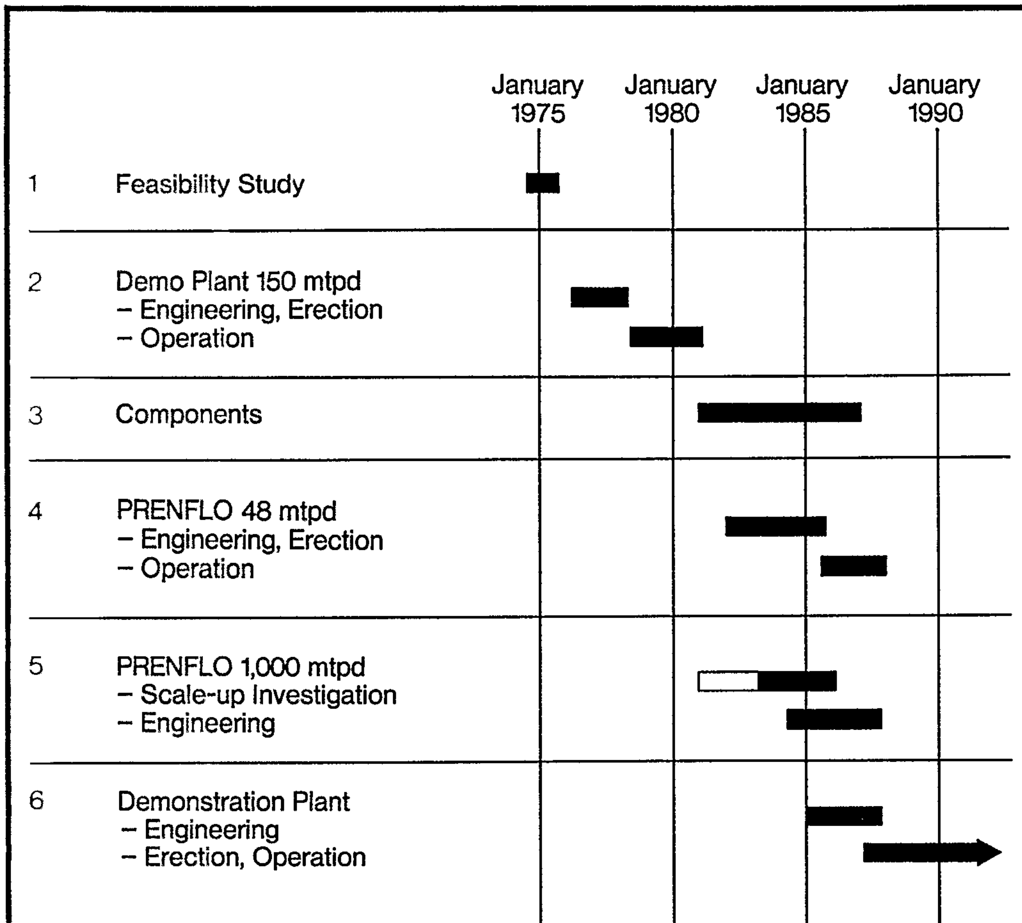
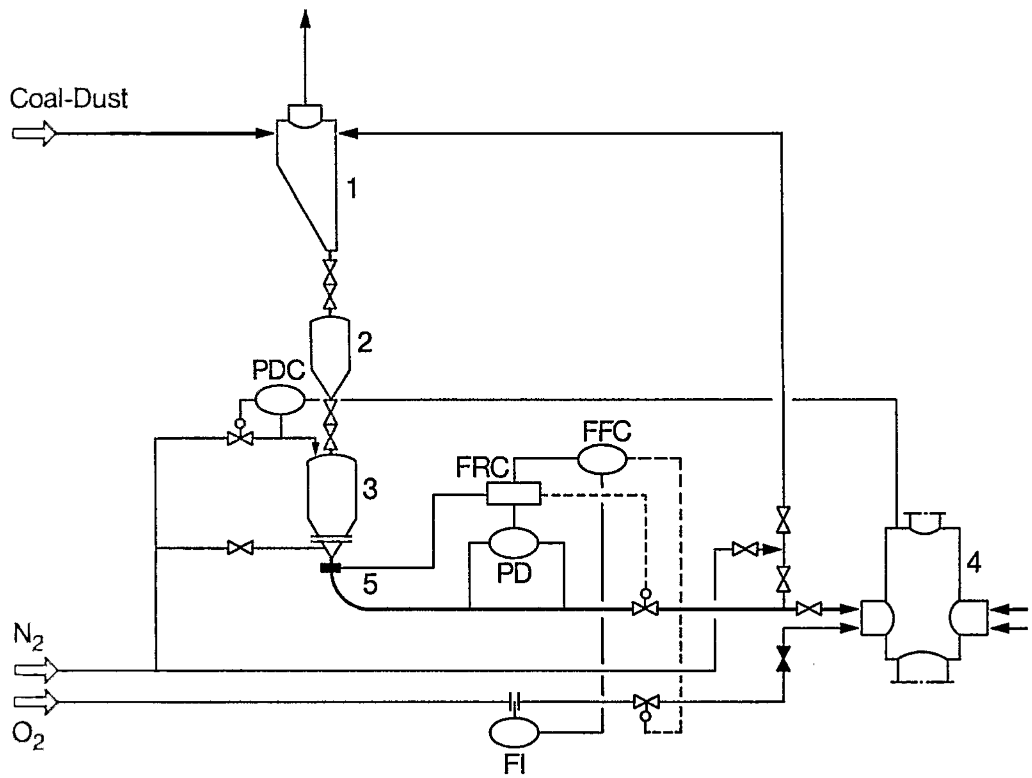
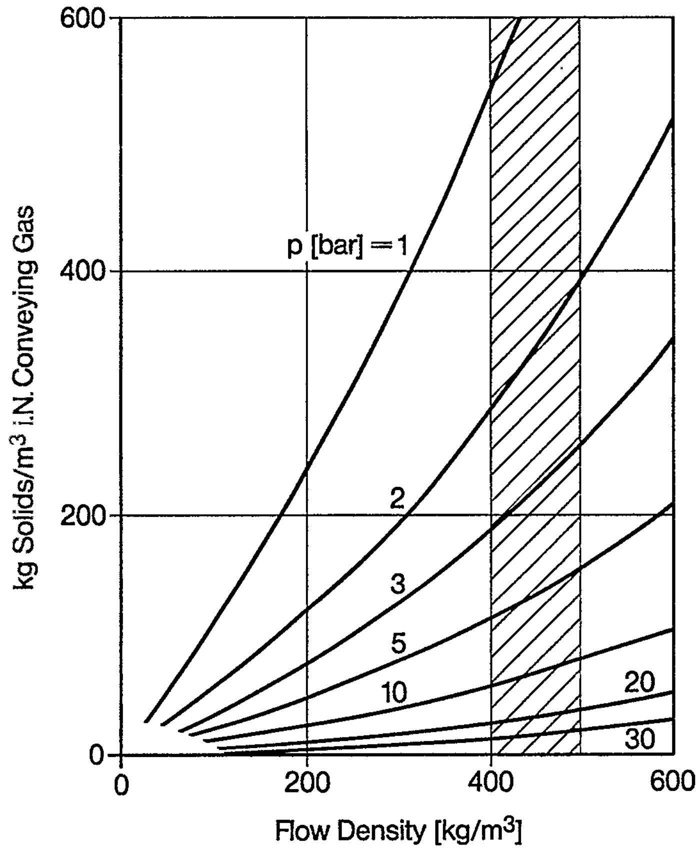


PRENFLO Development 14



1 Cyclon
2 Sluicing Bunker
3 Feed Bunker
4 Gasifier
5 Density Detector

	PRENFLO – Dry Coal-Dust Feeding-System	15



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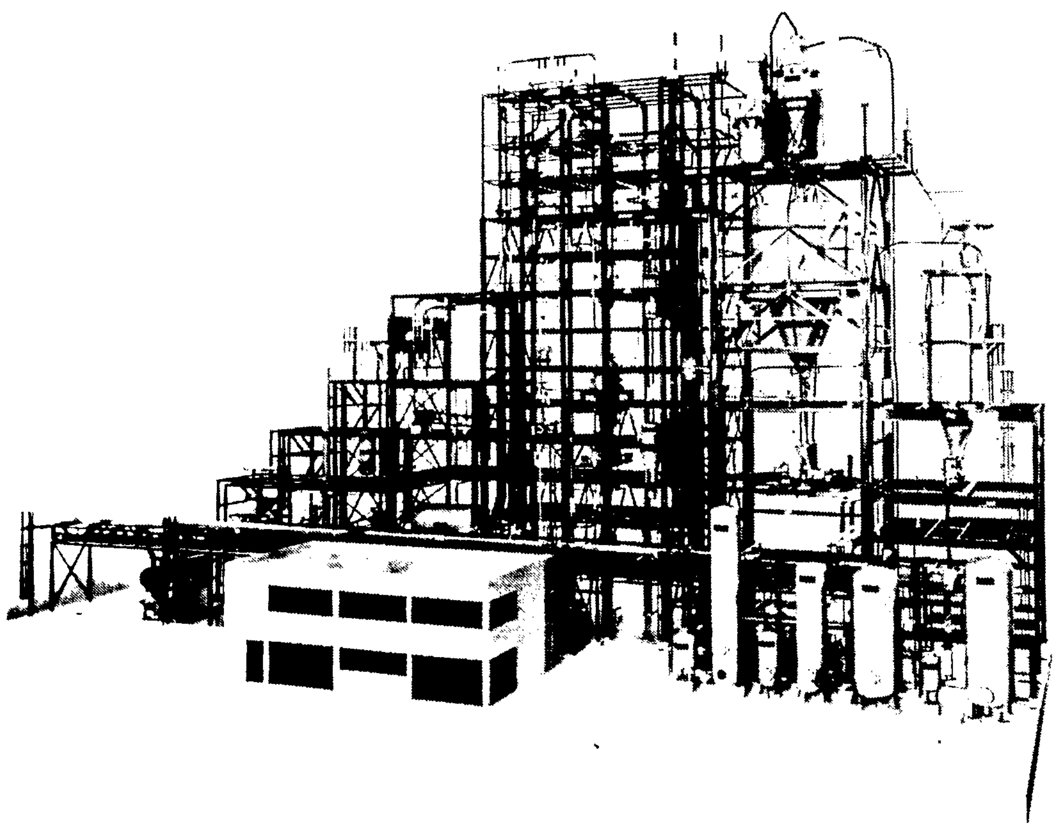

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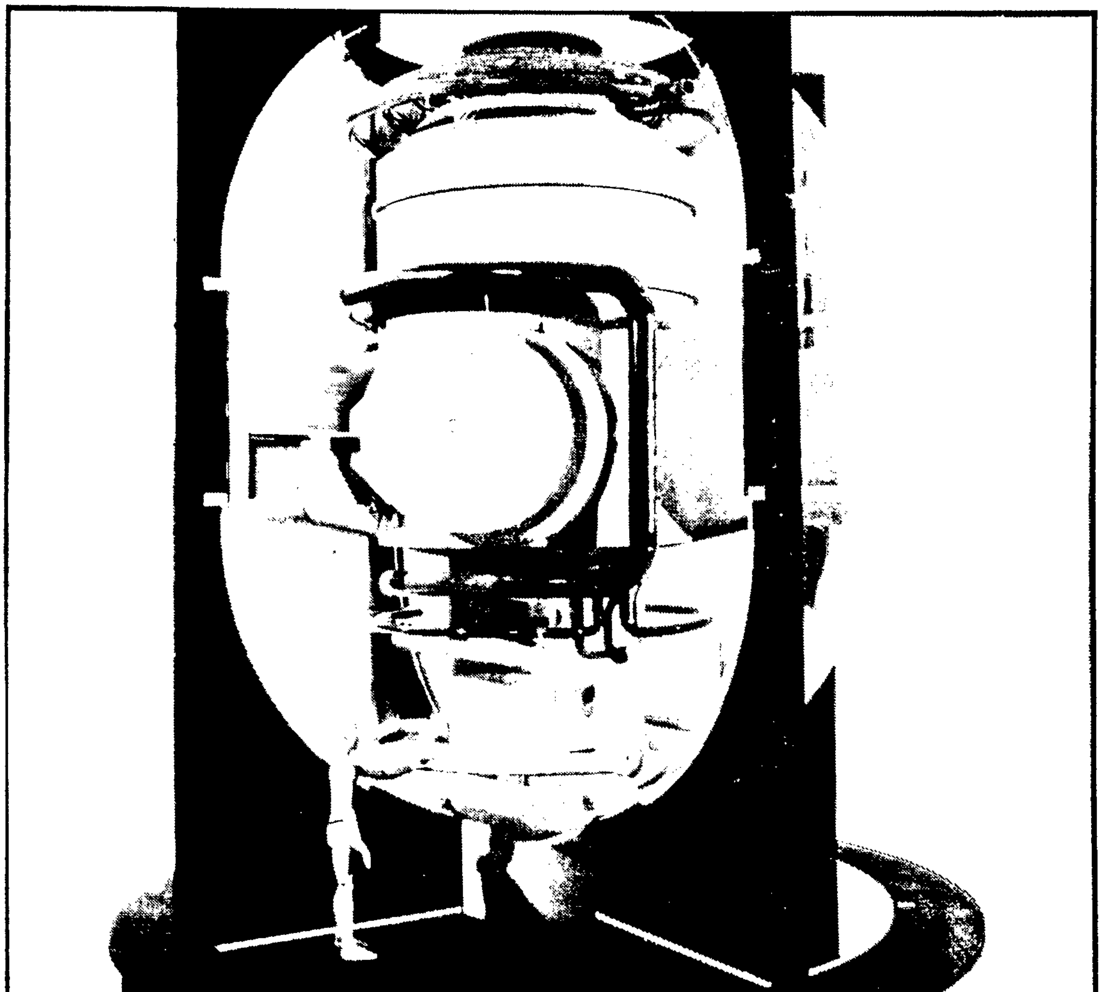

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