Section 21

THE KLÖCKNER PROCESS OF COAL GASIFICATION IN THE IRON BATH: HIGH EFFICIENCY AT MINIMUM POLLUTION ACHIEVED WITH A SIMPLE METALLURGICAL REACTOR

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1. Introduction

The technology of

" Coal Gasification in the Iron Bath "

developed by the Klöckner-Werke concerns a process especially distinguished by a high density of coal throughput as well as by low emission of pollutants and a high degree of environmental compatibility.

A research and optimization project carried out over several years in an industrial-scale plant designed for a throughput of up to 20 metric tons of coal per our provided the proof for the feasibility of the process on large industrial scale.

The required plant components have been taken over from the field of the ferrous metallurgical industry and, accordingly, have been tried and tested for many years past in the rough climate of iron and steel production.

2. Process

2.1.. Principles of process

The process is based on simultaneous carburization and decarburization of liquid iron. Principally, iron will neither be produced nor consumed, it merely performs the function of catalyst and heat exchanger and remains in the gasification vessel.

The gasification vessel resembles a steelmaking converter - a steel shell with refractory lining; in this vessel, high-carbon hot metal is contained. Ground coal and oxygen are injected through bottom tuyeres. Slag-forming additives such as lime, lime stone or slags already used in steelmaking can be added either through the bottom tuyeres in pulverized form or from above the bath. Then they can assume lumpy form (lime, limestone) or liquid state (steel slags) when gasifier is operated within a steel mill.

Figure 1 - Coal Gasification in the Iron Bath
Elementary Diagram

Represented in a simplified way, at a temperature of from 1450 to 1600°C the following process steps take place within the iron bath:

- Immediately, the volatile constituents of the coal are removed and cracked to C and H_2 by the high temperature.
- The carbon is dissolved in the iron.
- The ash component of the coal combines with the slag forming additives, such as lime or steelmaking slag, to form a basic liquid slag.
- The sulphur from the coal is first dissolved in the liquid iron, then reacts at the phase boundary to slag with Ca to form Ca S which is stable in the slag. To a small extent, S is also bound in the dust.
- The carbon dissolved in the iron bath reacts with the oxygen and thus forms the gaseous product, together with the H_2 from the cracked process.

2.2. Research and development works up-to-date

The first experiments by Eisenwerksgesellschaft Maximilianshütte, Sulzbach-Rosenberg, have already been carried out around the middle of the 70's. A 1 metric ton capacity OBM converter was used. The results indicated the follwing advantages of the process:

a) high specific rate of gasification

b) low CO_2 and $H_2 O$ contents in the gas produced (total about 1%)

c) low sulphur contents in the gas: the systems binds the sulphur (almost to 100%)

On the basis of these promising results further experimental programs were carried out in 6 and 20 metric tons capacity steelmaking converters and in so doing the follwing results were achieved:

- regarding CO and H_2, the composition of the coal gas satisfied the theoretical expectations
- the CO_2 component was below 1%
- the H_2O component was below 1%
- sulphur contents down to below 20 ppm were achieved
- the power density of the system was very high (0.4 metric tons of coal per ton of Fe x hour)
- the gasification system reacted fast to changes in parameters as presented by different types of coal input.

The favorable results of experiments induced Klöckner-Werke to the construction of a pilot plant.
The process schematic of this plant is shown in fig. 2.

Figure 2 - Coal Gasification in the Iron Bath
Process Schematic

In the meantime the technology of bottom blowing by using solid charges had been brought to maturity by the Maximilianshütte on large industrial scale for the purpose of increasing the scrap charge into steelmaking in the converter. In this input plant during 1980/1981, with EC subsidy, several experimental series in a 60 metric tons capacity production converter have been carried out.

The experiments provided ample proof that without scale-up risks oal gasification in iron bath can be satisfactorily done also in larger gasification vessels, above all with low concentration of pollutants in the gas and with high specific efficiency.

But the scatter range of various experimental results also indicated that process optimisation would also have to be worked onin various subdomains. Also the need to extend the field of application of the process became evident due to the changed economic conditions of world energy markets. It was also shown in the course of the experiments that for process optimisation the existing production plant would require more and more precise supplementary facilities for controlling and measuring.

Therefore, during the period from October 1981 to March 1984, an extensive R&D project had been carried out. The financial scope of this project was 33 million DM subsidised by BMFT.
The emphasis of this project was placed on large-scale experiments which were carried out under the direction of Klöckner Stahlforschung GmbH in the converter plant of Maxhütte which had been re-equipped extensively for this purpose.

Fig. 3: Process Schematic of the Maxhütte Pilot Plant
Fig. 3ashows Maxhütte steelmaking shop.
Fig. 4 shows the coal injection systems and fig. 5 the reactor vessel.

A number of university institutes and other public and private firms specialized in various subdomains of the programme cooperated.

Table 1:

Outline of R&D projects accomplished over the period from October 1981 to March 1984 in the field of coal gasification in iron bath reactor

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Company	Scope of Performance
Klöckner Kohlegas GmbH, Bremen	- Direction and Supervision of the project, coordination and reporting
Eisenwerk-Gesellsch. Maximilianshütte mbH, Sulzbach-Rosenberg (Maxhütte)	- Optimization of process technology by extension of plant equipment - preparation and availability of production plant (converter) and service departments (laboratory), - delegation of production and service personnel to carry out the experiments - Procurement of special equipment components
Maxhütte Planning and Construction Dpt.	- Engineering and installation of a dust recirculation plant

Klöckner Stahlforschung GmbH, Sulzbach-Rosenberg	- Cooperation in R+D of special installations - planning, direction and performance of the entire experimental programme, including dust recirculation tests - procurement of consumption materials - assessment of experiments and reporting
Klöckner Stahltechnik GmbH, Hamburg	- Development of an operational model for coal gasification in the iron bath (computer model) - elaboration of a study on the technology of coal preparation and transportation

Fig. 6: Coal gasification in the iron bath.
Flow sheet of Maxhütte pilot plant.

- The sulphur contents of input materials were essentially within the range of from 0.8 to 1.3%, only in the case of petroleum coke at 4.1%.

- The ash contents were mostly between 5 and 14%

- The calorific values (Hu) varied between 26,000 and 30,000 kI/kg.

2.3 Status of development, after conclusion of the 20 tph test programme

2.3.1 Coal throughput

Besides the gasification process, it is standard practice to add coal to steel melts in the KMS and KS melt shops of Klöckner Werke AG at Maxhütte and Georgsmarienhütte.
To date a total of more than 250.000 metric tons of coal have been processed successfully. The coal storage, pneumatic transport and injection systems designed and installed by Klöckner Stahltechnik GmbH, Hamburg, are identical to those used in coal gasification.

Up-to-date within the scope of research projects about 2000 metric tons of coal had been gasified for the purpose of coal gasification alone, without simultaneously producing steel. A wide range of coals had been used, from pit coal and lignite char through to anthracite, smith's coals and bituminous coals right up to gascoals and open burning coals, furthermore also petroleum coke, and similar refinery residue .

Table 2.

Since the coal is blown into the iron bath by pneumatic systems the grain size was set to be at maximum 1 mm and the residual moisture content at <3 %.

All the various coal types could be gasified in the iron bath reactor without any technical difficulties.

Table 2.

Summary of the types of coal throughput

	Pit coal coke	Brown coal coke	Anthracite	Smith's coal	Bituminous coal	Gas coal	Open burning coal	Delayed petroleum coke
Volatile constituents %	2.1	4.3 - 6.1	7 - 8.4	12.6	18.6 - 19.1	26.7 - 30.0	32 - 37.3	13.5
Ashes %	17.7	6.3 - 9.7	7.2 - 9.8	5.2	5.5 - 7.0	11.8 - 12.0	4.0 - 6.4	0.6
Moisture %	0.8	0.2 - 1.0	0.2 - 1.0	1.6	0.9 - 3.6	0.4 - 0.8	0.8 - 3.4	0.9
Elementary analysis:								
C %	78.9	86.9 - 89.1	82.2 - 84.6	81.6	79.9 - 83.4	69.6 - 70.1	43.3 78.9	87.7
H %	0.5	0.6 - 0.7	2.9 - 3.4	3.8	4.1 - 4.4	4.3 - 4.5	4.8 - 5.3	3.8
N %	0.6	0.3 - 0.6	1.0 - 1.1	1.2	1.2 - 1.4	1.2 - 1.3	1.2 - 1.5	1.4
O %	0.6	1.2 - 4.0	2.4 - 2.9	5.8	2.7 - 5.0	11.2 - 11.7	7.0 - 12.0	1.6
S %	0.9	0.3 - 0.6	0.7 - 0.8	0.9	0.7 - 1.1	0.6 - 0.7	0.6 - 1.4	4.1
Calorific value (Hu)								
kJ/kg	26,590	29,570-30,980	28,785-31,590	32,090	31,380-32,375	26,860-27,480	29,360-31,440	34,375
kcal/kg	6,350	7,063-7,400	6,875-7,545	7,665	7,495-7,735	6,415-6,565	7,013-7,510	8;210

The throughput was between 10 and 20 metric tons of coal per hour. Its upper limit was set by previously existing plant components, namely the off gas-system, designed for steel production which could nothandle higher volumes. The gasifier itself proved to be capable of handling more than 20 t/h.
A capacity of 400 kg C/+ Fe x hour is attainable.

2.3.2. Gasification medium and pressure stage

Until now the production of high-grade, low pollutant-containing fuel gas was in the forefront of interests. For this reason the gasification was carried out with oxygen. Coal gas was obtained without pressure. However, both, operation with pre-heated air and under pressure are currently being tested.

2.3.3. Addition of slag forming agents

Generally speaking, to bind the sulphur originating from the coal it is necessary to add a lime-basic mineral. In most cases unhydrated lime (CaO) was added. Experiments with limestone ($CaCO_3$) and with basic LD slags were quite successful.
The necessary quantity of addition depends on the composition of the coal and on the slag forming agents, also on the desired sulphur content in the final slag.

For a pit coal with 1 % sulphur content and 10 % ash content it is necessary to add about 100 kg of unhydrated lime per metric ton of coal. The precise amounts required - depending on the flux analysis - are determined by the process model.

2.3.4. Process control

The process control is not complicated. The only requirements are to maintain a temperature of from about 1520 to 1580°C in the gasifier and to maintain a carbon content between 2% and 4 %. These are relatively wide ranges and, as the experiments indicated, can be met.

On large industrial scale process control would be most appropriately carried out with the aid of a so-called "sub-lance" which in about 40 minutes interval automatically measures the temperature and takes a sample from the blowing converter. This sample is then analysed for carbon content. All measures necessary for continuous process control can be derived from this sample with the aid of a small computer.

2.3.5. Load variation

On the basis of the present status of knowledge, for the iron bath process the expected maximum coal throughput is 400 kg per metric tons iron and hour. The minimum throughput is a function of the minimum pressure on the oxygen tuyeres required to keep the tuyeres free of iron.

In the Maxhütte plant a pressure of about 3 bar represents an O_2 quantity of 6000 Nm^3 per hour, which corresponds to around 140 kg per metric tons iron and per hour. This gives a control ratio of around 3 : 1.

No specific problems arise in the course of load variation (throughput variation), since the quantity of oxygen is at all times adjusted to the coal throughput, similarly the addition of slag forming agents.

The flexible system control allows for immediate interruption of the gasification process to reduce the coal injection to zero and to compensate the pressure by intert gas.

2.3.6. Thermal balance and its consequences for process control

In the case of the iron bath process the following energy balance applies:

$$E_{Inp} = E_{chem} + E_{phys} + E_{Prz}$$

where:

E_{Inp}	energy input through carbon carrier,incl. a small contribution for the tuyere-protecting hydrocarbons
E_{chem}	chemical heat of coal gas (product from the quantity of gas and calorific value)
E_{phys}	physical (sensible) heat of coal gas and of slag
E_{Prz}	available process heat.

The available process heat (E_{Prz})

- covers the heat losses from the gasifier and, depending on the type of carbon carrier
- leads to an increase, drop or constancy in process temperatures or it may make compensation measures necessary (heating, cooling).

With the aid of a computer model thermal balances were established for the types of coal investigated to-date (Table 3). The experimental results ascertained the validity of these thermal balances.

Taking into account the various differences, especially in the ash contents, the table in which the types of coal re-arranged according to their volatile constituents, indicates the following trend:

Table 3.

- The available process heat decreases with increasing share of volatile constituents and this may lead to a decrease in the temperature of the iron bath.

- Chemical and physical heat of coal gas, under comparable ash and moisture contents, increase with increasing volatile volatile constituents in the coal.

Assuming that the ash and moisture contents remain constant, the carbon content decreases with increasing share of volatile constituents, while the hydrogen and oxygen contents will increase. Decreasing carbon content leads to a drop in the available process heat, since the source of this is the C - CO reaction in the gasifier. Hydrogen leaves the iron bath in non-oxidized form and yields no process heat. Nevertheless, increasing hydrogen content will raise the quantity of gas and this results in increasing physical and also chemical heat in the caol gas.

From the different behaviours of the individual types of coal the following consequences arise for the process control.

Table 3.

Coal Gasification in Iron Bath Reactor

Thermal Balances

		Pit coal coke	Brown coal coke	Anthracite	Smith's coal	Petroleum coke	Rich coal	Gas coal	Open burning coal
Volatile constituents	%	2.1	5.0	7.7	12.6	13.5	18.9	29.0	34.2
Ashes	%	17.7	7.3	8.1	5.2	0.6	5.8	11.9	5.3
Moisture	%	0.8	0.4	0.6	1.6	0.9	2.1	0.6	2.0
C	%	78.9	88.1	83.7	81.6	87.7	81.7	69.8	76.3
H	%	0.5	0.6	3.2	3.8	3.8	4.3	4.4	5.0
N	%	0.6	0.5	1.1	1.2	1.4	1.3	1.2	1.2
O	%	0.6	2.7	2.5	5.7	1.5	3.8	11.4	9.2
S	%	0.9	0.4	0.8	0.9	4.1	1.0	0.7	0.9

	Pit coal coke		Brown coal coke		Anthracite		Smith's coal		Petroleum coke		Rich coal		Gas coal		Open burning coal	
	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%	kcal/ kg K	%
Thermal input																
Calorific value - carbon carrier (including Hydrocarbons for tuyere protection)	6524	100	7545	100	7717	100	7918	100	8512	100	7867	100	6714	100	7488	100
Thermal output																
- chemical heat	4899	75.1	5471	72.5	5939	77.0	6005	75.8	6377	74.9	6184	78.6	5410	80.6	6052	80.8
- sensible heat	920	14.1	1022	13.5	1120	14.5	1135	14.3	1202	14.1	1170	14.9	1031	15.4	1149	15.3
Available heat																
Total:	705	10.8	1054	14.0	658	8.5	778	9.8	933	11.0	513	6.6	273	4.1	287	3.8
from this converter losses*)	268	4.1	268	3.6	268	3.5	268	3.4	268	3.1	268	3.5	268	4.0	268	3.6
for iron bath	437	6.7	786	10.4	390	5.0	510	6.4	665	7.9	245	3.1	5	<0.1	19	<0.2

*) in the case of 16 metric tons throughput per hour over minimum 1 hour process time

- When carbon carriers are processed of which the available heat is higher than the heat losses from the gasifier a cooling medium is required so that the temperature in the iron bath should not continuously increase. It is necessary to blend inlower quality coal or other carbon carriers, alternatively water or steam, or use limestone at a higher proportion.
  Both of the above variants are advantageous. The first allows to put to good use low-energy materials and the second, i.e.in the case of steam addition, allows to increase the volume of coal gas and simultaneously to reduce the oxygen requirement.
  As proved by the experiments, regarding the types of coal this applies to the range encompassing coke, lean coal, rich coal, but also petroleum coke.

- On the other hand, when carbon carriers are gasified of which the available heat can no longer cover the heat losses from the gasifier, as in the case of gas- and open burning coals, it will be necessary:

  either to jointly blow the lesser coal with the necessary amount of an appropriate carbon containing material that would provide more available heat (e.g. petroleum coke), or

  to effect partial post combustion (about 5 %) of the coal gas by reintroducing the hereby obtained heat into the iron bath. This is possible with high-speed injection of oxygen and/or air into the gas chamber above the bath and represents a technology developed for the KMS- and KS-steelmaking processes.

2.3.7. The coal gas

During the gasification appr. 2000 Nm^3 per metric ton of coal input will be produced when oxygen is used as gasification medium.

The gas from coal and oygen essentially consists of carbon monoxide and hydrogen. Depending on the the type of coal input, the contents of

CO are in the range of 65 - 90 %, and of
H_2 within the range of 35 - 10 %.

When the process is being controlled in technically satisfactory manner, the CO_2 and H_2O components are very low. These amount to 1 % total. The calorific value ranges from 11000 to 12000 kJ/Nm^3.

The coal gas is characterized by exceptionally low concentration of pollutants. Investigations in this respect have been carried out on extended basis and by using the very latest measuring instruments.

The concentration of pollutants in the gas is outlined below:

H_2S	$<$10 ppm (in coals to about 1.5% S)
COS	below the limit of detection (1 vpm)
CS_2	
SO_2/SO_3	
NH_3	appr. 15 vpm
Cl	$<$5 vpm
F	$<$5 vpm
NO_x	$<$5 vpm
C_mH_n	below the limit of detection

The coal gas was investigated for further organic sulphur components.

Individually the following compounds were investigated:

Carbon disulphide
methanethiol
ethanethiol
1-propanethiol
2-propanethiol
2-butanethiol
1-hexanethiol
di-sec. butylsulphide
3-hexanethiol
di-tert.butylsulphide
dimethyldisulphide
1-heptanethiol
dimethylsulphide
diethylsulphide
diethyldisulphide
dipropyldisulphide
dibutyldisulphide
thiophene
2-ethylthiophene
tetrahydrothiophene

In none of the cases were measurable concentrations determined. In the case of petroleum coke with 4.1 % sulphur the H_2S content was 20 vpm. The other values were as outlined above.

By comparing the concentrations of pollutants in the coal gas, as determined by investigations to-date, with data from other experimental procedures, the results obtained through the iron bath process appear very favourable indeed. It can be seen from data published in the literature that in the majority of cases the concentration of pollutants in other processes in the crude gas is higher by powers of ten, so that expensive gas purification processes must subsequently be carried out.
Subsequent to the Klöckner gasification, simple dry electrostatic de-dusting is sufficient.

2.3.8. Dust development

Alongside product gas also dust arises and is carried out with the crude gas and then extensively precipitated in the dust precipitation plant.

Fig. 7 shows the precipitator (Lurgi system)

In the experiments performed the dust load in the crude gas was within the range of 15 - 60 g/Nm^3. In the experimental electrostatic precipitator (Lurgi system) this could be reduced to from 10 to 50 mg/Nm^3. According to data from the Lurgi company, 5 mg/Nm^3 are achieved by hooking up a second precipitator.

The dust which essentially consists of metallic iron, iron oxides and carbon is able to take up accompanying elements of the coal and of the iron bath, respectively, in higher concentration.
This especially applies to sulphur, but also to chlorine, fluorine and to further elements. It is quite certain that the high purity of the coal gas is achieved by virtue of the dust's gettering function. Also heavy metals, as for example lead and zinc, will accumulate in the dust so that it seems possible that on this basis a process could be developed to recover valuable metals. The dust fractions can be fed back into the gasification process via a recirculation plant. Such facility was constructed within the scope of the subsidized research programme and has been successfully taken into operation. In this way major material losses through dust output can be prevented too.

2.3.9. Coarse spatter and scab formation

It is well known that steel converters, depending on the blowing conditions, discharage spatter in the form of iron and slag droplets. In the case of the intermittent by working steelmaking operations the converter spatter collects in the form of scabs on the adjusting collar and in the chimney during the blowing sections. During the staying times these scabs will drop off through cooling and shrinkage. In continuous operation, however, as in the case of coal gasification, specific measures must be instituted to eliminate the spatter.

Two possible ways can be considered:

- application of a conventional technology, i.e. institution of constructive measures in the area of the gasifier mouth

or

- modification of gasifier geometry, i.e. changing over to a horizontal construction form.

Since October 1984 such a drum-type vessel with about 10 metric tons iron content is available in the Maxhütte for carrying out corresponding experiments. Also gasification under pressure (4 bar) is researched there.

Fig. 8 shows this pilot converter.

Since in the Maxhütte large-scale plant constructive modifications on this scale could not be carried out within the scope of acceptable expenditures, until now only a semi-continuous mode of operation was possible. In so doing coal gasification sections of maximum 1 - 1 1/2 hours duration were alternated with converter holding times. The holding times were used for temperature measurements and for taking steel and slag samples. This semi-continuous mode of operation was not dictated by the process but was purely due to specific plant conditions. The information gathered from the Maxhütte large-scale plant over brief phases of gasification were found to be transferable to continuous mode of operation without restrictions.

2.3.10. Slag production and utilization

The task of slag in the iron bath during coal gasification is to stably bind the noxious constituents originating from the coal, especially the sulphur. This is ensured by the build-up of a lime-basic slag from coal ash in combination with intentionally introduced slag forming agents, in the case of the Maxhütte operation predominantly unhydrated lime (CaO). In view of the economical utilization of slag the sulphur content should not be higher than from 3 to 4 %. Generally speaking, a slag production in the order of magnitude of from 150 to 300 kg is to be expected per metric ton of coal throughput.

As indicated in the following table the composition of the slag is similar to that of the blast furnace slag.

Table 4.

Composition of slag

		Coal gasification slags Type A	Coal gasification slags Type B standard values	Blast furnace slags
SiO_2	%	21 - 30	30	34 - 41
Al_2O_3	%	7 - 13	12	10 - 13
CaO	%	42 - 54	40	34 - 45
MgO	%	5 - 20	as low as poss.	5 - 9
FeOx	%	1 - 4	2	1
S	%	1.5 - 3.5	3	1.1 - 1.5
CaO/SiO_2	%	1.6 - 2.0	1.3 - 1.4	0.8 - 1.3
$(S)/[S]$	%	15 - 170	30	20

In view of the possibility of economical utilization nowadays we are primarily aiming to produce the Type B slag. The iron and steel industry possesses comprehensive experience about blast furnace slags and their utilization in the cement industry and in the road construction industry. Although slag properties warrant harmless dumping the slag should
not be dumped, but should be utilized economically

- in granulated form for cement production
- in slowly solidified form for road construction (double broken and double screened chippings) and/or
- as fertilizer (fertilizing lime).

In this field Klöckner Kohlegas are working in close cooperation with the Forschungsgemeinschaft Eisenhüttenschlacken, Prof. Blunk, Rheinhausen. According to their test report the iron bath slags are rated as satisfactory for utilization as road construction material, fertilizer or raw material for cement production.

At the same time, however, the investigations on this field are not yet concluded. To some extent the results achieved on laboratory scale are yet to be repeated on large industrial scale.

2.3.11. Refractory lining of gasifier

In steelmaking practice pitch-saturated, low iron content magnesite bricks have been found suitable for lining the converters. It was shown, however, that this quality is less suitable for the coal gasification. Experiments with ceramic-bonded magnesite bricks, magnesite bricks with increased carbon content and with magtnesite-chromium qualities, resulted in distinctly longer refractory life.

A rate of wear of about 0.5 mm per operating hour was determined corresponding to an approximately 2000 hours of gasifier service life, with the customary 100 cm thick lining.

It should be pointed out, however, that this statement is based on test results obtained in intermittent operation, with alternating gasification and stand-by phases.

In the case of intermittent operation the refractory material is additonally exposed to temperature vaiations - which does not occur in the course of continuous operations - and which, quite certainly, would have a positive effect on the service life of the refractory lining. Continuous experiments planned in a small scale converter are expected to furnish proof of longer service life expectancy.

Further assistance for the selection of optimum brick qualities is also provided by Prof. Dr. Krönert, Head of the Institut für Gesteinshüttenkunde at the RWTH Aachen.

In principle, for a large-scale coal gasification plant an interchangeable vessel is intended so that relinings could be carried out at another location in the plant without the vessel blocking the gasification stand. For process economics, however, it could be more appropriate to recondition the gasifier more frequently, rather than to use very expensive refractory material.

3. Conclusion and Future Prospects

3.1. Immediate Future

Upon successful completion of the R+D programme in March 1984, Klöckner Kohlegas has applied for government subsidy of a direct follow-up project, in which the optimization of the results so far achieved will be continued. Authorization and approval for this second R+D package was received recently.

The total volume covers an amount of about 13 million DM for research and experiments to be carried out over a period of further 3 years from 1985 to 1987. Besides the optimization as explained above, this project will be extended by two important targets, namely

- establishment of an overall plant concept for a gas and steam power station with integrated iron bath gasification,

- processing of waste materials and residues of the chemical and petrochemical industry.

After completion of this supplementary programme we will dispose of comprehensive know-how gained in over 6 years' continuous research and experimental results. This potential will be the basis for the large-scale industrial application of the coal gasification process, mainly for power generating in the 90es.

In this connection we have recently started a joint programme with one of the internationally reputed contractors for power plants aiming at a large scale pilot plant. Coal gasification under pressure will be an essential part to permit the iron bath process to be combined with power generation.

3.2. Long-term outlook

In parallel to the R+D work accomplished until now, we have been active in projects for the construction of large scale demonstration plants in Germany as well as abroad. Potential locations are existing conventional oil- and coal-fired power plants as well as steel plants.

The utilization of the infrastructure and manpower generally available at iron and steel locations is of considerable advantage for the iron bath process implementation.
In Germany we have concentrated our efforts on the location of the Klöckner-Werke AG metallurgical complex at Bremen by way of utilizing the shut down open-hearth melt shop, and on the reconstruction of an oil-fired power station in Berlin. In both cases the projects were already fairly advanced in respect of feasibility and environmental authorization.

However, as we all know, economical conditions have changed over the past two years, mainly by a reduction in energy demands of the steel industry and also by a delay in realizing new processes to substitute oil and natural gas. Nevertheless, on account of the remarkable increase in the net efficiency, the long-term outlook for the iron bath process operating under pressure in combination with power generation via gas turbine and steam is in fact quite promising.

Apart from the outstanding environmental advantages, above all with respect to SO_2 and NO_x, the iron bath process will also be of great importance in the gasification of industrial waste and residues, the combustion or dumping of which is imposing serious problems. Among these are the wastes from the chemical industry, solvent residues, plastic wastes, oil-containing wastes, chlorinated hydrocarbons and sundry other materials.

For numerous problematic materials the iron bath reactor offers, apart from the possibility of non-hazardous disposal, chances of economical utilization. Insofar that the contents of sulphur and trace elements are the decisive factors, there is the possiblity of binding these in the slag and of enrichment in the iron bath or in the dust, with the further possibility of recovering valuable components (e.g. heavy metals).

We are at present undertaking joint efforts with reputed institutes as well as companies specialized in collection and disposal of waste materials, aiming at solutions to secure large scale gasification of the said components.

3.3. Coal gasification combined with smelt reduction

Another major area of our development is a dual-purpose process called KSG. This is a smelt reduction process for iron ores which are fed together with coal into the gasification vessel. Reduction of the iron oxides is achieved in molten state with optimum efficiency. This process, when fully developed under pressure should bring additional economic incentive to couple the iron bath with a combined cycle power station.

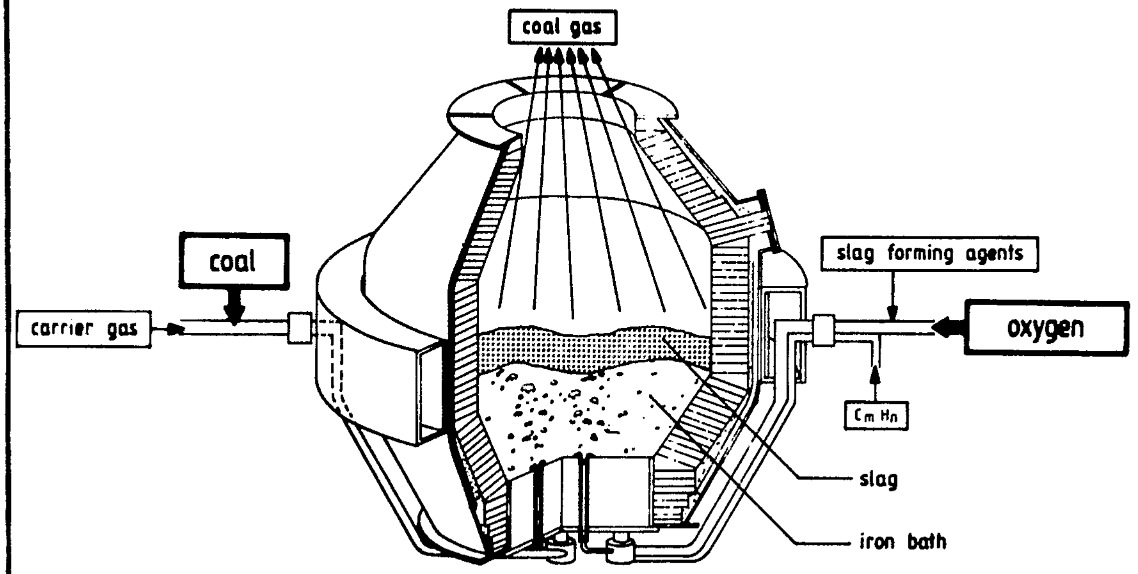

Figure 1 Coal Gasification in the Iron Bath Elementary Diagram

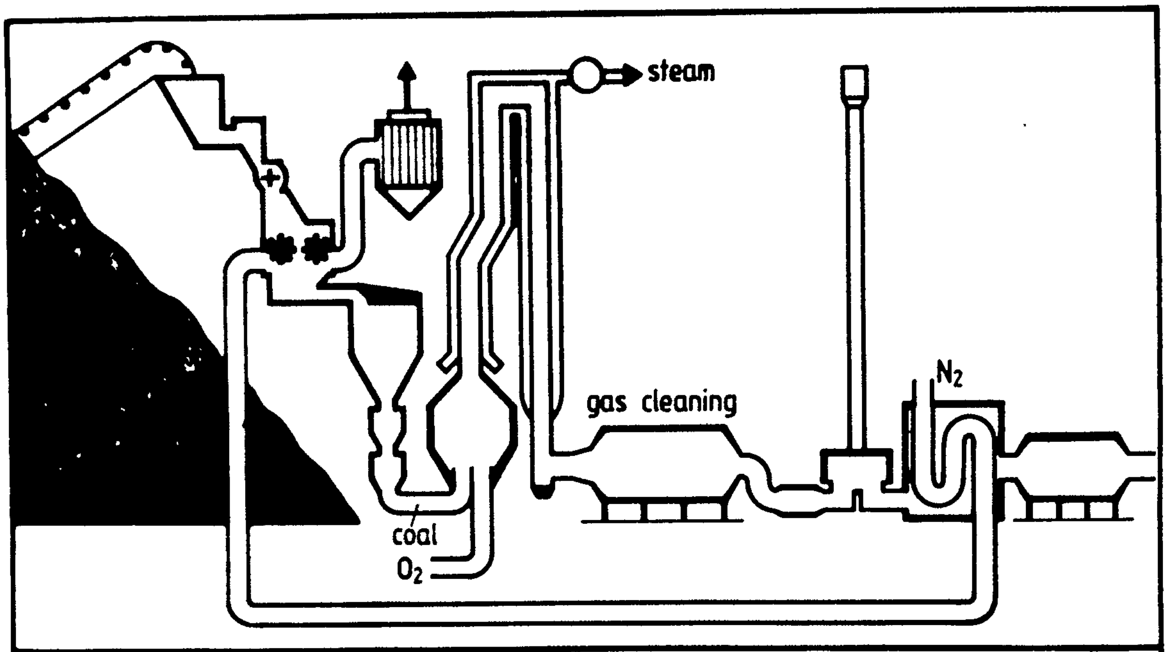

Figure 2 Coal Gasification in the Iron Bath Reactor Process Schematic

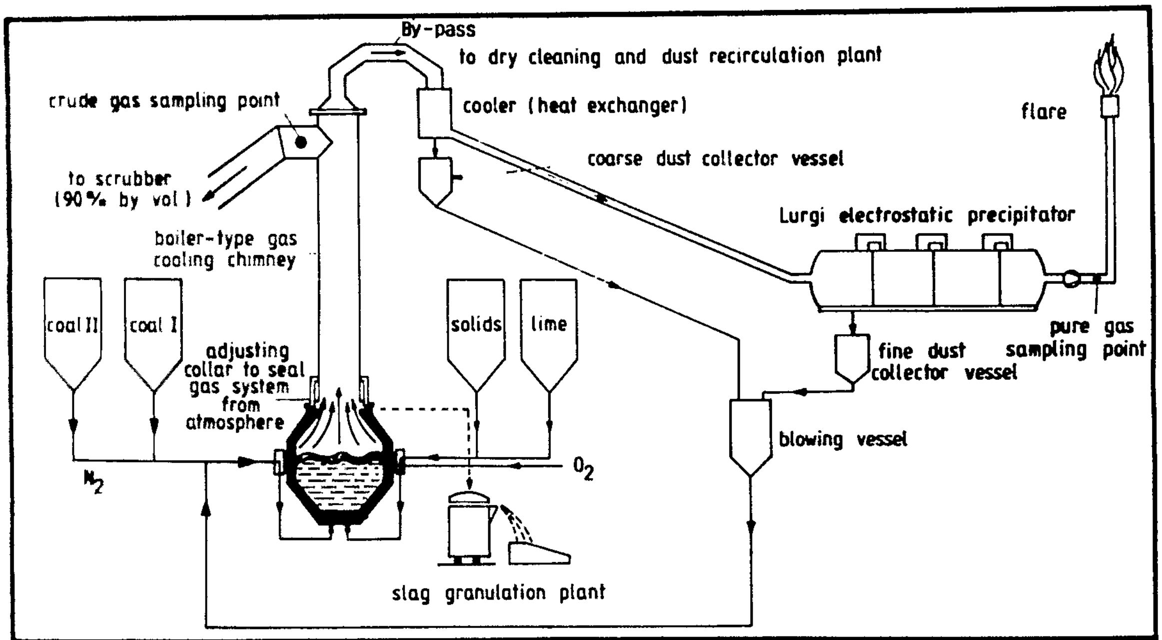

Figure 3

Coal Gasification in the Iron Bath
Process Schematic of the Maxhütte Pilot Plant

Figure 3a - Maxhütte Steelmaking Shop

General View

Figure 4 - Coal Injection System

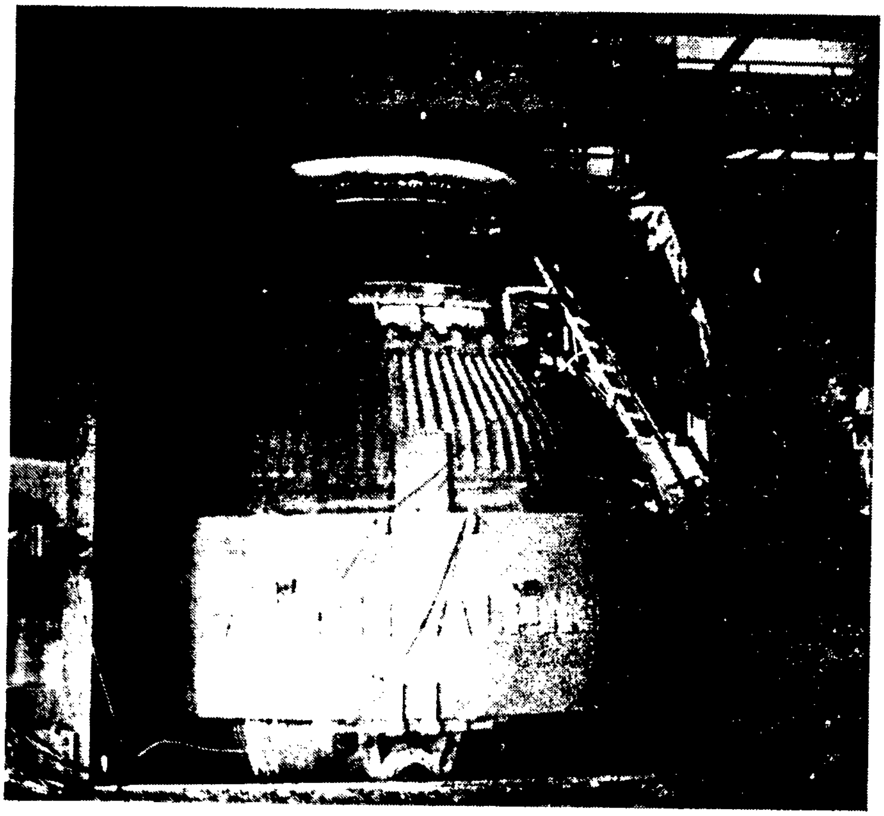

Figure 5 - Reactor Vessel

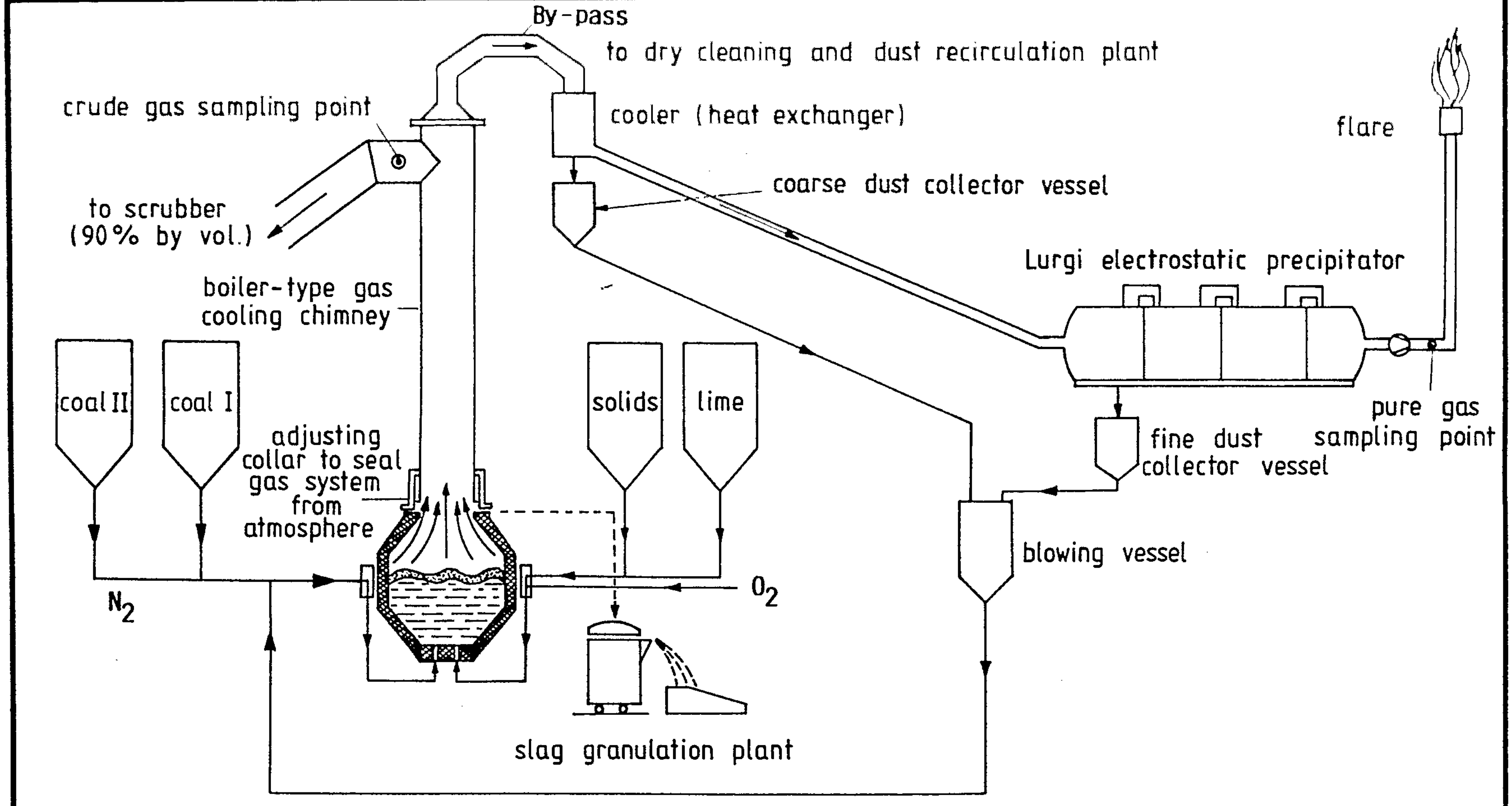

Figure 6

Coal Gasification in the Iron Bath
Process Schematic of the Maxhütte Pilot Plant

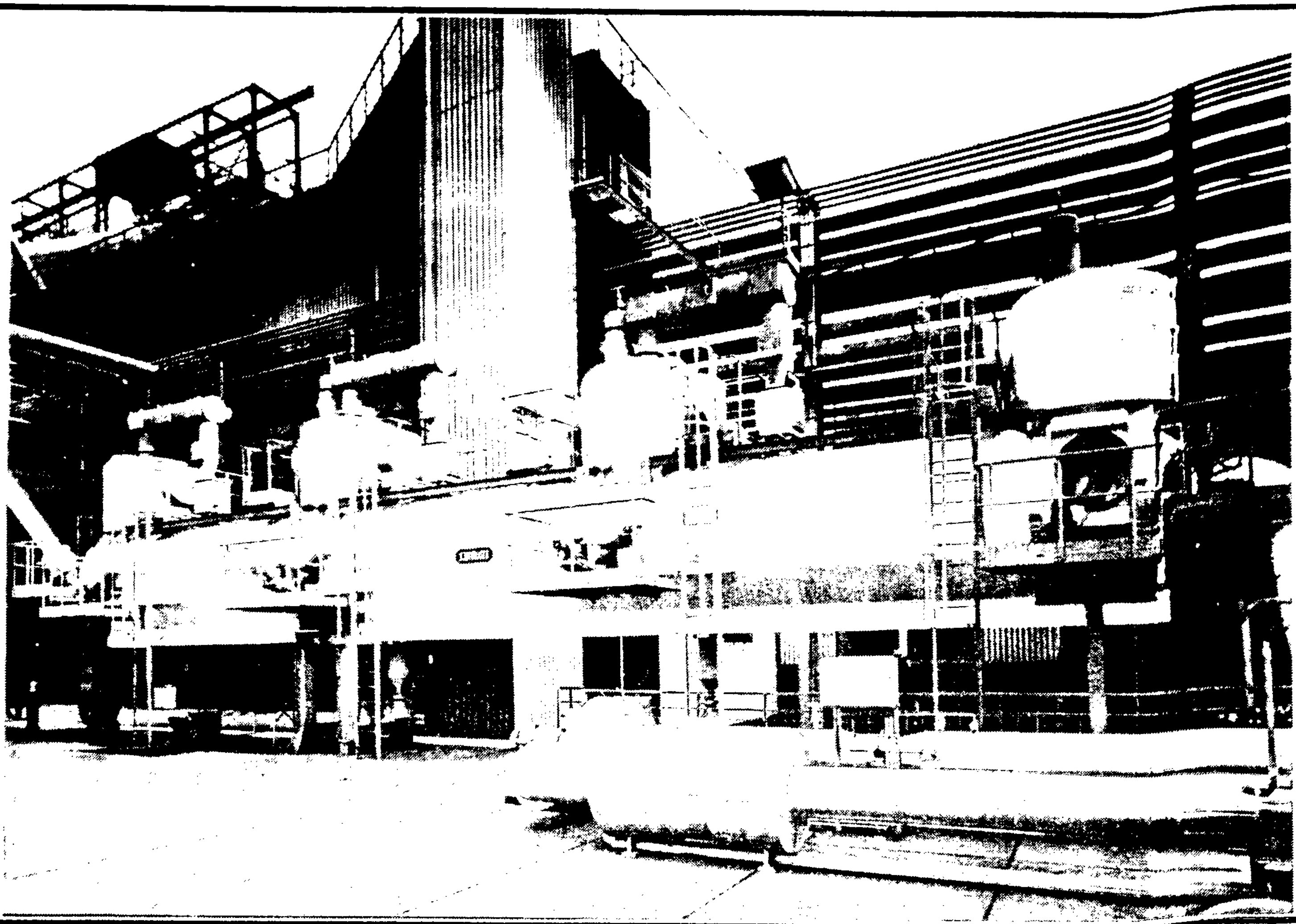

Figure 7 - Electrostatic Precipitator

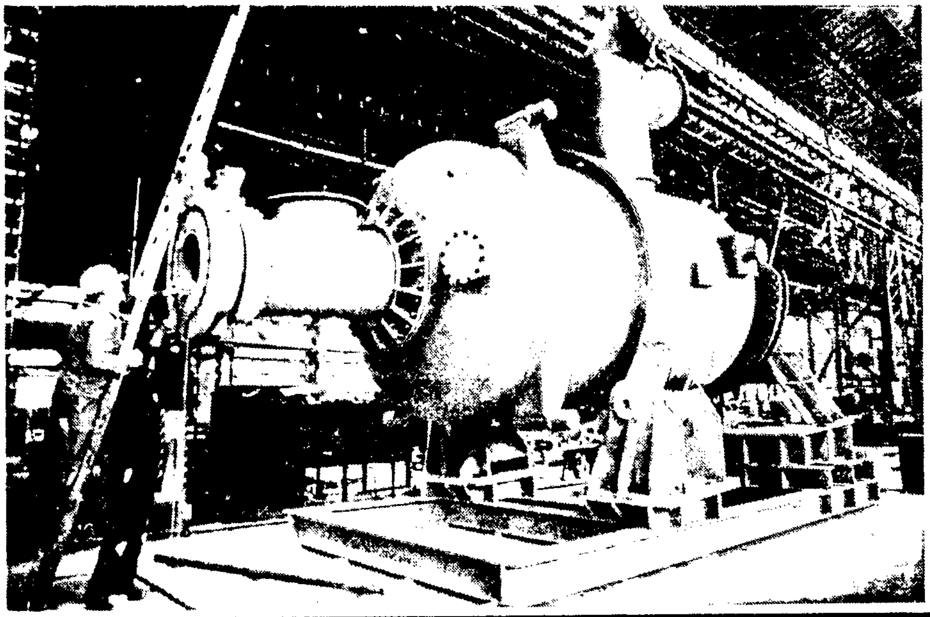

Figure 8 - Pilot Converter