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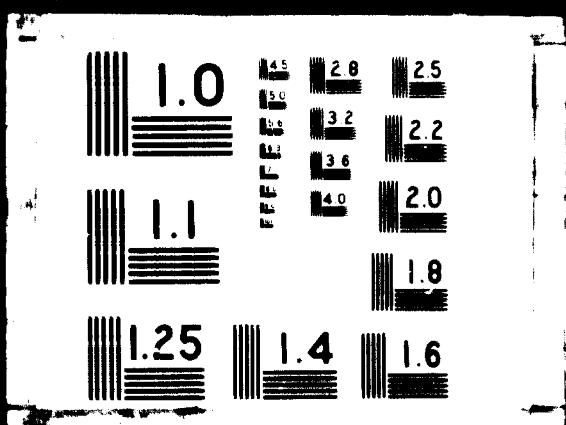

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Second Interregional Fertiliser Symposium

Kiev, USSR, 21 September - 1 October 1971
New Delhi, India 2 - 13 October 1971

Agenda item III/1h

SUMMARY

AMMONIA PRODUCTION ON THE BASIS OF COAL AND LIGNITE -- TECHNICAL AND ECONOMIC ASPECTS[1]

by

Eberhard Cocke

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The method of producing ammonia on a commercial scale through catalytic synthesis has been known for almost 60 years. Initially, the synthesis gas necessary for this was produced from coke.

Several processes for the production of Synthesis gas directly from coal or lignite which have been used as a basis for large commercial plants are described.

The Winkler gasifier with fluidised bed,

The Lurgi pressure gasifier which gasifies the coal in a fixed fuel bed in counterflow, and

The Koppers-Totzek gasifier which gasifies the coal in suspension concurrently, at high temperatures.

An existing plant for the production of ammonia using brown coal as feedstock, is described in detail.

A comparison of the most important operational cost figures for the production of ammonia is given when using lignite, coal, fuel oil, and naphtha. The capital costs

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including ancillary units for the corresponding plants are stated. The capital and operating costs have been determined and the production costs for 1 ton of ammonia have been shown by comparing the various feedstocks, based on the price of the feedstocks free works. Some general reasons for favouring the selection of coal or lignite as feedstock for the production of ammonia are shown.

Finally, an example of the annual foreign currency expenditure for the production of 1000 tons/day NH_3 is shown for a case where indigenous coal is available and fuel oil or naphtha, respectively, have to be paid for with foreign currency. As a comparison, also the annual foreign currency expenditure is stated which would be necessary for importing 1000 tons/day liquid ammonia.

Thus, it is evident that even today, the production of ammonia from lignite or coal can be advantageous and economical if certain prerequisites are fulfilled as is particularly the case in developing countries with own coal deposits.

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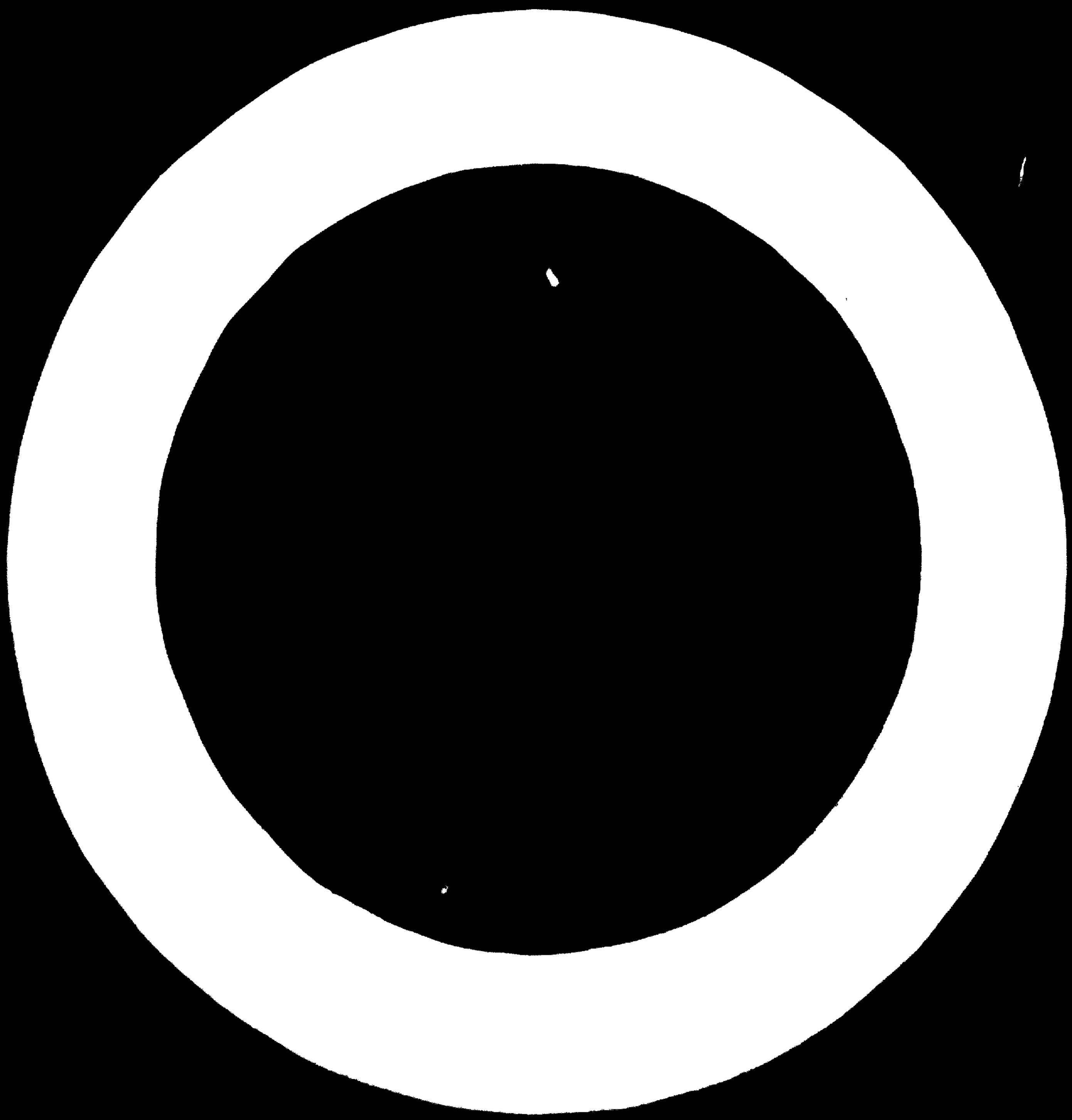

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I. HISTORY

1. The method of producing ammonia on a commercial scale from hydrogen and nitrogen by catalytic synthesis has been known for nearly 60 years. In the first few decades, the hydrogen required for the synthesis of ammonia was almost exclusively manufactured in coal based plants, where the synthesis gas was produced from coke oven gas or direct from coal.

2. In the course of time, particularly in the period following the Second World War, natural gas and petroleum fractions - predominantly fuel oil and naptha - were introduced to produce synthesis gas for the synthesis of ammonia. The chief reason for this was the favourable price of petroleum and natural gas compared to the price of coal.

II. VARIOUS COAL GASIFICATION PROCESSES

3. Although most of the ammonia manufactured throughout the world today is produced in petroleum and natural gas based plants, many lignite and coal based plants have been built in recent years.

4. A description is given of three processes for producing ammonia synthesis gas from solid fuels which have been used for the construction of large commercial plants after the Second World War.

Winkler Gasifier

5. The Winkler Gasifier (Figure 1) is a gasifier in which predominantly small size brown coal or soft coke from brown coal is gasified with oxygen and steam under normal pressure in a fluidized bed. [1] [2] A typical crude gas analysis at the outlet of the gasifier is shown in Table I.

6. In the last two decades, the following ammonia synthesis plants, using Winkler Gasifiers, have been built:

	Ammonia Production	Year
Azot Gorazde, Yugoslavia	50 t/24 h	1950
Empresa Nacional Calvo Sotelo, Puertollano Works, Spain	140 t/24 h	1950
Azot Sanayii TAS., Kütahya Works, Turkey	120 t/24 h	1950
Neyveli Lignite Corporation, Neyveli Works, India	300 t/24 h	1959

7. Further Winkler Gasifiers have been installed during this period in the USSR, CSSR and Bulgaria. Portatius [3] has reported on the new developments of the Winkler Gasifier in the Leuna Works, German Democratic Republic.

Lurgi Pressure Gasifier

8. A further process for the production of synthesis gas for the synthesis of ammonia is the Lurgi Pressure Gasification Process [4]. Figure 2 shows a sectional view of a Lurgi Gasifier. With this process, lignite or bituminous coal, over 3 mm in size, is gasified in counterflow with oxygen and steam at a pressure of about 30 atü in a fixed bed on a grate. A typical crude gas analysis at the outlet of the gasifier is shown in Table I.

9. An advantage of the Lurgi Pressure Gasification Process is the saving of compression energy due to implementation of the process under pressure, because only the gasification oxygen need be compressed, and not the essentially larger amount of synthesis gas produced. The crude synthesis gas, however, contains methane and higher hydrocarbons. In the course of gas treatment, these constituents must be removed. The methane fraction can be separated and also reformed to synthesis gas through catalytic steam reforming, for example.

10. The following ammonia synthesis plants, using this process, have been built:

	Ammonia Production	Year
Daudkhel, Pakistan	60 t/24 h	1956
Naju Fertilizer, Korea	150 t/24 h	1962

In South Africa, there is a very large synthesis gas plant with Lurgi Pressure Gasifiers in which synthesis gas is produced for the synthesis of hydrocarbons. Tail gas from the hydrocarbon synthesis plant is processed to ammonia there. Furthermore, plants for the production of fuel gas (town gas) have been built.

Koppers-Totzek Coal Dust Gasifier

11. A third process for gasifying lignite and coal is the Koppers-Totzek Coal Dust Gasification Process [5]. Figure 3 shows a Koppers-Totzek Gasifier. A mixture of coal dust and oxygen and, if necessary, a small amount of steam, is fed to the gasifier from several sides through special burners. Partial oxidation of the coal dust takes place in concurrent flow at normal pressure. Adjacent to the burner, temperatures of about 2,000°C prevail. The produced synthesis gas leaves the reactor at a temperature of about 1,500°C. Subsequently, the heat of the synthesis gas is utilised in a special steam boiler for the production of high pressure steam.

12. Due to the high reaction temperatures, the synthesis gas does not contain higher hydrocarbons. The methane content of the gas is only about 0.02 Vol. %. Depending on the reactivity of the coal, up to 99% of the carbon is gasified. Practically any type of coal can be gasified, independent of size, caking quality, etc. A typical gas analysis at the outlet of the gasifier is shown in Table I.

13. Coal based Koppers-Totzek plants for the production of synthesis gas for the synthesis of ammonia have been built, as follows:

	Ammonia Production	Year
Typpi Oy., Oulu Works, Finland	120 t/24 h	1950
Nihon Suiso Kogyo Kaisha, Ltd., Onahama Works, Japan	100 t/24 h	1954
Empresa Nacional Calvo Sotelo, Puentes Works, Spain	100 t/24 h	1954
Chemical Fertiliser Co., Ltd., Mae Moh Works, Thailand	100 t/24 h	1963
Azot Sanayii TAS., Kütahya Works, Turkey	340 t/24 h	1966
Nitrogen Chemicals of Zambia, Kafue Works, Zambia	100 t/24 h	1967
Nitrogenous Fertilizers Industry S.A., Ptolemais Works, Greece	405 t/24 h	1969
The Fertilizer Corporation of India Ltd., Ramagundam Works, India	900 t/24 h	under construction
The Fertilizer Corporation of India Ltd., Talcher Works, India	900 t/24 h	under construction

III. EXAMPLE OF A PLANT CONSTRUCTED

14. In the following, the production of ammonia from coal is described in detail, using a plant already constructed as an example. The plant described is the Kütahya Plant of Azot Sanayii TAS, Ankara, Turkey, which produces 340 tons ammonia per day.

15. Figure 4 shows a simple block diagram of the plant. It illustrates that only raw brown coal, water and electric power are necessary for the production of ammonia; and, of course, small amounts of chemicals and catalysts.

16. The composition of the raw brown coal charged is shown in Table II. The raw water is supplied from wells adjacent to the Works. The cooling water is recirculated and recooled. The boiler feed water is produced in an ion exchanger unit. The complete ammonia unit is self-sufficient with regard to steam, and the electric power is supplied from the local power grid.

Coal Preparation Unit

17. The coal is supplied to the Works in railway wagons from an open-cast mine about 15 km away. An open coal storage unit is provided in the Works, which can stock coal to cover a period of about 6 weeks. From the storage unit, the coal is passed via a crusher, where it is broken to a size of below 30 mm, to the coal crushing and drying unit. In this unit, the coal is dried from a water content of about 45% to about 8% and is crushed in a tube mill to a fineness of 80% under 0.09 mm. The dust contained in the waste gas from the drying unit is almost completely removed in electrostatic precipitators to fully suffice regulations governing the prevention of environment pollution. The coal crushing unit comprises two streams, each for 60% of the total capacity. The brown coal dust produced is fed to the gasification plant pneumatically.

Air Fractionation Unit

18. The oxygen necessary for the gasification plant, and the pure nitrogen required for the synthesis gas mixture, are recovered in an air fractionation plant. The air fractionation plant consists of two streams, each for 60% of the total capacity.

Gasification Plant

19. The gasification plant (Figure 5) consists of 4 Koppers-Totzek gasifiers, 3 for operation and 1 as standby. A special feature is the high degree of carbon gasification; in the Kütahya Plant it is about 99%, although the ash content of the coal, referred to dry coal, is between 35 and 40%.

20. The larger part of the coal ash in the gasifier is liquid, and flows off in a continuous stream. In the ash extractor under the gasifier, the ash flows into a water bath where it is granulated to a size of about 3 - 5 mm. This slag is free of carbon, causes no dust and is suitable for making roads and paving.

21. A minor part of the coal ash is entrained with the gas passing through the waste heat boiler downstream the gasifiers, and is subsequently removed with water in scrubbers and mechanical washers. The wash water is circulated through the settling tanks and cooling tower. The sludge accumulated in the settling tanks is pumped through a pipeline to a disposal point about 2 km from the plant. The cooling water discharged from the cooling water circuit is utilized as make-up water for the wash water circuit, so that there is no additional water consumption in the wash water system.

22. The entire low pressure section (coal preparation unit, wash water system and gasification plant) is monitored and serviced from a central control unit (Figure 6).

Gas Treatment and Ammonia Synthesis Units

23. From the gasification plant, the gas is passed through a gas holder to the crude gas compressors, where it is compressed to a pressure of about 10 ata. The crude gas compressors are designed as turbo-compressors. Two compressors are provided, each with a capacity of 60% of the total capacity.

24. The gas is passed from the compressors to a Sulfinol desulphurisation plant in which the H_2S and organic sulphur contained in the gas are removed to a total sulphur content of below 20 ppm.

25. The gas is next conveyed to the high pressure compressors (piston compressors), which compress the gas to a pressure of about 500 atü necessary for the synthesis. Two compressors, each with a capacity of 60% of the total capacity, are provided.

26. After the first compression stage, CO conversion is carried out at a pressure of about 25 ata. Subsequently, the CO_2 is removed in a cold methanol wash, at about minus 45 °C. The cold methanol wash is combined with the post-installed liquid nitrogen wash, where the residual CO and other impurities are removed from the gas and the synthesis mixture $3H_2 + 1N_2$ is adjusted.

27. The synthesis of ammonia takes place at a pressure of about 500 ata. The synthesis circulation is effected by an injector fed with fresh high pressure synthesis gas. The ammonia synthesis plant is provided with a semi-cooled spherical ammonia tank, which can accommodate the ammonia produced in one week.

28. The entire high pressure section (Figure 7), including the air fractionation unit, is controlled and operated from a central control unit (Figure 8).

IV. COMPARISON OF OPERATIONAL FIGURES USING LIGNITE, COAL, FUEL OIL AND NAPHTHA

29. A comparison is now given of the most important operational figures for the production of ammonia when using the abovementioned feedstocks. Natural gas as feedstock has not been included in the comparison, because coal will hardly ever be considered as feed if natural gas is available locally.

30. The comparison was based on feedstocks with analytical data as shown in Table III. Table IV shows the consumption figures for feedstock, water and power referred to one ton NH_3. The consumption figures for lignite and coal are understood to refer to wet coal with water contents as stated in Table III.

V. COMPARISON OF ECONOMY

31. Hereinafter, we show the production costs for ammonia when using the feedstocks stated in Table III.

32. When determining the capital expenditure, plants for the production of 1,000 tons ammonia per day are used as a basis. In each case, facilities are provided for storing a month's supply of feedstock and a week's production of ammonia. Furthermore, the plant costs include units for steam production, cooling water recovery and feed water preparation, as well as the items necessary for the complete Works, such as the acquisition of land, tracks and roads, administration building, laboratories, repair workshops, and fencing, as well as erection and civil work.

33. The investment cost for a complete turnkey, 1,000 tons per day, ammonia plant for the various feedstocks is as follows:

For lignite	US$ 40 Mill.
For coal	US$ 39 Mill.
For fuel oil	US$ 30 Mill.
For naphtha	US$ 25 Mill.

34. The capital costs per ton ammonia have been calculated at a rate of interest of 7% and a 12 year amortisation period. The following considerations have been based on 8,000 operating hours per year.

35. The costs for feedstock, water and power, as well as chemicals and catalysts, servicing and administration have been taken into account when determining the operating costs. It is assumed that the necessary steam will be produced in the plant. The cost of electric power has been adapted in a suitable relation to the relevant cost per BTU of the feedstock. The capital and operating expenditure, calculated according to the aforementioned prerequisites, is plotted in Figure 9 against the cost of the various feedstocks. The cost of feedstock is understood free Works, that is, including the cost of transportation to the Works.

36. It can be seen that, with favourable coal prices, the production of ammonia from lignite or coal is quite competitive with fuel oil or naphtha. This applies particularly when the price of fuel oil or naphtha is burdened with transportation

costs, duty or taxes.

37. From a technical point of view, the production of ammonia from lignite or coal presents no problems. For all types of coal there are suitable gasification processes, the high standard of which has been proved beyond all doubt.

38. Moreover, considerations of national economy may favour the selection of coal as a basis for the production of ammonia. From a national point of view, the discovery of local coal deposits can offer many advantages, for instance, mining of the coal will provide additional jobs. Once the coal resources are being exploited, the coal can be used also for other purposes. In many cases, rational mining methods and favourable coal prices can only be achieved when a large consumer, for instance, a nitrogen plant, guarantees to accept large amounts of coal continuously. This means that coal will be available also to other consumers at favourable prices which, in turn, will attract other branches of industry to the area, and domestic coal can be supplied to the population cheaply. The construction of a nitrogen plant can be a great advantage to the development of a whole district.

VI. FOREIGN CURRENCY REQUIREMENT

39. In a country which has its own coal resources but, as mentioned above, no crude oil, also the shortage of foreign currency can favour the use of coal. Table V shows the foreign currency requirement for the construction and operation of ammonia plants using various feedstocks. For lignite and coal, it is assumed that 50% of the total investment costs will have to be paid in foreign currency by a credit, to be paid back over a period of 12 years, on which an interest of 7% per annum will be charged. This results in an annual capital service for depreciation and interest of 12.6% of the plant capital. In the case of fuel oil and naphtha, it is also assumed that 50% of the total investment costs will have to be paid through a foreign currency credit, as above, and that the fuel oil or naphtha will have to be procured with foreign currency. For fuel

oil, it is assumed that a foreign currency portion of US$ 12 per ton, and for naphtha US$ 24 per ton, will be required.

40. It can be recognised that, under the abovementioned conditions, a coal based plant will require considerably less foreign currency than a plant for which the feedstock has to be procured with foreign currency. To complete the data, the foreign currency which would be required to import liquid ammonia, has been entered in Table V. US$ 40 per ton has been assumed as foreign exchange portion of the price of ammonia.

VII. SUMMARY

41. The production of synthesis gas based on coal or lignite, known for many decades, has been continuously developed and has now reached a technical standard corresponding to that of the modern chemical industries. Although nowadays the bulk of ammonia is produced on the basis of natural gas or mineral oil products which in most parts of the world are cheap as compared with coal, nevertheless coal or lignite based plants have been built time and again quite recently. Several plants are at present under construction. The manufacture of ammonia from coal or lignite can be economically competitive even today, especially if cheap solid fuels are available and mineral oil products are encumbered with high transportation costs and other charges. Also general and overlying aspects may favour the choice of solid fuels as feedstock for the synthesis of ammonia, such as the saving of foreign exchange. In countries with resources of cheap solid fuel, the production of ammonia on the basis of this indigenous raw material should be seriously taken into consideration.

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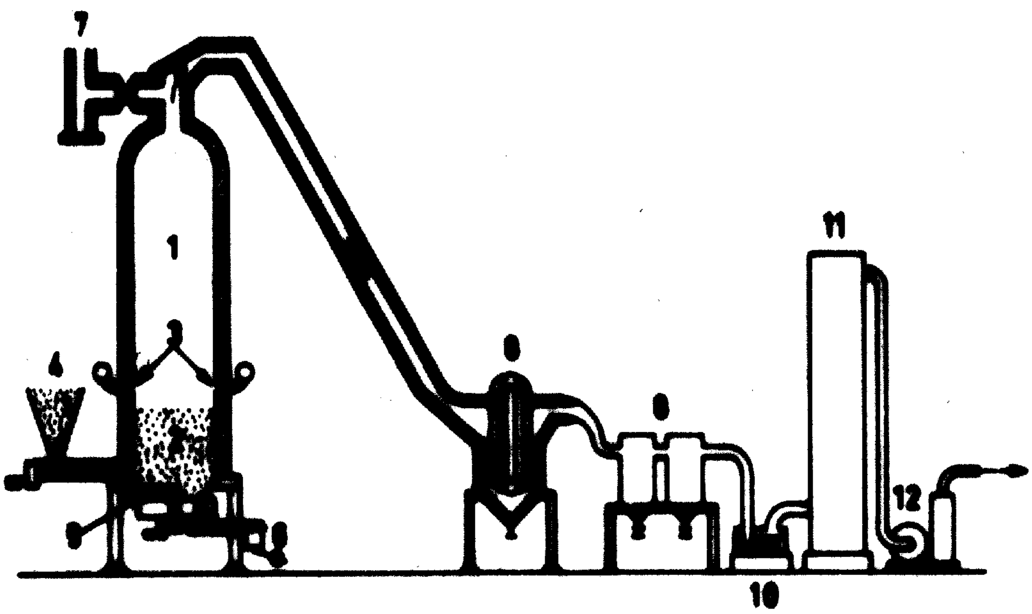
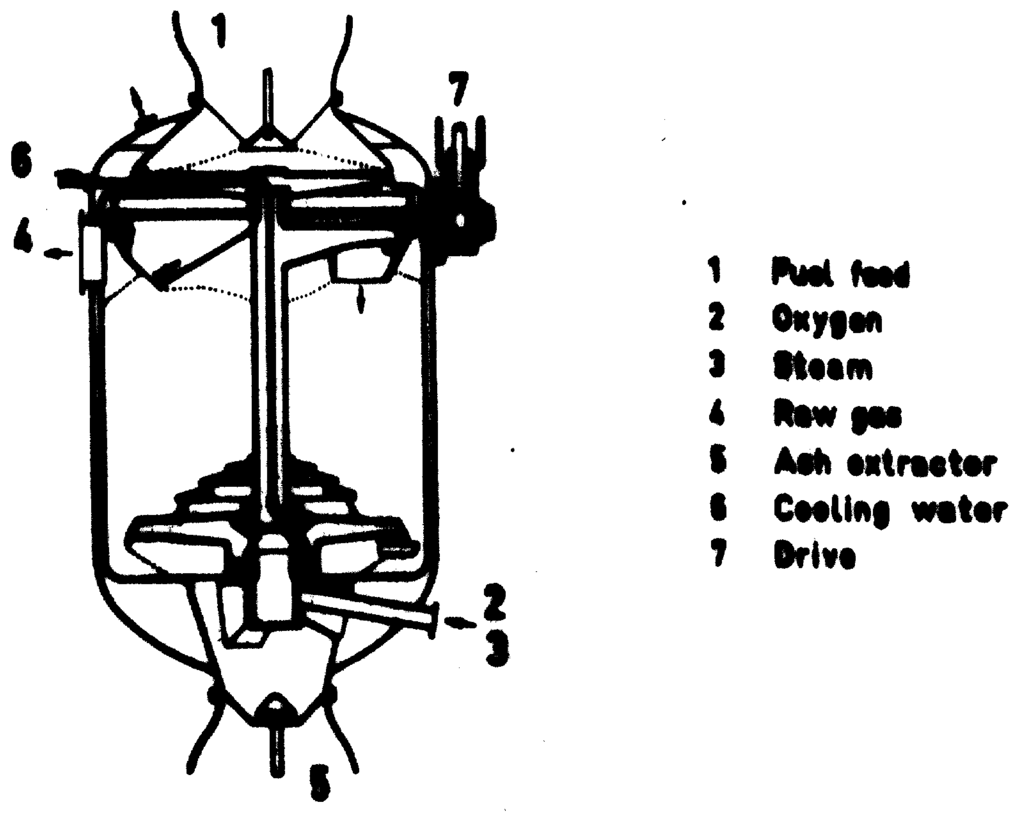


1	Winkler gasifier	7	Flare
2	Fluidized bed	8	Waste heat boiler
3	Top nozzles	9	Dust separator
4	Fuel feed	10	Receiver
5	Agitator	11	Washer
6	Ash extractor	12	Disintegrator

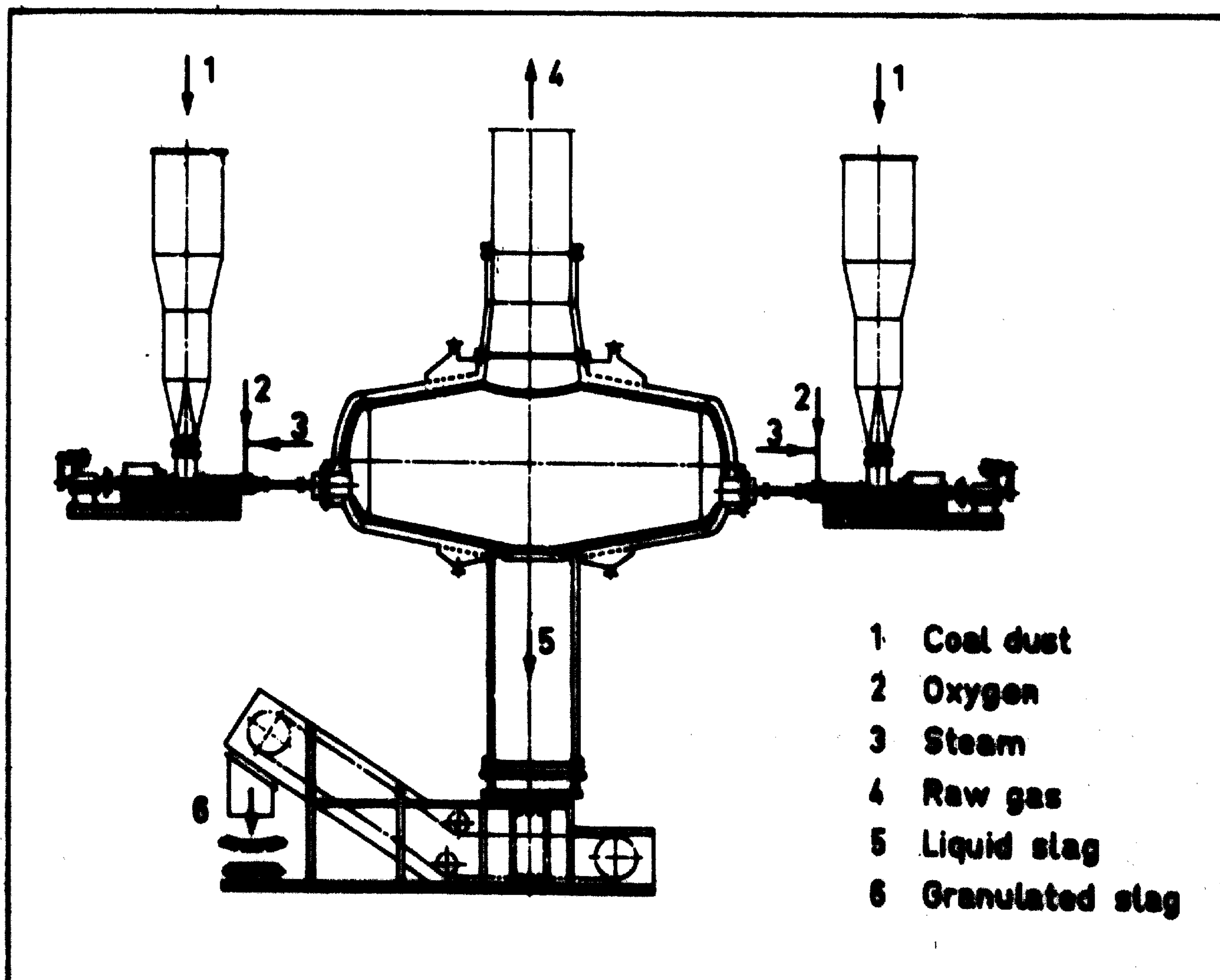
Winkler Producer Plant

Figure 1

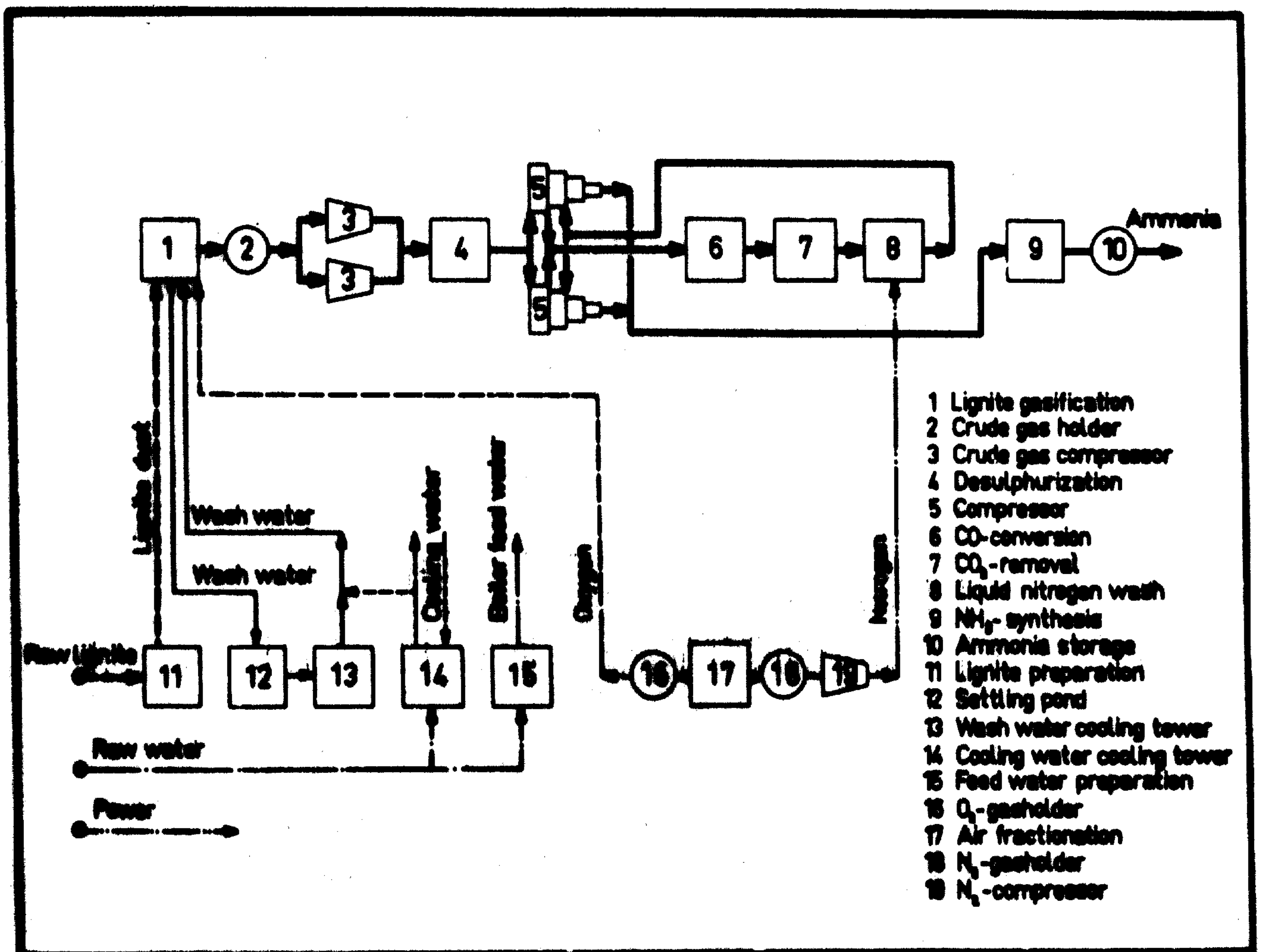


Lurgi Pressure Gasifier

Figure 2

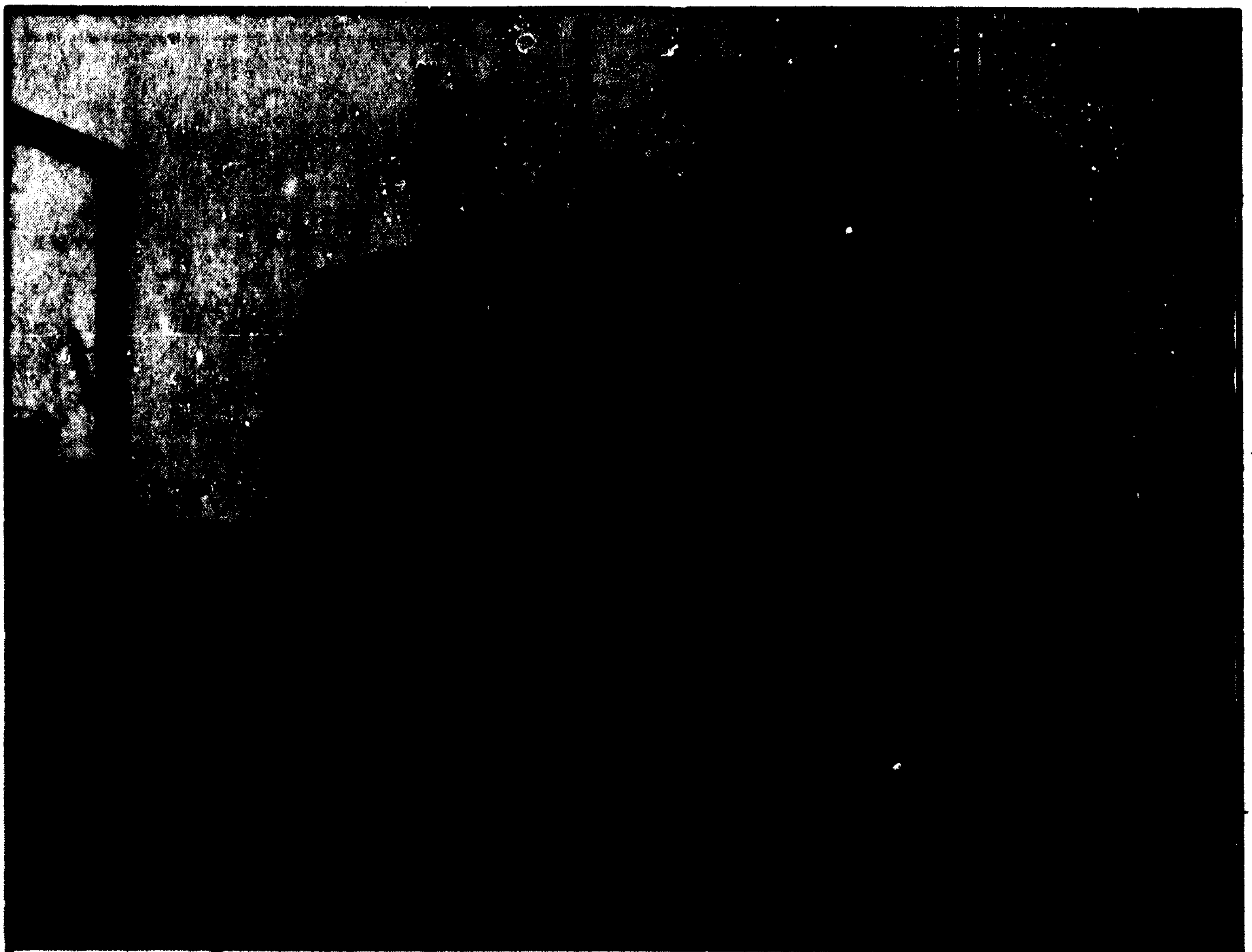


	Koppers-Totzek Gasifier	Figure 3



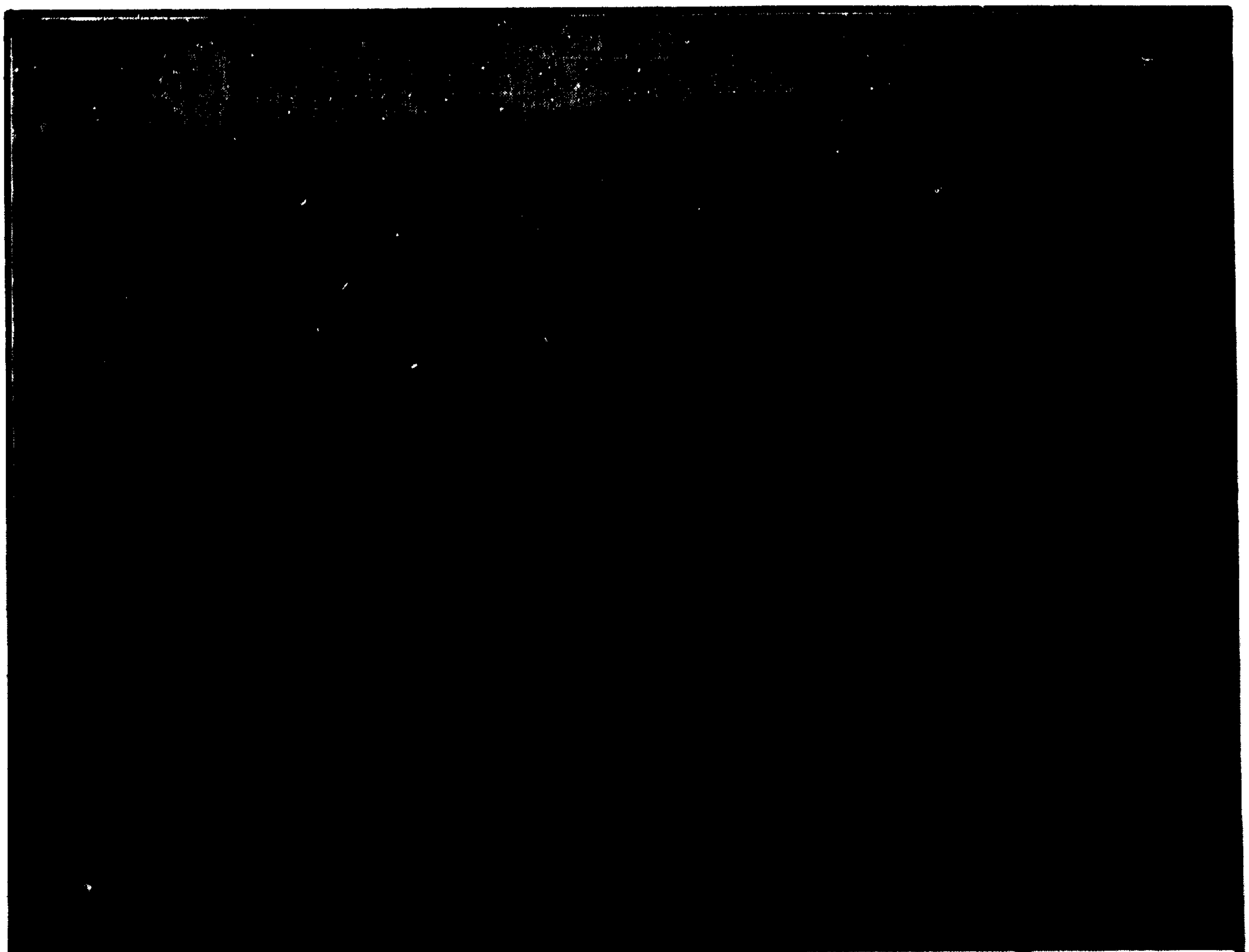
Ammonia Plant

Figure 4



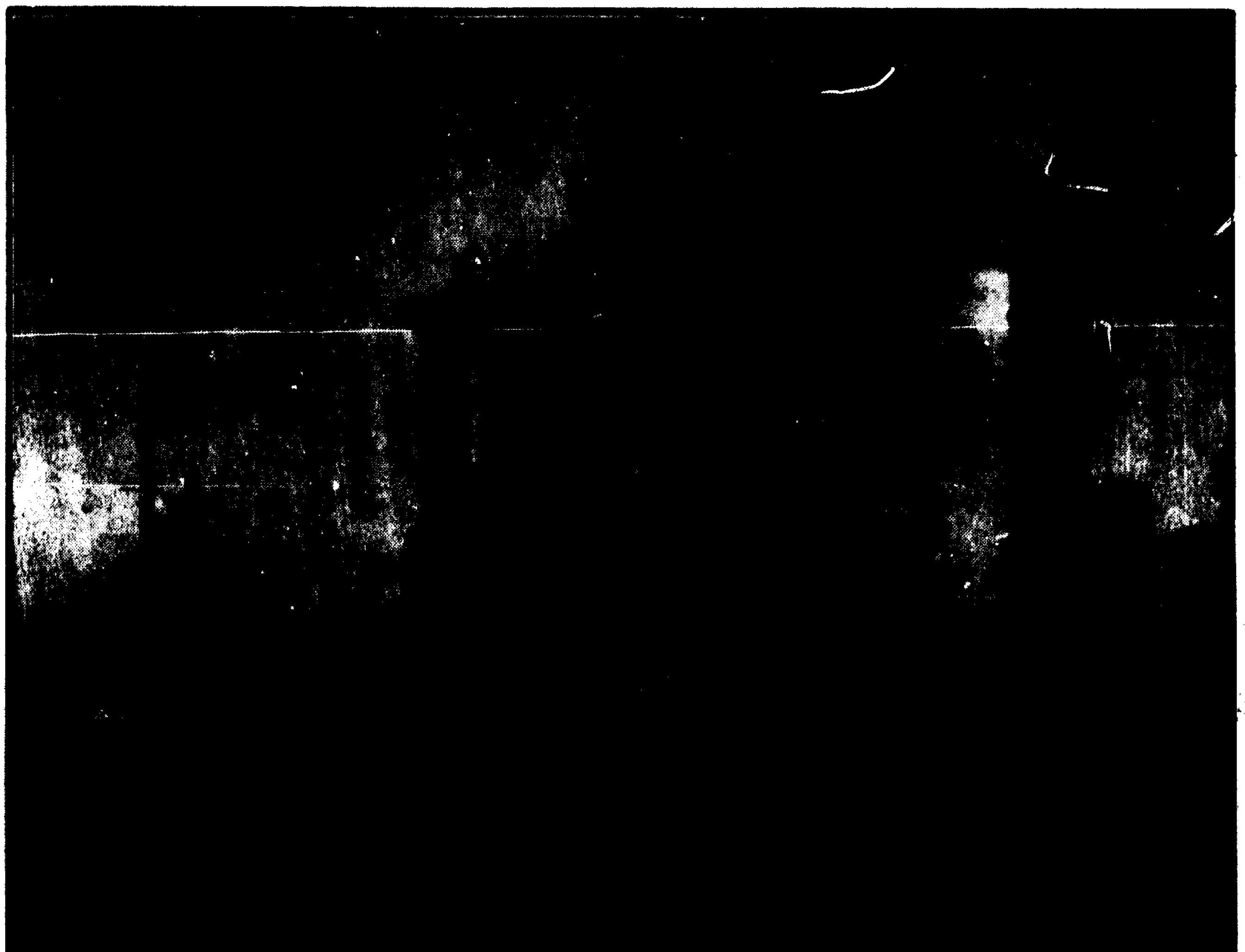
Gasification

Figure 5



Control Room LP-Units

Figure 6

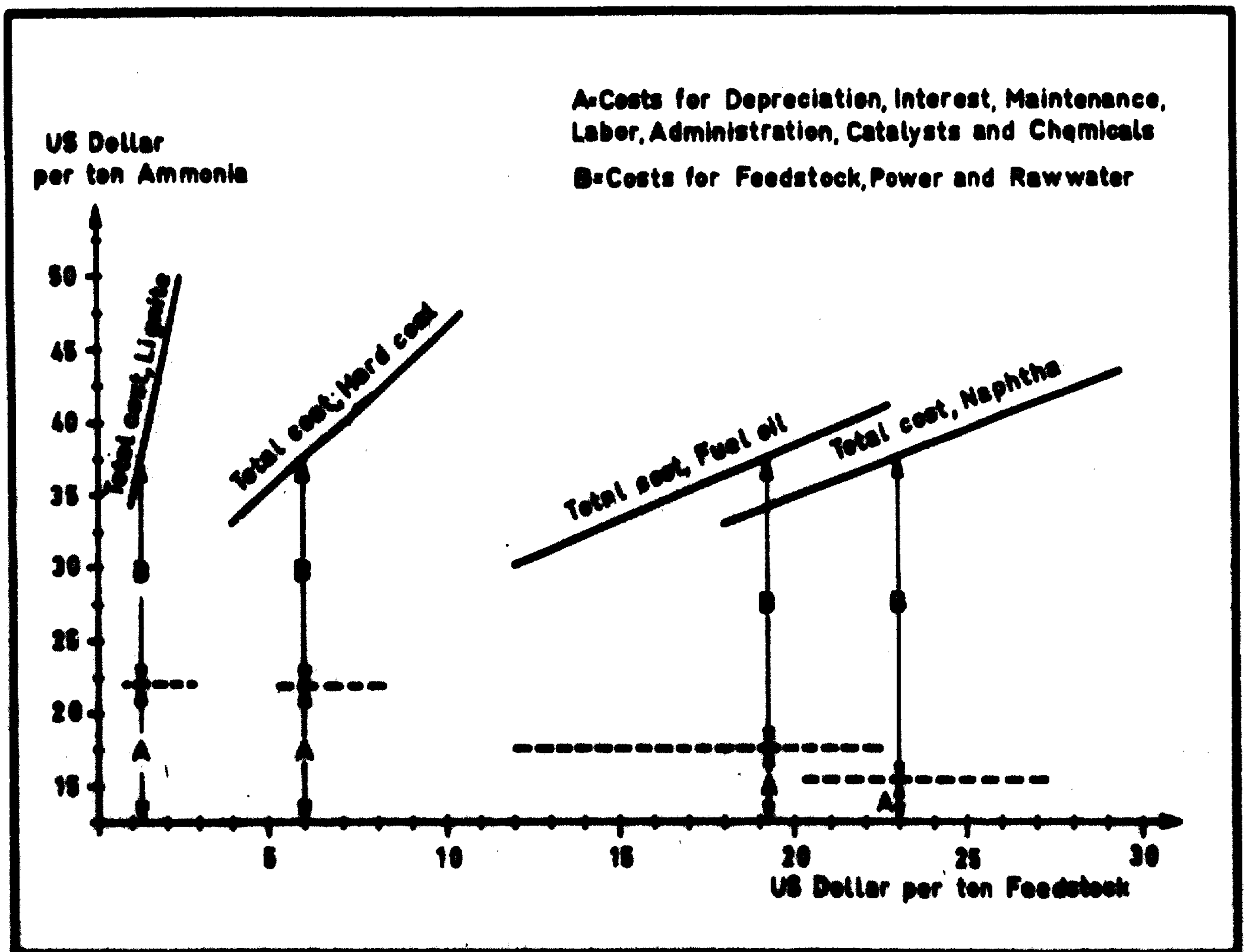


Gas Treatment and NH_3-Synthesis

Figure 7

Control Room HP-Units

Figure 8



Cost per ton Ammonia

Figure 9

		Winkler Gasifier	Lurgi Pressure Gasifier	Koppers-Totzek Gasifier	
Feedstock		Browncoal Coke	Hardcoal	Hardcoal	Lignite
Crude Gas Analysis					
CO_2+H_2S	% vol.	18,4-26,0	28,0-32,3	12,0	13,0
O_2	"		0,0- 0,01	Traces	Traces
CnHm	"		0,2- 0,2	-	-
CO	"	30,0-40,0	22,4-16,4	58,1	55,9
H_2	"	40,0-46,0	38,0-39,4	28,3	29,0
CH_4	"	1,0- 1,5	10,9-11,3	0,1	0,1
N_2+Ar	"	0,5- 1,5	0,5- 0,4	1,5	2,0

Crude Gas Analyses

Table I

Lignite Analysis

Water	%wt.	33,0
Ash,wf.	%wt.	32,0
C waf.	%wt.	65,0
H "	"	5,8
S "	"	1,2
N "	"	2,0
O "	"	26,0
Total	%wt.	100,0

Ash Analysis

SiO_2	%wt.	46,0
Fe_2O_3	"	15,8
Al_2O_3+TiO_2	"	18,2
CaO	"	6,9
MgO	"	4,0
SO_3	"	5,5

Ash Melting Behaviour

Softening point	°C	1100
Melting point	°C	1150
Flow point	°C	1200

Kütahya Lignite — Table II

		Lignite	Hardcoal	Fuel Oil	Naphtha
Water	% wt.	52,50	2,40	-	-
Ash	"	15,45	15,23	0,07	-
C	"	20,83	67,72	84,60	84,00
H	"	1,62	3,87	11,30	15,96
S	"	0,86	0,57	3,50	0,04
N	"	0,64	1,65	0,40	-
O	"	8,10	8,56	0,13	-
Sum-Total	% wt.	100,00	100,00	100,00	100,00
Lower Heating Value	kcal/kg	1 970	6 300	9 840	10 380

Feedstock Analyses — Table II

		Lignite	Hardcoal	Fuel oil	Naphtha
Lignite	kg	8700	-	-	-
Hardcoal	kg	-	2200	-	-
Fuel oil	kg	-	-	940	-
Naphtha	kg	-	-	-	880
Power-current	kWh	485	330	180	140
Raw water	m^3	20	18	8	11

Consumption Figures per ton Ammonia

Table II

Feedstock	Lignite	Hardcoal	Fuel Oil	Naphtha	Ammonia
Foreign exchange requirement per year for interest and repayment of foreign exchange credit for investment costs	5,04	4,91	3,78	3,02	-
Foreign exchange requirement per year for foreign exchange portion of feedstock	-	-	3,75	7,12	13,35
Total foreign exchange requirement per year	5,04	4,91	7,53	10,14	13,35
Total foreign exchange requirement in 12 years	60,48	58,92	90,36	121,68	160,20
Annual foreign exchange requirement after repayment of foreign exchange credit for investment costs	-	-	3,75	7,12	13,35

Foreign exchange requirements in mill.US $
for 1000 tons/day ammonia plants

Table [illegible]

8. 8. 73