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Ammonia from Coal Projects

A TECHNICAL AND ECONOMIC REVIEW OF COAL-BASED AMMONIA PRODUCTION

Presented by

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Because of the natural gas shortage, there is concern about meeting U.S. fertilizer needs. Planning must take into account the possibility that natural gas will be either available only at very high cost or unavailable at any cost, so alternate fuels and feedstocks have to be considered. The problem is urgent. At least one-third of the food and fiber produced in this country is attributed to fertilizers with nitrogen being the nutrient of major importance. Practically all nitrogen fertilizer is made from ammonia, which is in turn made from natural gas. If natural gas is unavailable, and the ammonia production is lost, a substantial portion of the food and fiber produced in this country will be lost. Neither this country nor the world can tolerate such a situation.

The fertilizer industry uses only about 3 percent of the natural gas consumed in the U.S. However, the total picture indicates that natural gas reserves in the U.S. are said to be about 240 trillion cubic feet and total annual consumption to be about 22 trillion cubic feet. Even including gas resources due to increased production from known fields plus gas likely to be discovered in the future, most experts predict that our gas will be depleted during the next 30 years or so. Between now and then, we expect gas to become increasingly costly or unavailable to those on interstate (regulated) supplies.

During the winter of 1976-77, about 730,000 tons of ammonia production was lost because of natural gas curtailment. In 1975-76, about 350,000 tons was lost and before that, a significantly lesser amount. Ammonia production losses due to gas curtailment are therefore increasing rapidly so there is a pressing need to develop the technology and economics for using alternate feedstocks.

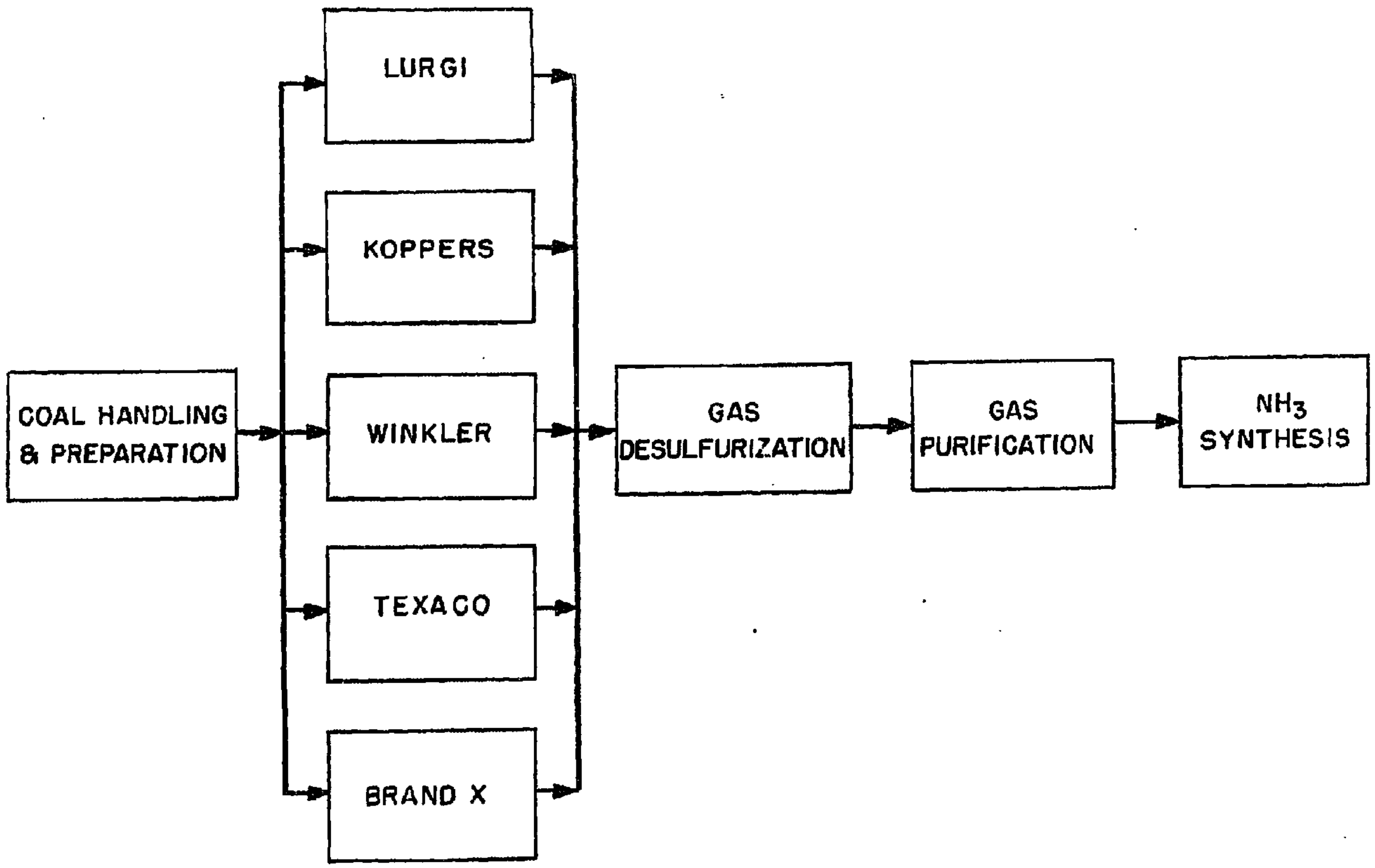
Naphtha or fuel oil could replace natural gas, but they are also scarce and are expensive. Coal represents the only viable alternative for the foreseeable future.

Coal has been used for years to produce ammonia. The Germans developed the technology before World War II, and the technology is still in use in Europe, Africa, and Asia. However, there is a need for the development and demonstration of U.S. technology using U.S. equipment, methods, and expertise.

During 1975 TVA and The Fertilizer Institute (TFI) identified the need to develop efficient U.S. technology for production of ammonia from U.S. coal as the number one priority need for the nation's fertilizer R&D. In August of 1975, TFI appealed to TVA's Board of Directors for TVA to undertake the development and demonstration of the production of ammonia from coal. About this time, other U.S. organizations also identified the solution to the ammonia feedstock problem as being the number one R&D need in the industry. TVA responded to this need and the Ammonia from Coal Project was initiated.

The initial problem was to define a course of action. In view of the uncertainties involved as to the most appropriate gasification process to be used, initial plans were to construct pilot plants (0.9 metric ton of coal per hour capacities) which would test and demonstrate five of the leading processes as shown in Figure 1. Common coal handling and preparation

FIGURE I
MULTIPROCESS PILOT PLANT

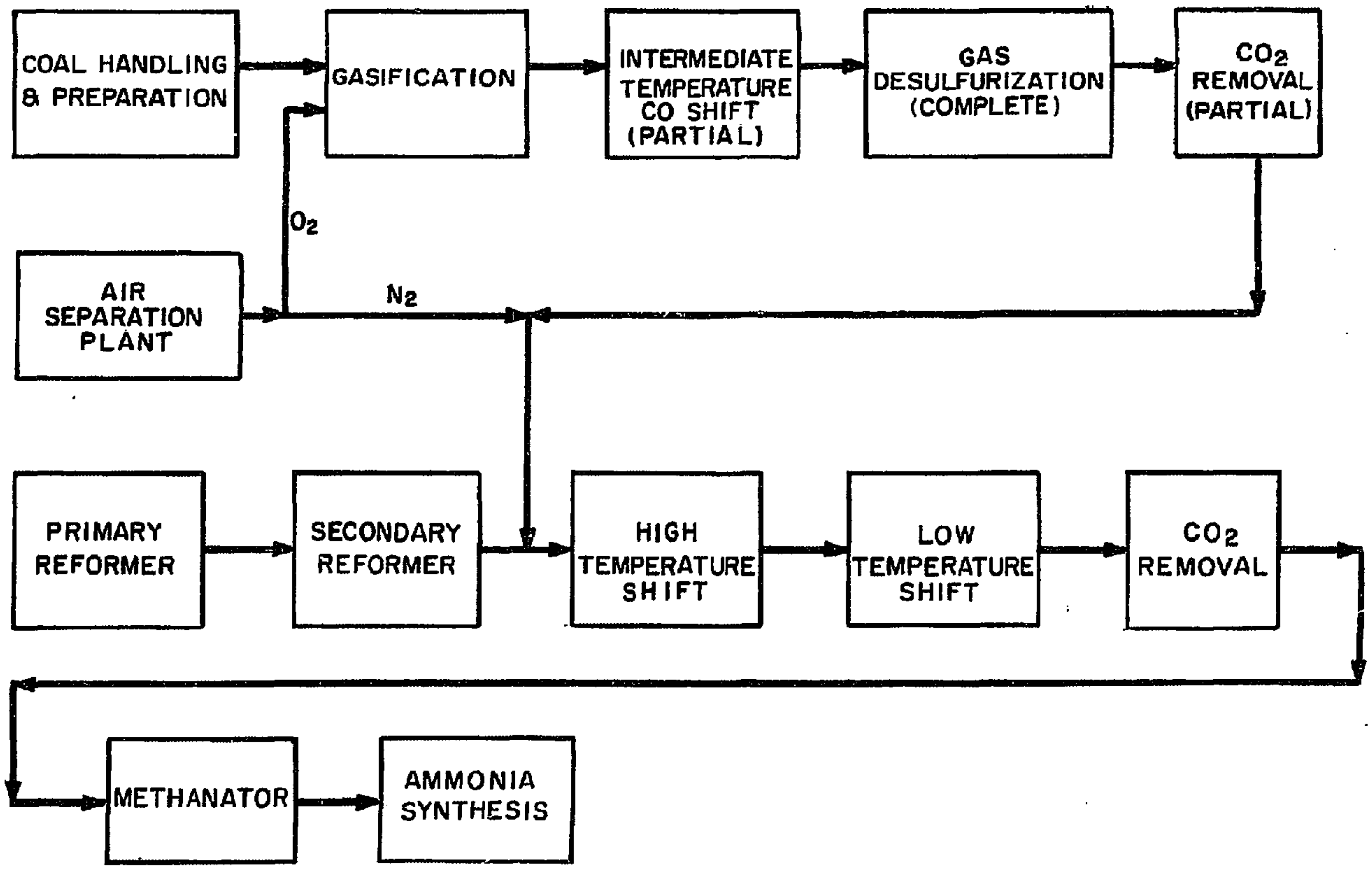


facilities, gas desulfurization and purification, and an ammonia synthesis section would be installed to serve the multi-pilot-plant facilities. A cost estimate was prepared for this system, but because the cost appeared excessive and the time involved in obtaining useable results would be too long, this approach was abandoned.

Further analysis revealed that the lowest cost and quickest way to meet the immediate needs of the U.S. fertilizer industry was to retrofit a coal gasification system onto TVA's small, but modern, ammonia plant at Muscle Shoals. The TVA ammonia plant is a 225-ton-per-day, natural gas, steam reforming plant, completed in 1972. The plant has two reciprocating compressors, each with 60-percent capacity; therefore, the plant can be turned down to 60 percent of capacity. The least-cost installation, therefore, would be a coal gasification facility that would produce 60 percent of the gas needed by the ammonia plant. In order that the greatest use be made of the existing plant, the gas should be introduced as near to the front end of the ammonia plant train as possible as shown in Figure 2. Thus, the existing shift, CO_2 removal, methanation, and synthesis sections would be utilized to minimize the amount and size of new equipment required. The technical problem would be to provide a gas that would match the composition, temperature, and pressure of the gas coming from the existing secondary reformer. With this arrangement, the plant could be operated with 60 percent of the synthesis gas from coal and 40 percent from natural gas or at 60-percent capacity with synthesis gas only.

FIGURE 2

COAL GASIFICATION RETROFIT TO EXISTING NH_3 PLANT



A set of criteria was developed for selecting the gasification process. These criteria were (1) that the synthesis gas be composed of primarily hydrogen, CO, CO_2, and nitrogen in the same concentrations that exist in the present plant downstream of the secondary reformer, (2) that the gas be at the same temperature and pressure at this point, (3) that the gasification process not produce a large amount of methane which would require separation for either reforming or burning as fuel, (4) that the process accepts a variety of U.S. coals, (5) that the process not produce oils, tars, phenols, and other contaminants which would have to be disposed of in an economically and environmentally acceptable way, (6) that the process be developed at a commercial or near-commercial state of the art, (7) that the process be of U.S. development, and (8) that the process be economically competitive with other available coal-based processes. After a thorough review of all the processes that could be considered, it was concluded that the partial-oxidation process available from the Texaco Development Corporation, which had been commercialized with oil feedstock, best met the criteria, so it was selected for the TVA project. Design conditions are to gasify 168 tons per day of coal at a pressure of 490 psig to produce 135 tons per day of ammonia.

The TVA demonstration facility should provide a basis for retrofitting existing plants. There are about thirty 1000-ton-per-day natural gas-steam reforming ammonia plants operating in the U.S. In total, there are about 100 natural gas-steam reforming ammonia plants producing about 17 million tons of ammonia per year in the U.S.

It is recognized that differences from plant to plant will require special consideration. A case in point is high-pressure steam generation for steam turbines driving centrifugal compressors. TVA's compressors are electric-motor driven. The typical 1000-ton-per-day ammonia plant has high-pressure steam generation in the reformers and waste heat boilers. If this steam were not produced because the reformers were eliminated, the steam would have to be raised either by waste heat recovery or in coal, coal gas, or fuel oil-fired steam boilers. This requirement could be about 400,000 pounds of 1500-psig steam per hour for a 1000-ton-per-day ammonia plant. It is unlikely that this total amount could be produced as waste heat at the gasifier, and additional boiler capacity probably would have to be provided.

Waste heat recovery from the raw gases from the gasifier presents difficult problems as to slag deposition on tubes, erosion, and metallurgy. For this reason a waste heat boiler will not be installed initially in the TVA project. Provisions will be made for possible future installation.

The current status of TVA's Ammonia from Coal Project is as follows: Contracts have been awarded to Foster Wheeler Energy Corporation, Badger Plants, Inc., and Brown and Root Development, Inc., to prepare definitive engineering studies and cost estimates on the coal gasification and gas purification unit. These awards were made on the basis of competitive bidding after eight bids were received. The three contractors, in accepting the awards, have agreed that they will submit lump sum bids based on their studies and cost estimates for the engineering, procurement, and erection of the facility. A final contract will be awarded for this phase in January 1978. An award has been made for the air separation plant to Air Products and Chemicals, Inc., to provide the oxygen and nitrogen to the facility. Work by TVA forces is proceeding on the engineering, procurement, and erection for the coal handling and preparation, ash disposal, modifications to the existing ammonia plant, and services and utilities for the entire complex. The TVA facility will begin operation in late 1979.

In addition to the TVA Ammonia from Coal Project, there are two other coal gasification projects applicable to ammonia that are being conducted by the U.S. Energy Research and Development Administration (ERDA). One is a contract with W. R. Grace & Company, in conjunction with Ebasco Services, Inc., and the other is an agreement to negotiate a contract with Air Products and Chemicals, Inc. The Grace/Ebasco plant would use the Texaco process and gasify 1700 tons per day of coal at a pressure of 2500 psig. The gas would be scrubbed, purified, and sent to a new ammonia plant not funded by ERDA. A feasibility study will be made first and operation is scheduled for mid-1982 if a "go" decision is made. This is one of two contracts competing for funds available for one plant. The other contract is with Memphis Light, Gas, & Water Division, which does not involve ammonia. The Air Products Plant would use the Koppers-Totzek process and gasify 1210 tons per day of Texas lignite to produce H_2 and CO which are to be distributed through an existing pipeline to chemical industries in the gulf coast region. Operation is expected to begin in late 1981. The ERDA and the TVA projects complement each other in that the ERDA plants involve grassroots projects, and the TVA plant is a retrofit project. Also, the TVA project is on an accelerated schedule that should provide useful information for the ERDA ammonia from coal projects scheduled to come on stream later.

In addition to the projects mentioned above, ERDA is engaged in numerous synthetic natural gas and low-Btu fuel gas projects. One of these involves the installation of Lurgi gasifiers on the Powerton Project in conjunction with Commonwealth Edison and the Electric Power Research Institute.

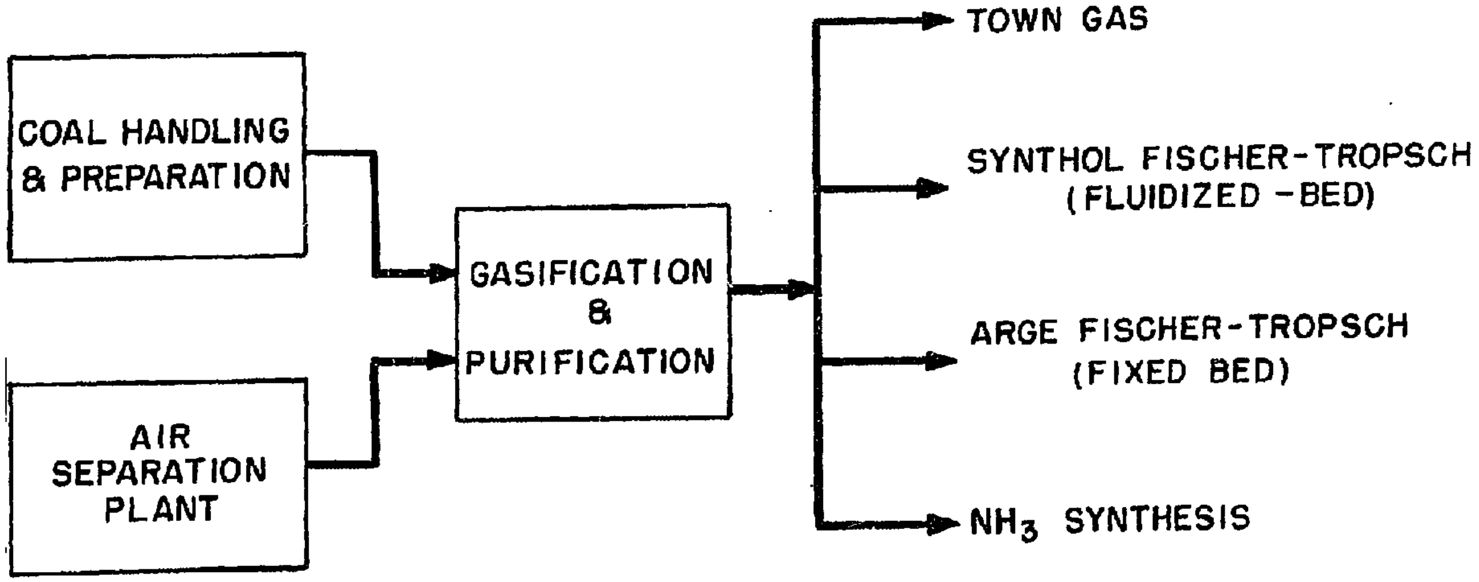
Aside from the TVA and ERDA efforts, there is a great deal of work being done around the world based on German coal technology and Shell and Texaco petroleum technology. At present, there are at least fourteen coal-based ammonia plants in operation: one Lurgi, ten Koppers-Totzek, and three Winkler. None of these plants are in the U.S. There are also larger numbers of Shell and Texaco petroleum-based partial-oxidation plants in operation producing ammonia, some of which are in the U.S. Of the current world ammonia capacity of about 77 million short tons N, 64 percent is based on natural gas, 13 percent on naphtha, 12 percent on coal or coke, with the remaining 11 percent equally divided among other feedstock sources.

In order to assure having as much background information as possible for the pursuit of the TVA project, and to obtain information to present to the U.S. fertilizer industry, members of TVA's Ammonia from Coal Project staff traveled to South Africa, India, and Germany during the summer of

1977 to visit operating plants and process developing firms who were concerned with producing ammonia from either coal or petroleum products. The group traveled to South Africa and visited the South African Coal, Oil, and Gas Corporation Limited (SASOL) plant in Sasolburg and African Explosives and Chemicals Industries Limited (AE&CI) in Modderfontein. The SASOL plant is large, complex, and relatively old. The SASOL staff were quite outspoken in their praise for the Lurgi process and considered it to have major advantages over other coal gasification processes. The plant consists of 13 Lurgi coal gasifiers that produce gas used in four different ways as shown diagrammatically in Figure 3: (1) to furnish town gas, (2) to feed the Synthol (developed from the old Kellogg process) Fischer Tropsch unit to produce gasolines and light hydrocarbons in a fluidized bed unit, (3) to feed the Arge (based on old Ruhrchemie/Lurgi technology) Fischer Tropsch process to produce heavy oils and waxes in a fixed-bed unit, and (4) to produce ammonia in a 230 mtpd ammonia plant.

The coal used contains 21 percent volatiles and 30 to 36 percent ash. The ash fusion temperature is between 2460° F and 2730° F. Oxygen is produced with a purity of 98 percent. The gasifier operating pressure is about 400 psia. Gasification temperature is around 2190° F. The raw gas from the gasifier contains significant quantities of condensibles, such as ammonia, phenols, and tars which are recovered for fuel usage or sale. Water from biological treatment is used to transport the ash. The ash improves the water color and precipitates fluorine from the water.

FIGURE 3
SASOL PLANT



Of the 13 gasifiers, SASOL runs 11 and maintains 2 on standby. Four larger gasifiers are currently under construction. The existing 13 gasifiers are about 12 feet in diameter and the 4 new gasifiers are about 13 feet in diameter. It was said that two of the new gasifiers would supply a 1100 stpd ammonia plant. The present gasifier availability was given at about 85 percent.

The AE&CI plant was designed to produce 1100 stpd total combined NH_3 plus methanol. The methanol plant is rated at 57 stpd and was completed late in 1974, but they are just now getting good operation. During the five days preceding the visit of the TVA team, 1025 stpd of NH_3 plus 75 stpd of methanol were produced. The plant has six Koppers-Totzek gasifiers. All six are normally used, but if necessary, full production can be maintained with five gasifiers only.

In early operations there was trouble with serious loss of the refractory in the gasifiers. The remedy for this was, initially, to operate at a lower temperature, with lower efficiency but, subsequently, modifications were made to the system. Despite the other difficulties encountered, raw gas composition has always been satisfactory.

The coal, containing 7 percent moisture, is dried and pulverized to 90 percent passing 175 mesh size. The gasifiers are two-headed and jacketed; each head is provided with two screw feeders. Oxygen and steam are admitted into the screw feeder where they are mixed with the coal, thus conveying it into the gasifier by entrainment. The gasifier reactions take place at 2900-3600° F and slightly above atmospheric pressure.

After gasification and water scrubbing, the raw gas is stored in a gas holder as shown in Figure 4. It then passes through two electrostatic precipitators to centrifugal compressors, which compress the gas to 450 psig and later to 750 psig. It is then sent to further processing in a Rectisol unit, a shift converter, a liquid nitrogen wash tower, and an ammonia synthesis unit.

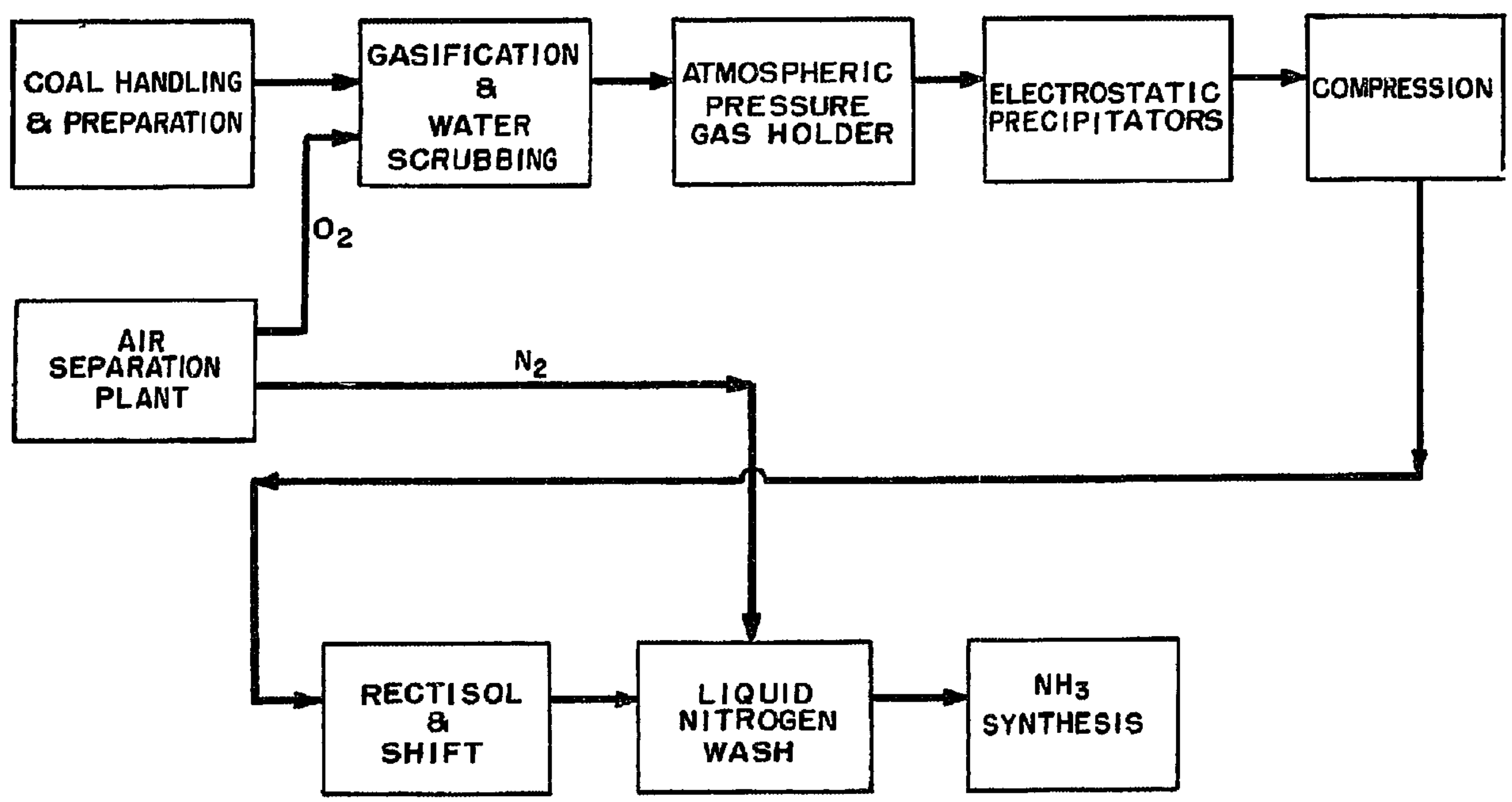
In the compressor house, there is a 12-point CO monitor that monitors specific equipment points at which CO is most likely to be present; general atmospheric monitoring is considered to be inadequate.

The Fertilizer Corporation of India (FCI), Talcher, coal-based plant is designed to produce 1000 stpd ammonia and 1650 stpd urea. It will receive 3300 stpd coal and 15 million gallons of water per day, and use 55-MW of electric power. It is on an 830-acre site and is said to have cost about $184 million.

The coal-based ammonia plant at Ramagundam is to be essentially identical to the Talcher plant. The Talcher plant is 98-percent complete and Ramagundam is about two months behind Talcher. The previously announced plant to be built at Korba has been indefinitely postponed.

The Ramagundam and Talcher plants have three Koppers 4-headed gasifiers, each equivalent to about 330 stpd of ammonia, for a total gasification capacity equivalent to 1000 stpd of ammonia at each plant.

FIGURE 4
AE & CI PLANT



Design gasification temperature is 2900° F at 16 inches of water pressure. Gas and entrained slag, after quenching to $1600-2000^{\circ}$ F, will flow upward into a large waste heat boiler. Slag will flow out the bottom of the gasifier into a water quench seal and collecting pit located below the gasifier. Ash solidified and separated in the waste heat boiler will also fall through a duct into the collecting pit.

The waste heat boiler is a large cylindrical vessel containing a radiant section and a two-part convection section. The gases will be cooled in the radiant section at very low velocities to a temperature of $930-1100^{\circ}$ F, which is well below the ash fusion temperature. For the most part, the ash particles will agglomerate and fall through the duct into the collecting pit. After the radiant section, there is a convection section with slanted tubes to allow the ash collected on them to fall off. This section is followed by a horizontal tubed section. The gas exit temperature will be 570° F.

The gas will pass to a cooler-washer where most of the remaining flyash will be removed and the gas cooled to 100° F. Further particulate removal will be accomplished in Tyssen separators and two primary and one secondary electrostatic precipitators.

The gas will then go to a gas holder after which turbine-driven raw gas compressors will deliver the gas at 460 psia to HCN removal, desulfurization, shift conversion, CO_2 removal, and nitrogen wash. From here, the gas will go to a standard ammonia synthesis unit.

The Talcher plant is in the final phase of construction and initial commissioning. One of the two air separation units had been run for several days and the other was started the day before the visit. The steam boilers were also in operation.

In Germany, visits were made to the process developing firms of Lurgi in Frankfurt, Krupp-Koppers in Essen, and Davy Powergas, which offers the Winkler process, in Cologne.

It was suggested at Lurgi that part of the condensibles, the "oil," could be hydro-treated over a catalyst to convert organic sulfur to H_2S, to reduce the CO content to five percent, and to reduce the HCN to methane and ammonia. The resulting purified naphtha could be used as fuel. It was also suggested that the other part of the condensibles, the "tars," might be used directly as a fuel under some conditions.

Lurgi stated that the most economical scheme would be to treat the condensibles separately by converting them to marketable byproducts and to use the purified synthesis gas for ammonia production. It was suggested that methane and CO could be separated in a cryogenic unit and sold for town gas or be fed by compression to a steam reformer.

It was pointed out that Lurgi has the lowest oxygen requirement of all commercial gasifiers. Other conditions being equal, the requirement ranges from 0.11 scf oxygen per scf of synthesis gas for active lignites to 0.21 scf/scf synthesis gas for anthracites. In addition, it was stated that Lurgi requires an oxygen purity of only 90 percent, which should reduce the cost of the air separation plant by about 10 percent.

At Davy Powergas (DPG), it was learned that DPG has the experience of having built 16 plants with a total of 36 Winkler generators using a wide variety of coals. Twelve of these 16 plants have been for the production of ammonia, and 3 plants are still in operation. All of these plants were operated at near atmospheric pressure. However, a DPG task force has been working on a pressure system for about 3 years. DPG is now ready to offer, with guarantees, a process operating at 45 psig.

The reasons for choosing 45 psig for ammonia synthesis applications are:

(1) It does not involve the use of novel equipment.

(2) The pressure is sufficient to allow final particulate removal in venturi scrubbers rather than electrostatic precipitators.

(3) The slight increase in methane content caused by operation at 45 psig can be counteracted by a slight increase in temperature. The modern Winkler generators with a radiation ring boiler near the top of the generator allow operation at higher temperatures as has been proved at a plant built by DPG in Turkey.

(4) The gas needed for a 1100 tpd NH_3 plant can be produced in 2 Winkler generators of a commercially proven size if operated at 45 psig.

(5) Major savings in capital cost and compression costs can be obtained at this pressure level without increasing the methane content of the synthesis gas. The ash leaves the gasifier mainly in the form of a flyash. This Winkler flyash is a combustible char containing about 6-12 percent of the carbon in feed depending on coal properties. Over 90 percent of this flyash is removed in a dry state and used as an auxiliary fuel for producing additional high-pressure steam which is needed in coal-based ammonia plants. The ash removed at the bottom of the generator and the remaining flyash removed in the wet scrubbing section, contain only about 2-3 percent of the carbon in the feed; thus 97-98 percent of the carbon values in the feed are utilized within the ammonia plant.

DPG is currently looking at higher pressures, at least 200 psig. This is the minimum pressure needed for combined cycle power generation processes.

A wide variety of coals has been gasified in the Winkler gasifier. However, lignites and subbituminous coals are preferred. The Winkler is a nonslagging gasifier operating at temperatures lower than the ash fusion temperature but still high enough to prevent formation of methane and condensibles. Coals with reactivity lower than that of lignites and subbituminous coals can also be gasified by operating the generator with a closer approach to the ash fusion temperature in the suspension zone. This is done by including a radiant ring boiler in the upper section of the gasifier.

DPG feels that the major advantages for the Winkler gasifier are its simplicity and high capacity per unit and that the nonslagging operation gives a high on-stream efficiency. The large inventory of the fluidized bed provides a safety against oxygen breakthrough and tends to even out the variations in the quality of feedstock. Additionally the process is not sensitive to feed size distribution. The unit can operate successfully on run-of-mine coal fines -0.79 in + 0 in. The preferred range is -0.39 in + 0 in, with the natural distribution obtained during simple crushing operations. This is an advantage, especially, when gasifying low-grade high-ash coals since no pulverization of coal is required.

At Krupp-Koppers the Koppers-Totzek process was reviewed in detail. Koppers stated that the Shell-Koppers development program at the Harburg refinery of Deutsche Shell A.G., near Hamburg, involved the installation of a demonstration gasifier that has a coal feed rate of 165 st of coal per day at a pressure of 440 psia and is expected to reach mechanical completion in December 1977. Initial operation will begin shortly thereafter. Dry pulverized coal feed will be used. About 10 million SCFD of synthesis gas will be produced.

Visits were also made to the following firms:

(a) Fredrich Uhde, GmbH, Dortmund; the engineering offices and computer facilities.

(b) Braunkohlenwerke, A.G., Cologne; a coal gasification pilot unit under construction, based on the high-pressure (45 psia) Winkler process.

(c) Ruhrchemie, A.G., Oberhausen; a 7-ton-per-hour Texaco coal gasifier is under construction. The plant will produce a $CO-H_2$ synthesis gas to be used in the Oxo-process plant for the manufacture of aldehydes from olefins. The facility features direct wet-grinding of coal in a concentrated slurry with water and a waste heat boiler in conjunction with the Texaco gasifier.

At each point visited specific questions were asked about incidents, experiences, and histories of (1) air and stream pollution, (2) occupational health, particularly results of exposure to carcinogens or cancer-producing materials such as coal tars, and (3) safety problems.

Air pollution problems are being handled in varying degrees, depending on the emission regulations in effect at the particular location. Generally speaking, air pollution controls in the U.S. will have to be much more extensive than those seen during the trip. SASOL has, up until recently, released H_2S through a boiler stack, but they have now installed a Stretford sulfur recovery unit. The coals used in most places visited were low-sulfur coals. Carbon monoxide release to the atmosphere was allowed in some of the plants.

Water pollution in South Africa is rigidly controlled because water is scarce and plant water effluents go into the community water supply system. Close monitoring for heavy metals has been practiced but no corrective action has been needed.

Incidents with toxic fumes were reported. There have been fatalities from carbon monoxide and nitrogen asphyxiations. Incidents have also occurred with methanol fumes. Effective corrective action has been taken by installing suitable detection devices and making plant modifications. At no plant was there any report of cancer being caused by exposure to coal tar chemicals. At Ruhrchemie, where coal chemistry has been practiced since the early 1930's, it was stated that they were unaware of any problem. SASOL established a health program 23 years ago and monitored the workers for cancer, and there has not been a single cancer case. It was reported that the incidence of colds and flu was lower in their plant workers than in other persons in the area.

It is apparent then that the experience levels of the German coal-based processes and similar oil-based processes are entirely adequate for the design and construction of ammonia from coal plants. These firms are continuing to advance their process technology and are anxious to have their processes put into operation in the U.S.

Each coal gasification process studied has certain apparent advantages in given situations. The Lurgi process would have prime application where there would be a use or market for a multiplicity of products consisting of synthesis gas, methane, oils, tars, phenols, etc. Its best use is with those coals that have noncaking characteristics. The Lurgi process requires the lowest oxygen consumption.

The Koppers-Totzek process is said to be applicable for coals having varying ash melting behaviors and temperatures, reactivities and where coal tar condensibles are not desired. The Koppers-Totzek process produces high-pressure steam in a commercially proven waste heat boiler. The Winkler process performs well with certain coals but cannot be used with others. Winkler does not produce condensibles, but it does produce a char that must be burned or disposed of; this would not be a problem in NH_3 production because of high-steam requirements. The Texaco process is not advanced to commercial use with coal but offers the potential of operating at elevated pressure and is expected to accept a variety of coals without producing condensibles.

Development work is being carried out with both the Winkler and Koppers-Totzek processes on gasification at elevated pressure. Lurgi is developing a slagging type gasifier.

Very little capital or operating cost information was available during the TVA team's visit. The information obtained was either inapplicable to U.S. conditions or was out of date. TVA has, however, recently prepared a series of conceptual designs and cost estimates on 1000-short-ton-per-day grassroots ammonia plants. The estimated cost of a natural gas-steam reforming plant is about $75 million, and a coal partial-oxidation ammonia plant is about $140 million. The estimated ammonia sales price, f.o.b. plant, for 1000-ton-per-day plants is shown on Figure 5 for various feedstocks. The sales price includes the cost of raw materials and chemicals, operating labor and supervision, utilities, maintenance, simple depreciation at 15 years, insurance, plant and administrative overheads, a 50-50 debt-equity capital structure, interest at 10 percent on borrowed capital, marketing and a 14 percent after-tax return on owner's equity. Ammonia could be produced in a natural gas-steam reforming ammonia plant built in 1977 at a sales price of about $120/ton, using $2/MCF natural gas. The sales price for a coal-based plant would be about $150/ton, using $25/ton coal. It can be seen that if natural gas rises to $3/MCF, coal would be competitive at $25/ton. Naphtha, heavy oil, and electrolytic hydrogen are also shown on the curve and can be seen to be noncompetitive with coal at current costs of $13/bbl for fuel oil, $120/ton for naphtha, and 20 mills/kWh for electricity. In order to bring all of this into perspective, ammonia prices delivered to retail dealers in the Midwest are currently about $125-130/ton, about $100/ton on the Gulf Coast, and less for spot prices on small shipments. Coal costs at Muscle Shoals are currently between $25 and $30 per ton. The cost would be about $17-23 per ton for a coal-based plant located at the coal mine (high-sulfur, bituminous).

The conclusion reached at this point is that both the technical and economic aspects of coal-based ammonia production are unclear. It is apparent that no one gasification process will be applicable for all ammonia from coal applications in the U.S. In addition to the selection

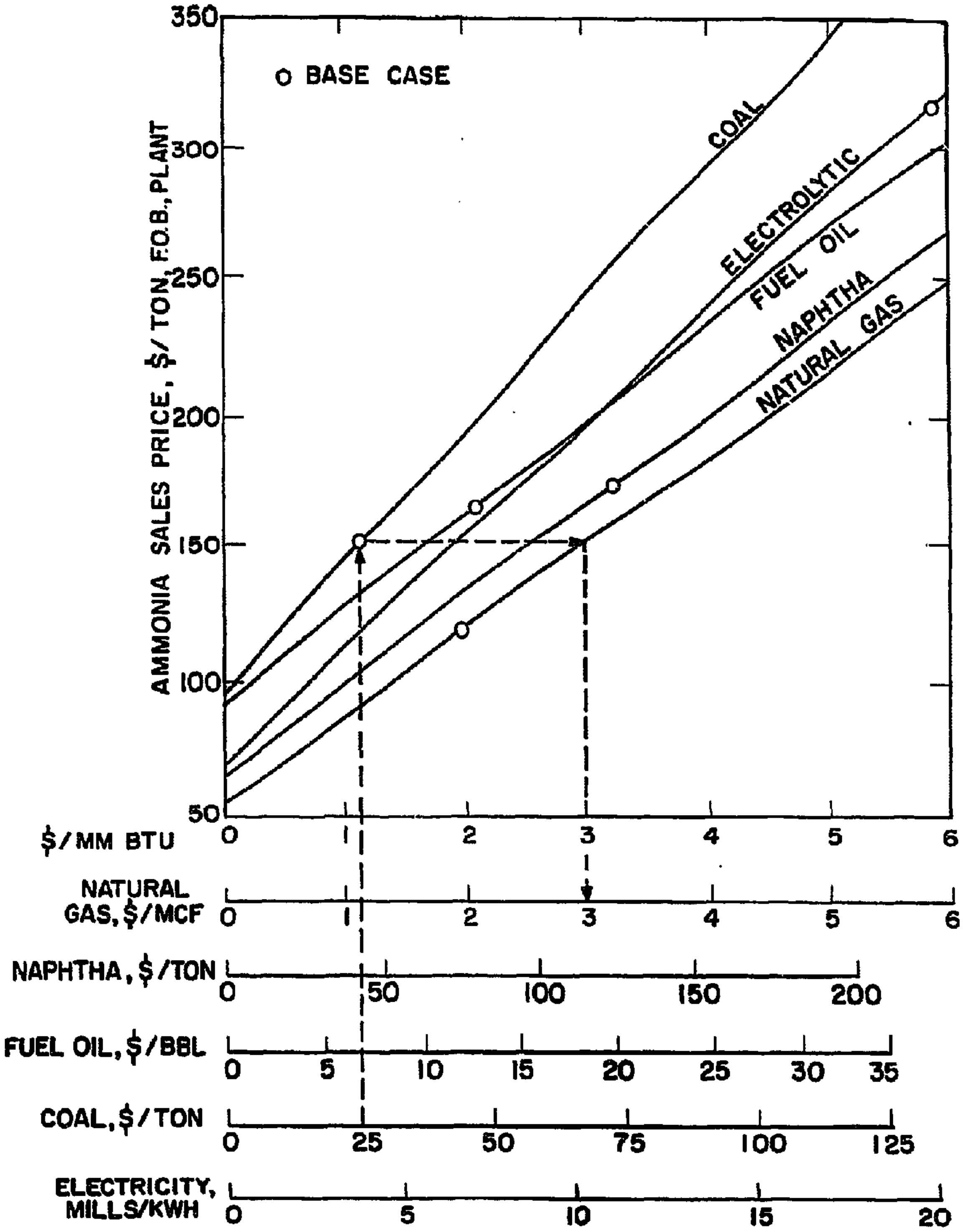


FIGURE 5
AMMONIA SALES PRICE VERSUS FEEDSTOCK COSTS

of the gasification process, there are numerous other technical alternatives that the ammonia producer must consider, depending on his particular circumstances. The economic picture will depend on future availability and costs of feedstocks. We expect that natural gas costs will continue to increase in the future. We also expect the cost of coal to increase. It would appear that coal costs will not increase as much as natural gas in the next 10 to 15 years, but there is no certainty of this. One main objective of the TVA project is to firmly establish the economics of producing ammonia from coal. Accomplishment of this objective will provide a useful yardstick for U.S. industry as producers consider alternatives for meeting the nation's nitrogen fertilizer demand in the future.