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AMMONIA FROM COAL

MASTER

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This paper discusses the ongoing TVA Ammonia From Coal Project for which plant startup is expected in 1980. The paper also discusses anticipated investment and production costs for both retrofit and grass roots ammonia from coal projects.

Ammonia producers in the U.S. are concerned about gas shortages. Most ammonia today is produced from natural gas. Natural gas supplies are expected to be in short supply in the future. Where will this lead us? Imported ammonia is cheap today, but just like oil, the price can be raised. Fortunately, the U.S. has extensive deposits of coal which can serve as a substitute feedstock for the production of ammonia.

There are about 100 natural gas-steam reforming plants in the U.S. and about 30 of these are large, 1,000-ton-per-day plants. If these plants can be retrofitted so that they can use coal, the present investments in these plants can be protected.

Why TVA?

The National Fertilizer Development Center (NFDC) was established within TVA to assure the U.S. fertilizer and agricultural industries of continuing research and development in the field of fertilizer production and usage. Consistent with this charge, TVA has developed a demonstration program for ammonia from coal. This program will involve retrofitting an existing ammonia plant but it will also provide information for "grass roots" ammonia from coal production facilities.

Many of the problems involved in retrofitting are different from those with grass roots plants. Others, such as W. R. Grace and Company and Ebasco Services, Incorporated, are pursuing grass roots ammonia from coal technology on a U.S. Department of Energy project.

Demonstration Project

The TVA Ammonia From Coal Project (Figure 1) consists of retrofitting an 8-ton-per-hour coal gasification and gas purification facility onto the front end of an existing natural gas-steam reforming ammonia plant located at the National Fertilizer Development Center at Muscle Shoals, Alabama.

Capacity of Demonstration Plant

The ammonia production capacity of the TVA plant is 225 tons/day. The plant can be operated at a turndown rate of 60%. The coal gasification facility will be designed to produce 60% of the gas required to operate the ammonia plant at 100% rate. Therefore, the ammonia plant can be operated at the design rate with 60% of the feed gas supplied from coal and the remaining 40% from natural gas; or, the plant can be operated at 60% of design rate (135 tons/day of ammonia) with all of the feed gas supplied from coal. The gasification unit is being designed for a coal feed rate of about 8 tons/ hr. The capability of operating the ammonia plant with 100% natural gas feed will be retained. This arrangement should make the greatest use of the existing plant and minimize the amount and size of new equipment required. Also, the coal gasification facilities can be operated independently from the ammonia plant by burning the carbon monoxide and hydrogen gas in an existing steam boiler.

The coal gasification unit will be based on the Texaco partial oxidation process. The engineering, procurement, and erection of the coal gasification and gas purification facility are being performed by Brown & Root Development, Inc. The air separation plant required to provide high purity oxygen and nitrogen for the process will be handled similarly by Air Products and Chemicals, Inc. The engineering, procurement, and construction of the coal handling and preparation area, interconnections to the existing ammonia plant, slag disposal, and services and utilities required for the complex will be performed by TVA.

To Use Several Types of Coal

The plant is being designed to use Illinois No. 6 coal. Pilot-plant tests were run by Texaco with this coal to determine the design conditions. This coal was selected because it has the largest reserve in the U.S. and is located in the Midwest where there is the greatest consumption of fertilizer. Sufficient flexibility is being designed into the plant to allow for test operation using coals with different heat, ash, and sulfur contents, and with different grinding characteristics.

A flow scheme for the TVA ammonia from coal project is shown in figure 2. Coal is received by rail and is either sent to open storage and later recovered by front-end loader or it is crushed in a primary crusher to minus 1/2 inch and conveyed directly to the coal slurry preparation area.

Coal is pulverized in a wet pulverizer as required for the gasifier operation. From the pulverizer, the slurry goes to one of two mix tanks where fine adjustments to the slurry concentration can be made. The slurry is pumped to a 10-hour capacity feed tank and then metered to the reactor (gasifier) at the process rate of about 8 tons of coal/hour. Gaseous oxygen from the air separation plant is fed to the reactor at about 8 tons/h through a metering system interlocked with the coal slurry feed system.

High Temperature and Pressure

The gasification process takes place in the reactor at a pressure of about 510 psig and at a temperature in excess of 2,200°F. The carbon in the coal is reacted with steam to produce carbon monoxide and hydrogen. Oxygen is injected to burn part of the coal to provide heat for the endothermic reaction. In addition to the carbon monoxide and hydrogen, carbon dioxide is formed from coal combustion and sulfur compounds in the coal are gasified in the reactor reducing atmosphere to produce primarily hydrogen sulfide (H_2S) and some carbonyl sulfide (COS). Small quantities of other compounds such as ammonia and methane are also formed. According to Texaco's pilot-plant experience, essentially no long-chain or aromatic hydrocarbons are formed.

Slag produced from the ash in the coal is removed from the reactor through a lockhopper system. The slag is glassy in appearance and is very similar to the bottom ash produced in a coal-fired power plant boiler. Initially, trucks will be used to transport the solids to a disposal area. A slurry pumping system may be installed later to handle and transport the slag to the disposal area as a slurry. In such a system, the slag would be washed and screened to remove oversize material which is crushed to a size suitable for slurrying and pumping.

The gas leaving the reactor is water-quenched and particulate matter (fly ash) is removed in a scrubber. A blowdown stream is taken from the recirculating water loop and pumped to a wastewater treatment facility, which uses both chemical and biological treatment processes. In the chemical treatment unit, wastewater is first clarified by addition of ferrous sulfate and hydrated lime to flocculate solids. The liquid fraction from the clarifier is steam-stripped to remove ammonia which is recovered and routed to the coal slurry preparation area to neutralize the acidic slurry. The stripped aqueous material, containing organic matter as formates and cyanates, along with water from washdown operations from all sumps, is sent to an equalization-cooling basin for pH control, mixing, and cooling. The effluent from the equilization cooling basin flows to an activated sludge unit for biological treatment. The overflow from the activated sludge unit is metered and sampled on its way to discharge. The sludge from the biological treatment is combined with flocculated sludge from the clarifier and conditioned with ferric chloride to improve filtration. The conditioned sludge is pumped to the filter press where the solids are removed for disposal.

Downstream Processing

Two shift converters are employed to adjust the H_2/CO ratio to the desired value. A sulfur-resistant shift catalyst supplied by Haldor Topsoe is employed.

Following shift conversion a hydrolysis unit containing a catalyst also developed by Topsoe is employed to hydrolyze the COS produced during gasification. By this means the COS is reduced to very low (PPM) levels.

Acid gases (CO_2 and H_2S) are removed in a physical solvent absorption system (Allied Chemical's Selexol Process). Sulfur is reduced to less than one (1) PPM. A Stretford system designed by Peabody Process Systems is employed to recover sulfur from the two (2) offgas streams from the Selexol unit.

Nitrogen from the air separation plant is added to the process gas to adjust the H_2/N_2 ratio to the desired 3/1 value needed for ammonia synthesis. Steam is then added and the gas is introduced to the existing ammonia train downstream of the high temperature CO shift converter. The pressure and composition of this gas is essentially the same as that in the present natural gas based plant. The composition is given in Table 1.

Plant Cost

The ammonia from coal facility's total plant cost is estimated to be about $43.2 million. Since the TVA Ammonia from Coal Project contains developmental and first-time-out design features, this cost should not be scaled up to obtain the investment for commercial size plants. Instead, Brown & Root prepared conceptual designs and cost estimates for retrofit and grass roots facilities. These investment estimates are based on actual and estimated costs of the TVA Ammonia from Coal Project and other studies prepared by Brown and Root; they are for a 1000T/D ammonia plant in mid-1979 dollars. The results are as follows:

Case 1 - $120 million for a retrofit plant which uses the existing shift, acid gas removal, ammonia loop and ammonia storage.

Case 2 - $126 million for a retrofit plant which uses all new shift, and acid gas removal but uses the existing ammonia loop and ammonia storage.

Case 3 - $157 million for a grass roots plant.

A breakdown of these estimates is shown in Table 2. Case 1 is for retrofitting an ammonia plant and uses existing shift and acid gas removal systems. The acid gas removal system in the existing ammonia plant is assumed to be based upon chemical absorption. Shift and acid gas removal units would still be required in the retrofit plant so that the gas can be accepted upstream of the shift converter in the existing ammonia plant. In all cases, the Selexol Process developed by Allied Chemical Company is used in the retrofit facility. The Selexol unit uses physical absorption with relatively low steam requirements compared with chemical absorption systems.

Case 1 used a coal-fired boiler for steam generation. The investment is estimated to be about $6 million less than for Case 2, which is for a retrofit plant that uses all new shift converters, acid gas removal units, and steam generation using waste heat boilers on the coal gasifier effluent. The steam requirement in Case 2 and Case 3 is lower than in Case 1 because the acid gas removal system in the existing ammonia plant is not operated. In Case 3, additional investment is required for the general plant, the ammonia loop, refrigeration, and ammonia storage.

Figure 3 is a plot of estimated investment cost versus capacity for retrofit and grass roots plants.

There is a degree of uncertainty regarding the accuracy of these investment costs because they were estimated on the basis of conceptual designs. Results from the TVA demonstration unit operation will assist in improving design and estimated investment for these units.

In the following discussion, the production costs for Case 1 are considered to be equivalent to Case 2 with the savings in capital charges offset by an increase in operating costs.

For retrofitting a particular plant, in-depth investigations would be necessary to determine how much of the existing shift and acid gas removal systems should be used.

Ammonia Production Costs

Figure 4 shows a typical production cost calculation for ammonia from coal both for a retrofit situation and a grass roots plant. As shown, production costs for a 1000 T/D ammonia plant are estimated to be $161 per ton of ammonia for a retrofit and $185 per ton for a grass roots coal plant. Estimated production costs are also given for a range of plant sizes from 800 to 1500 T/D. For any particular installation, the calculation would be repeated using financial parameters, etc. appropriate for the operating company involved.

Constant figures for utilities, catalysts, and chemicals and operating labor have been employed in figure 4, as they are small compared to the overall production cost. These figures have been taken from reference 1. In the case of the retrofit plant, figure 4 does not include charges for the book value or capital investment of the existing natural gas based ammonia plant. Depending on the remaining book value for the existing ammonia plant, depreciation could range from zero to perhaps $60 dollars per ton of ammonia. (See Table 3.)

In many cases, the existing ammonia plant might be considered a "sunk" cost for which no capital charges really are valid. This would be appropriate in the case in which natural gas was not available and the plant would not be operated otherwise.

The production costs (figure 4) must be compared to current ammonia prices. In September 1979, the price of ammonia delivered to retail dealers in the Midwest was about $150/ton and on the Gulf Coast, the price was about $135/ton. These prices reflect recent increases from a depressed market for ammonia. Recent indications are that ammonia prices are continuing to rise.

Current plans are to operate the TVA Demonstration Plant for three (3) years and obtain data which should help in design improvements and cost estimates. As the project goes on, it is possible that results will enable ammonia from coal plants to be designed with a lower cost than the information presented in this paper indicates. The future economic picture will depend on availability and costs of feedstock. We expect that natural gas costs will continue to increase. 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.

References

1. Waitzman, D., et al. Fertilizer from Coal. Presented at Faculty Institute on Coal Production, Oak Ridge, Tennessee, July 30-August 11, 1978.

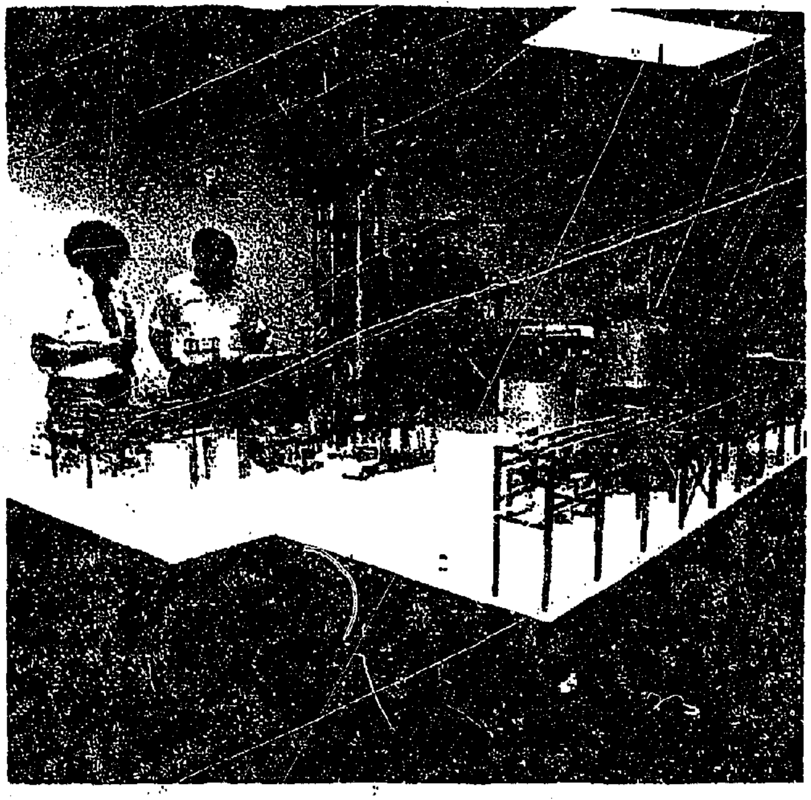


FIGURE I.

MODEL OF TVA PROJECT

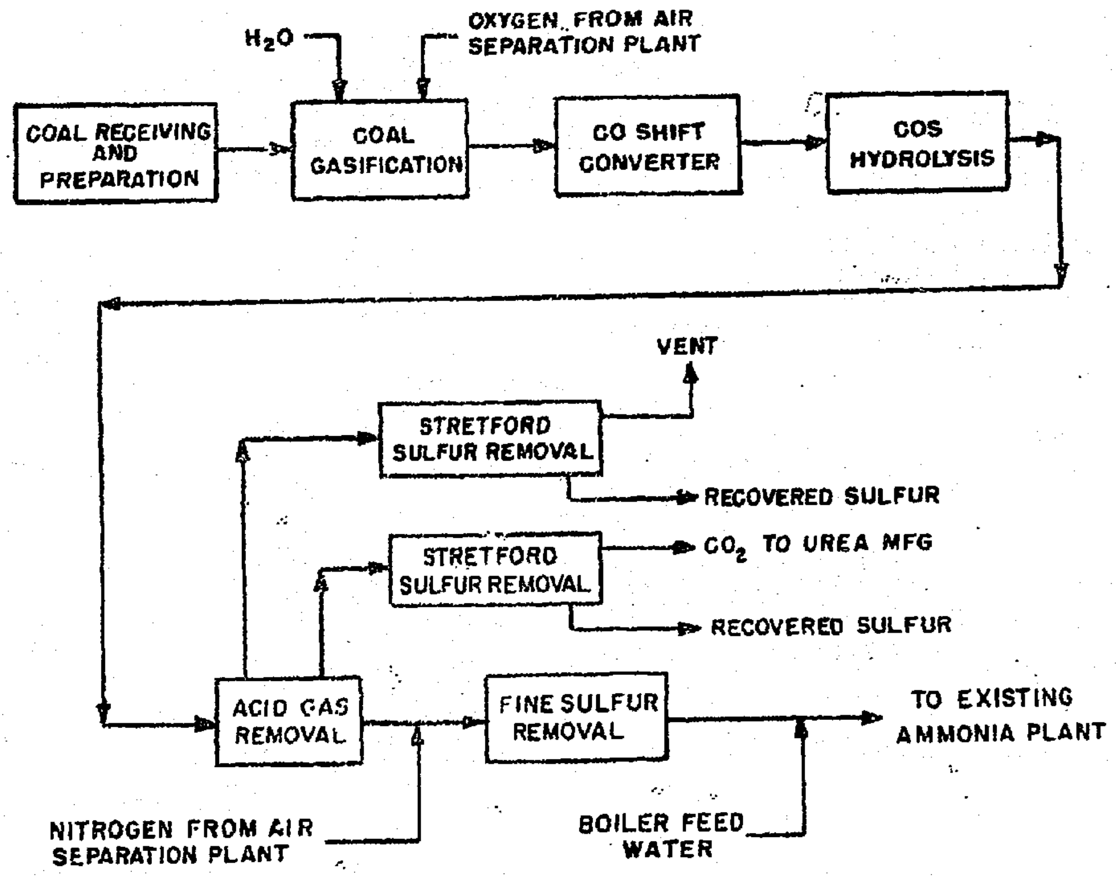


FIGURE 2

FLOW SCHEME FOR TVA'S AMMONIA FROM COAL PROJECT

FIG. 3

AMMONIA FROM COAL

INVESTMENT
VS.
CAPACITY (OF NH_3)

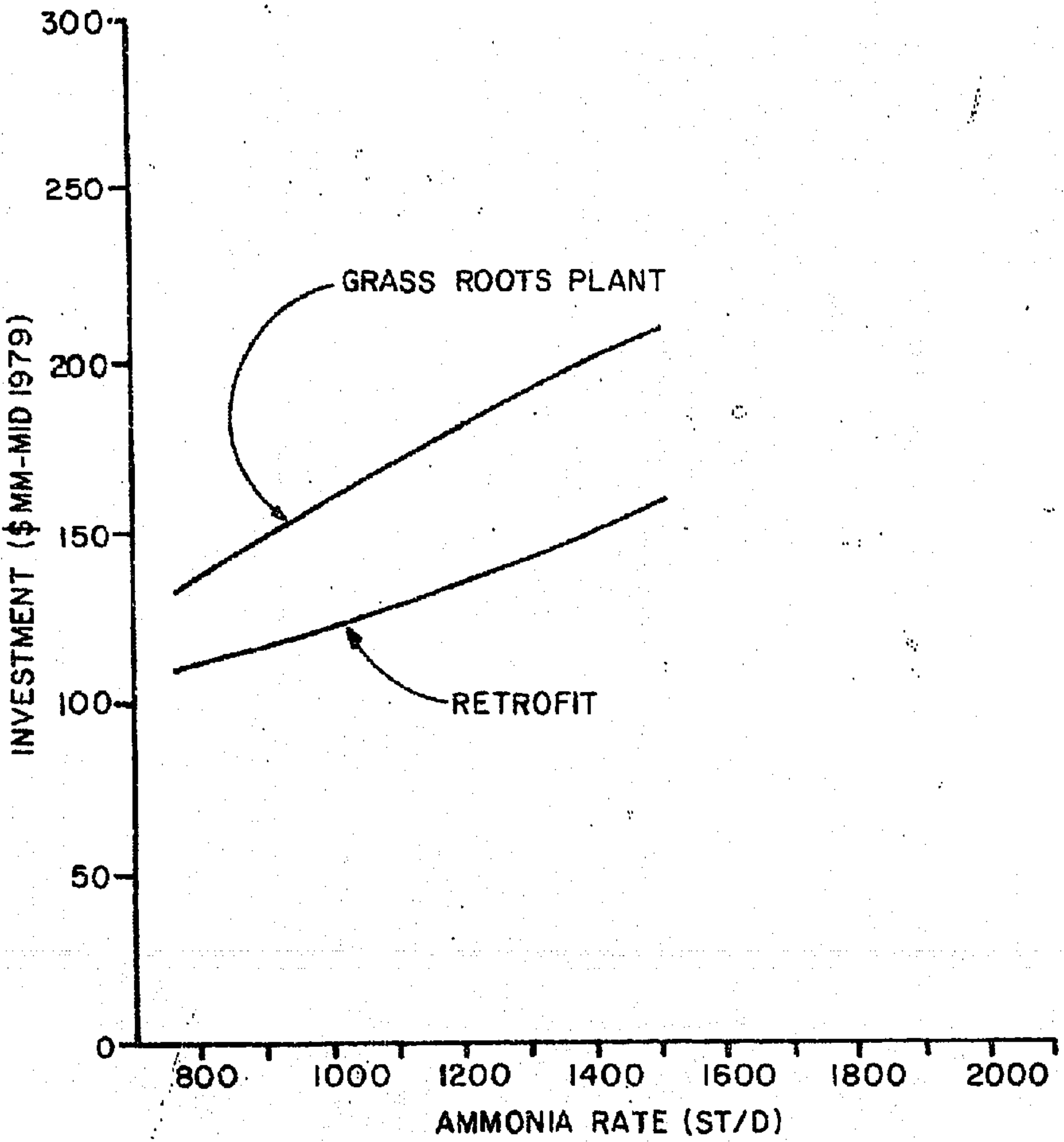
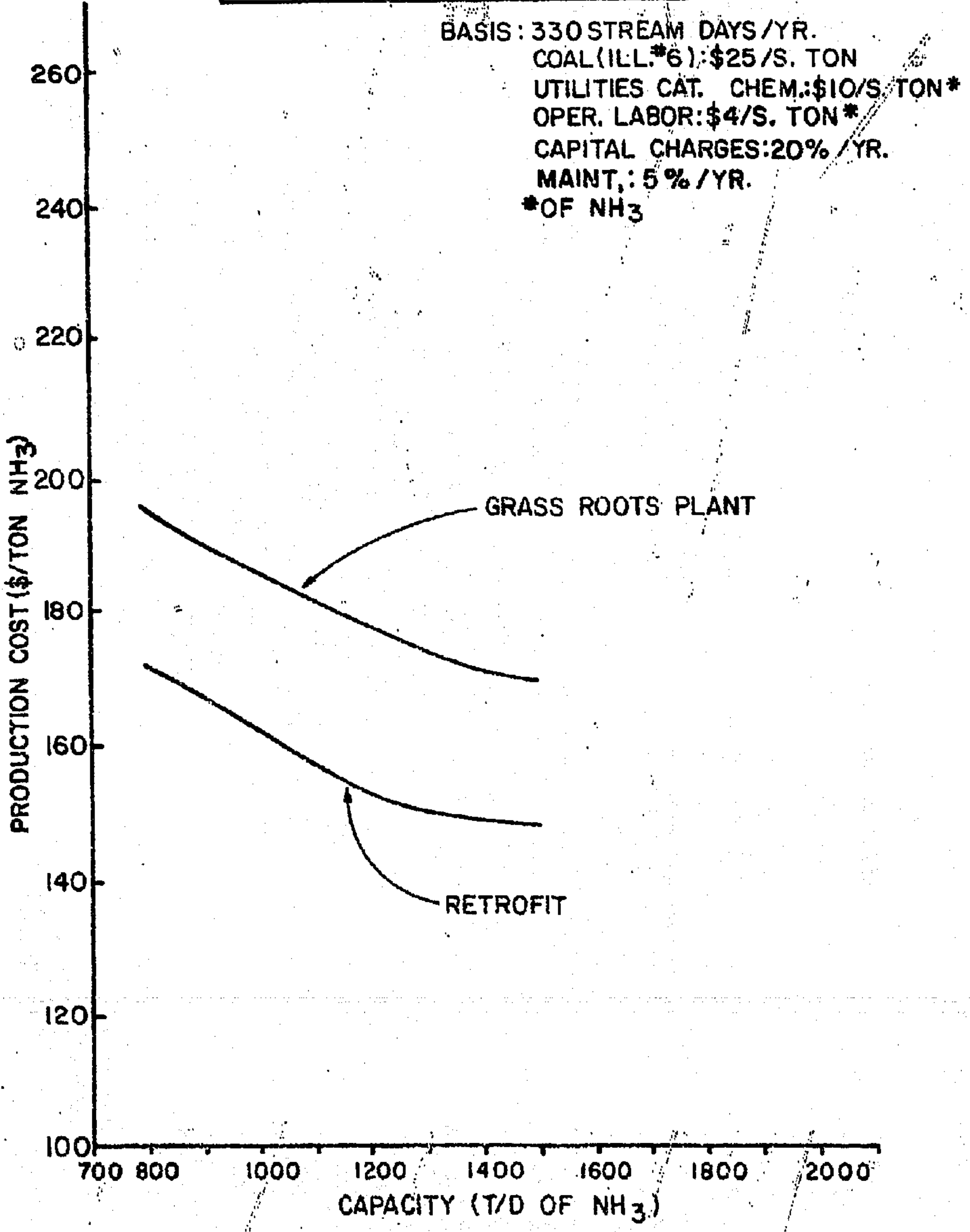


FIG. 4

PRODUCTION COST
VS.
CAPACITY (OF NH_3)



BASIS: 330 STREAM DAYS/YR.
COAL (ILL.#6): $25/S. TON
UTILITIES CAT. CHEM.: $10/S. TON*
OPER. LABOR: $4/S. TON*
CAPITAL CHARGES: 20%/YR.
MAINT.: 5%/YR.
*OF NH_3

TABLE I

APPROXIMATE COMPOSITION OF GAS MANUFACTURED FROM COAL AT THE TVA DEMONSTRATION FACILITY

	% BY VOLUME	
COMPONENT	WET BASIS	DRY BASIS
HYDROGEN	42.0	60.6
NITROGEN	14.1	20.3
CARBON MONOXIDE[a]	2.3[a]	3.3[a]
CARBON DIOXIDE	10.8	15.6
METHANE	0.1	0.1
ARGON	0.1	0.1
WATER	30.6	—
TOTAL	100.0	100.0

BASIS: TOTAL SULFUR = 0.1 ppmv MAXIMUM
STEAM-GAS RATIO = 0.44
HYDROGEN-NITROGEN RATIO = 3.0

NOTE: [a] THE CARBON MONOXIDE CONTENT OF THE GAS IS BASED ON END-OF-RUN CONDITIONS FOR THE SHIFT CONVERSION CATALYST.

Table 2

TYPICAL INVESTMENT COST BREAKDOWNS FOR 1000 TPD RETROFIT AND GRASS ROOTS AMMONIA PLANTS

	INVESTMENT $ MILLIONS		
	Case 1	Case 2	Case 3
	Retrofit maximizing Use of existing equipment	Retrofit optimizing steam balance	Grass Roots Plant
Coal and Ash Handling	7.9	7.9	7.9
Gasification & Slurry Preparation	22.0	36.0	36.0
Steam Boiler	21.0	—	—
Shift, AGR and Sulfur Units	30.0	40.6	40.6
Air Separation Unit	25.5	25.5	25.5
Wastewater Treatment	5.7	5.7	5.7
General Plant, Royalties and Offsites	8.0	10.0	14.0
Ammonia Loop and Refrigeration	—	—	22.0
Ammonia Storage	—	—	5.0
Total Plant Investment	120.1	125.7	156.7

Table 3

ADDITIONAL CHARGES FOR RETROFIT CASE
(TO PAY OUT EXISTING NH_3 PLANT BOOK VALUE)

Basis: 1000 Tons/Day of NH_3

Book Value Remaining For Existing NH_3 Plant, $MM	Added Charges To Retrofit Case (Fig. 4) $/Ton NH_3
75	57
50	38
25	19
0	0