MANUFACTURE OF AMMONIUM SULFATE FERTILIZER FROM GYPSUM-RICH BYPRODUCT OF FLUE GAS DESULFURIZATION - A Prefeasibility Cost Estimate

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ABSTRACT

Costs for constructing and operating a conceptual plant based on a proposed process that converts flue gas desulfurization (FGD)-gypsum to ammonium sulfate fertilizer has been calculated and used to estimate a market price for the product. The average market price of granular ammonium sulfate (\$138/ton) exceeds the rough estimated cost of ammonium sulfate from the proposed process (\$111/ton), by 25 percent, if granular size ammonium sulfate crystals of 1.2 to 3.3 millimeters in diameters can be produced by the proposed process. However, there was at least ±30% margin in the cost estimate calculations. The additional costs for compaction, if needed to create granules of the required size, would make the process uneconomical unless considerable efficiency gains are achieved to balance the additional costs. This study suggests the need both to refine the crystallization process and to find potential markets for the calcium carbonate produced by the process.

INTRODUCTION AND BACKGROUND

The 1990 amendments to the Clean Air Act mandate a 2-stage 10-million ton reduction in sulfur dioxide emissions in the United States. Emission controls using flue gas desulfurization (FGD) technologies have been commercially demonstrated. However, in addition to capital costs for equipment and operating expenses, plants burning high sulfur coal and using FGD technologies must also bear increasingly expensive landfill disposal costs for the solid waste produced. FGD technologies would be much less of a financial burden if successful commercial uses were developed for the gypsum-rich byproducts of wet limestone scrubbing.

A process for converting FGD-gypsum to calcium carbonate and ammonium sulfate by allowing it to react with CO_2 and ammonia or by allowing it to react with ammonium carbonate was studied at the ISGS. A variation of this process could provide electric utilities a means converting the CO_2 and SO_2 in their flue gas to useful commercial products. The fertilizer industry would also be provided with an abundant source of ammonium sulfate to supply sulfur nutrient in NPK fertilizer blends. If successful, the results of this project could provide a solution, from both the environmental and economic standpoints, to the problem of disposing of large quantities of by-products from FGD processes. The technical feasibility of producing fertilizer-grade ammonium sulfate from FGD-gypsum has been assessed (Chou et al., 1995). It is important, therefore, to assess the economic feasibility of producing commercial-grade ammonium sulfate fertilizer from FGD-gypsum The preliminary process flow diagram and the rough cost estimates of the process are presented in this paper.

PROCESS FLOW DIAGRAM

The proposed process is similar to the one used in Europe and India in the 1960s to produce large quantities of ammonium sulfate from natural gypsum (Sauchelli, 1964). Some modifications were made on the gypsum conversion reactor based on pilot plant tests by the TVA (Meline et al., 1971).

Figure 1 shows the proposed flow diagram for the conversion of gypsum to ammonium sulfate fertilizer and calcium carbonate. The flow diagram contains four major units: 1) absorption tower, 2) gypsum converter, 3) concentrator-crystallizer, and 4) solid handling system .

In an absorption tower, ammonium carbonate, a major reactant, is formed by reacting carbon dioxide and ammonia in aqueous solution. The ammonium carbonate solution is then mixed with gypsum ($CaSO_4{\cdot}2H_2O$) and delivered to a gypsum conversion unit .

In the gypsum converter, the mixture is converted to ammonium sulfate solution and calcium carbonate by the following reaction:

$(NH_4)_2CO_3 + CaSO_4{\cdot}2H_2O \rightarrow (NH_4)_2SO_4 + CaCO_3 + 2H_2O$

The overflow from the gypsum converter, containing all of the $(NH_4)_2SO_4$ produced, will give a solution of 35% ammonium sulfate. The solution will be concentrated from 35 to about 42 to 45% in a standard Swenson vacuum-type concentrator with forced circulation. A vacuum crystallizer equipped with a heat exchanger (evaporator-crystallizer) designed to control the conditions for crystal formation is used. The ammonium sulfate solution should be supersaturated within a metastable field during the process of crystallization, in order to produce the larger crystals (particle size 1.2 to 3.3 millimeters with average 2.4 millimeters) required for fertilizer application. Two medium-sized crystallizers are used to provide a shorter retention time during crystallization.

The slurry with crystals from the crystallizer is centrifuged and the crystals are washed with dilute aqueous ammonia. The solution from the centrifuge is used to dissolve fines from screening the product. The $(NH_4)_2SO_4$ crystals are first dried then cooled in rotary type equipment. Material from the cooler is screened on double deck vibrating screens. Oversized and undersized crystals from the screens are directed to the dissolution tank. Suitable size crystals (1.2 to 3.3mm) are delivered to bulk storage.

ASSUMPTIONS FOR RAW MATERIALS ESTIMATION

Gypsum - The yearly production of FGD-gypsum from a 550 Mw electrical generating plant was calculated based on data (Hillenbrenner, 1995) from the City Water Light and Power Utility of Springfield, IL. This company uses a limestone scrubbing process to remove sulfur dioxide from the exhaust gases by converting it to gypsum ($CaSO_4{\cdot}2H_2O$). The plant consumes coal at a rate of 0.96 pounds per kwh and the sulfur content of the coal is about 3%. Based on a load factor of 65% for 300 days per year of operation, the plant produces 200,000 tons gypsum per year.

Ammonia gas - Assuming 98% recovery, one ton of gypsum could produce 0.752 tons of ammonium sulfate. This requires 0.22 tons of ammonia gas (10% excess) consumption per ton of gypsum (Bennett, 1962; Hillenbrenner, 1995) or 0.292 tons of ammonium gas consumption per ton of ammonium sulfate. The proposed plant will require about 123.4 tons of ammonia gas per day (or 43,800 tons per year to produce 150,000 tons of ammonium sulfate per year.

Carbon dioxide - The proposed plant would be built near a utility or a lime producing plant that could supply the carbon dioxide. It was assumed, for this estimate, that the CO_2 would be obtained from the utility or a lime producing plant at no cost.

It is assumed that the 0.581 tons of $CaCO_3$ produced per ton of gypsum processed (or 0.773 tons of $CaCO_3$ per ton of ammonium sulfate) will be recycled to the scrubber. This will result in recycling 325.9 tons of $CaCO_3$ per day.

EQUIPMENT AND COST ESTIMATIONS

The cost estimates are based on the assumption that a linear projection of the TVA pilot plant equipment (Meline et al, 1971) to a commercial scale plant will result in at least a 30 percent increase in production capacity and allow for usual plant down-time while producing 150,000 tons of ammonium sulfate per year. All cost estimates are for a conceptual plant design. Additional references used in the calculation include the sixth edition of the Chemical Engineer's Handbook by Perry & Green and economics factors for 1993 and 1994 found in the chemical engineering journals. See Tables 1 to 3 for the cost summary.

COMPACTION ALTERNATIVE

A specific size of ammonium sulfate is demanded by the fertilizer and chemical industries. If sufficiently large crystals of ammonium sulfate can not be produced, an alternative is to compact the smaller crystals. Based on available literature information (Compaction, 1983), a process for compacting the smaller size product was developed and used to estimate the additional costs.

For the compaction process, the smaller size ammonium sulfate is delivered to a fresh feed hopper. The crystals are weighed and then delivered to the compactors, which are two rolls that are hydraulically operated so that the materials passing between the rolls are compressed into flakes. The flakes are broken to desired sizes by a specially designed coarse crusher. Materials from the crusher are screened to extract the desired particle size. Oversize materials from the screens are returned to the crusher, fines from the screens are recirculated to the compactor. The sized product is usually passed through a rotary drum to remove the rough edges from the product.

RESULTS AND DISCUSSION

The total cost and individual unit costs for the installed equipment for the basic process are shown in Table 1. The fixed capital and working capital investments are shown in Table 2. Table 3 lists the costs for raw material, operating cost, other cost, in-plant (transfer) cost and the ex-gate cost. These estimates assume the cost of ammonia in Illinois is $200 per ton (Green Markets, March '95) and the total material cost is to be $58.40 per ton of product. The operating cost was calculated to be $26.14 per ton (Table 3). Since the calcium carbonate will be recycled, the process receives a credit for the cost of the limestone that is replaced (based on $15 per ton for limestone). The calculations show this credit should be $11.60 per ton of ammonium sulfate. The net production cost of the ammonium sulfate without considering capital cost is $72.94 per ton. The capital costs shown in Table 2, were used to determine the cost of depreciation, taxes, and insurance. With these costs the subtotal cost was estimated to be $86.58. In addition, the cost of interest, the minimum equity return, and pre-tax incentive return need to be added. These costs are calculated using the capital cost in Table 2. These data show the total in-plant cost to be $106.78 per ton of ammonium sulfate. This in-plant cost of ammonium sulfate is used in the next section to calculate the plant sale price for compacted material. A general sales and administrative cost ($4.00 per ton of ammonium sulfate) added to the in-plant cost, yields an estimated sale price of $110.78 of no compaction is needed to produce crystals of the required size.

Price Comparison with Commercial Products- As recorded in "Green Markets," a respected publication of the fertilizer industry, the March price for granular ammonium sulfate in Illinois for the past 3 years were $137 to $154/ton, $134 to 141/ton, and $123 to $135 $/ton for 1995, 1994, and 1993 respectively. These data give an average market price of granular ammonium sulfate of $138/ton.

The average market price of granular ammonium sulfate ($138/ton) exceeds the estimated cost of ammonium sulfate from the proposed process ($110.78/ ton), by a margin of 25 percent. However, there is a margin of error of ±30 percent in the cost estimates. The product could have a very competitive price if the crystals produced fall in the required size range (1.2 to 3.3 millimeters) for granular products.

Costs Including Compaction- If desired size crystals can not be produced, compaction of the smaller crystals will be necessary. A cost estimate (Tables 4 to 6) was made including the additional cost of compaction. In this estimate, the raw material costs include ammonium sulfate at the in-plant transfer price ($106.78/ton) and a binder cost at $0.6/ton. The total raw material cost, therefore, is $107.38 per ton. The additional operating cost for compaction was estimated to be $8.40 per ton. After capital costs, taxes and insurance were added, the total estimated production cost was $126.49/ ton. This results in an estimated in-plant price of $143.09 per ton. When general sales and administrative cost are added, the sale price would be $147.09 per ton. This is about $10 per ton higher than the average March commercial price for the last 3 years, but, close to the average March price for this year ($146).

CONCLUSIONS AND RECOMMENDATIONS

Considering that the costs are for a conceptual plant design and as such subject to the usual margin of error, the results of this study indicate that the proposed process could be economically feasible if crystals of 1.2 to 3.3 millimeters can be produced without compaction. Because the average market price of granular ammonium sulfate ($138/ton) exceeds with the estimated cost of ammonium sulfate without compaction from the proposed process ($110.78/ ton), a profit margin of 25 percent could be possible. If smaller crystals are produced and compaction is necessary, cost estimates show a negative margin between the market price and the sale price. This study indicates the need both to refine the crystallization process and, perhaps, to find other potential markets for the by-product calcium carbonate.

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Table 1. Plant Equipment and Costs

Unit	Dollars
Absorption Tower Tower, Air filter, Pumps, and handling equipment and Installation	$ 625,000
Gypsum Converter Equipment, Foundations, auxiliary equipment, and Installation	$1,500,000
Concentrator Auxiliaries and Incidentals Equipment and Installation	$ 330,000
Crystallizer crystallizer, centrifuge, and Installation	$2,330,000
Solids Handling Dryer, Cooler, Screens Elevator, Conveyors, Dust controlling system, and Installation	$2,100,000
Total	$6,885,000

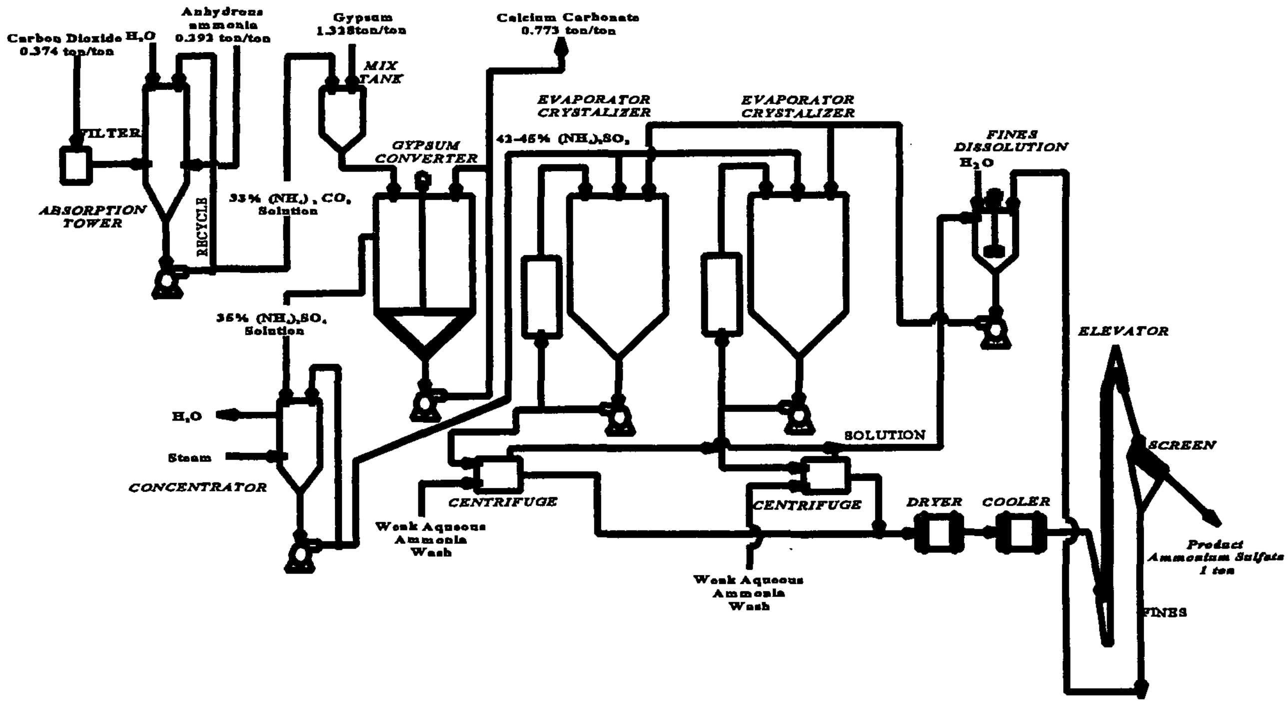

Figure 1: Flow Diagram of the process to convert gypsum to ammonium sulfate.

Table 2. Plant Capital Investment for Ammonium Sulfate (non-granular) Production at a capacity of 422 tons per day or 150,000 tons per year.

ITEM NO.		COST (x 10^6 $)
A. Fixed Capital - Depreciable		21.985
■	Installed Equipment	6.885
■	Design Engineering, etc.	3.400
■	Site Preparation	1.000
■	Auxiliary Facilities	3.525
■	Dry Storage	2.000
■	Incidental and Overheads	5.175
B. Fixed Capital - Nondepreciable		0.94
■	Spare Parts, 2% A	0.44
■	Land	0.50
C. Working Capital - Nondepreciable		1.293
■	30 - day raw materials cost	0.739
■	15 - day Inventory Value	0.554
D. Total Fixed Capital (A+B)		22.923
E. Total Capital (A+B+C)		24.218
F. Average Capital (0.53 A+B+C)		13.885

Table 3. Cost estimate - Production of ammonium sulfate crystalline fertilizer from FGD-gypsum at a capacity of 422 tons per day or 150,000 tons per year (355 days)

Raw Materials	Units	Units/ton	$/Unit	Cost, $/ton
Ammonia	TON	0.292	200	58.40
Gypsum	TON	1.328	0	0
Carbon Dioxide	TON	0.374	0	0
Total raw material cost			**A**	58.40
Operating				
Direct labor (calculated 0.408 man-hrs/ton X $17.00/hr)				6.94
Maintenance (calculated 0.15mh/ton x $20/hr)				3.00
Utilities (estimated)				12.61
Supplies (20% maintenance)				0.60
Plant overhead ($/ton) calculated				2.99
Operating costs,			B	26.14
Cr. for rec. limestone (0.773 tons/ton $(NH_4)_2SO_4$ X $15/ton)			C	11.60
Net operating cost			**B - C**	14.54
Capital				
Depreciation 6.7% A (from Table 2)/TY*				9.82
Ins. & taxes 2.5% (A+B, from Table 2)/TY				3.82
Total capital cost			**D**	13.64
Others				
Interest 10% F (from Table 2) X 0.5/TY				4.62
Minimum equity return 0.075x F(from Table 2) X 0.5/TY				3.47
Pre-tax incentive return 0.075x E(from Table 2)/TY				12.11
Total other costs			**E**	20.20
In-Plant Transfer				
General Sales & administrative cost			**F**	4.00
Ex-gate price, $/ton			**A + (B - C) + D + E + F**	**$110.78**

*TY is tons of ammonium sulfate produced in one year.

Table 4. Compaction Plant Equipment and Costs

Unit	Dollars
Compaction Plant Equipment, Installation, Additional building, offsites	$ 16,000
Total	$ 16,000

Table 5. Additional Capital investment for Compaction of Ammonium Sulfate

ITEM		COST (x 10^6 $)
A. Fix Capital - Depreciable		17.47
■ Installed Equipment	16.00	
■ Start-up Allowance	0.48	
■ Construction Capital	0.99	
B. Fixed Capital-Nondepreciable		0.00
C. Working Capital-Nondepreciable		2.11
30 - day raw materials cost	1.37	
15 - day Inventory Value	0.74	
D. Total Fixed Capital (A+B)		17.47
E. Total Capital (A+B+C)		19.58
F. Average Capital (0.53A+B+C)		11.36

Table 6. Cost estimate - Production of ammonium sulfate crystalline fertilizer from FGD-gypsum at a capacity of 422 tons per day or 150,000 tons per year (355 days), with compaction.

Raw Materials	Units	Units/ton	$/Unit	Cost, $/ton
Ammonium Sulfate	TON	1	106.78	106.78
Binder	TON	0.01	0.60	0.60
Total raw material cost			A	107.38
Operating				
Direct labor (calculated 0.408 man-hrs/ton X $17.00/hr)				2.70
Maintenance (calculated 0.15mh/ton x $20/hr)				1.00
Electricity (45kwh/ton X $ 0.10 /kwh) (estimated)				3.00
Supplies (20% maintenance)				0.20
Plant overhead ($/ton) calculated				1.50
Total operating costs,			**B**	8.40
Capital				
Depreciation 6.7% A (from Table 2)/TY*				7.80
Ins. & taxes 2.5% (A+B, from Table 2)/TY				2.91
Total capital cost			**C**	10.71
Others				
Interest 10% F (from Table 2) X 0.5/TY				3.97
Minimum equity return 0.075x F(from Table 5) X 0.5/TY				2.84
Pre-tax incentive return 0.075x E(from Table 5)/TY				9.79
Total other costs			**D**	16.60
In-Plant Transfer				
General Sales & administrative cost			**E**	4.00
Ex-gate price, $/ton			**A + B + C + D + E**	$147.09

*TY is tons of ammonium sulfate produced in one year.