420
3-26-81

Dr. 2469

NTIS-25
BINS-158
special-200

ENERGY

CONSERVATION

DOE/CS/40276-T1

CONSERVATION OF ENERGY IN AMMONIATION-GRANULATION PLANTS

Development of Technology in the Production of Fertilizers in Ammoniation-Granulation Plants

Progress Report No. 12 (Final Report)

September 1980

Work Performed Under Contract No. AI01-76CS40276

Tennessee Valley Authority
National Fertilizer Development Center
Muscle Shoals, Alabama

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

DISCLAIMER

DISCLAIMER

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A03
Microfiche A01

DOE/CS/40276-T1
Distribution Category UC-95f

CONSERVATION OF ENERGY
IN
AMMONIATION-GRANULATION PLANTS

Development of Technology in the Production of Fertilizers in Ammoniation-Granulation Plants

Progress Report No. 12
(Final Report)
September 1980

Prepared for
Division of Industrial Energy Conservation
U.S. Department of Energy
Washington, DC

by
Tennessee Valley Authority
National Fertilizer Development Center
Muscle Shoals, Alabama

Project Officers

Larry R. Kelso, Chief
Agriculture and Food Process Branch
Division of Industrial Energy Conservation
Office of Conservation and Solar Application
U.S. Department of Energy
Washington, DC 20585

Frank P. Achorn, Senior Scientist
Head, Process and Product Improvement Section
Tennessee Valley Authority
Division of Agricultural Development
National Fertilizer Development Center
Muscle Shoals, Alabama 35660

Interagency Agreement
TVA Contract No. TV-4369A
E(49-28)-1018

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

CONTENTS (continued)

CONSERVATION OF ENERGY IN FERTILIZER AMMONIATION-GRANULATION PLANTS

The United States fertilizer industry produces about 50 million tons of fertilizer each year. This fertilizer is marketed in four types: homogeneous granular NPKS, bulk blends, suspensions, and true solutions. Production of these fertilizers requires about one percent of the nation's energy consumption (1).

Granular fertilizers continue to be a significant portion of fertilizer production in the United States. TVA estimates the 1979 U.S. production at 1.5 million tons of monoammonium phosphate (MAP), 9.4 million tons of diammonium phosphate (DAP), and 10.0 million tons of homogeneous granular NPKS fertilizers. Homogeneous granular NPKS fertilizers are produced in about 100 regional ammoniation-granulation plants. The majority of these plants are located in the eastern United States, and most of them were built between 1955 and 1970. These are the plants considered for energy conservation demonstrations covered by DOE-TVA contract TV-4369A E(49-28)-1018. These NPKS homogeneous fertilizers have several advantages inherent in their production and use. They can be produced from a wide variety of byproducts and materials of low quality. Sulfuric and phosphoric acids are used with ammonia (most economical source of N), particularly if granulation plants are equipped with pipe-cross reactors. The nutrient, sulfur, is easily included in this fertilizer production method. Homogeneous NPKS fertilizers can be bagged, handled in bulk, and applied with fewer grade penalties than bulk blends. Also, micronutrients can be readily incorporated in these homogeneous granules. Lastly, as minimum-till cultivation practices increase to conserve energy, homogeneous NPKS fertilizers can be used without fear of germination injury to seeds (2, 3, 4). For these reasons it is expected this industry will continue to grow.

These ammoniation-granulation plants use about 5 gallons of fuel oil per ton of product for drying their products and generating steam used in granulating. Work conducted in this project demonstrates procedures and equipment to conserve about 83 percent of this fuel.

Theory of Granulation

Before discussing either conventional or pipe-cross reactor granulation, a brief look at the general mechanism of granulation should be helpful. Various solid materials, usually smaller than 2 mm, and liquid materials enter the granulator simultaneously. Within the granulator, owing to its rotary movement, there is simultaneous mixing, chemical reaction, and particle size growth. This growth occurs for several reasons. It usually is dependent upon the amount of chemical heat released and the amount of salts in solution. The result is that a mixture of particles, larger than those that went in, comes out of the granulator. This is achieved by means of two chief processes:

a) Agglomeration occurs when small particles are wetted by the liquid and joined on contact. During the drying process, the liquid crystallizes and gives more cohesion to the final particle.

b) Layering occurs when a small particle is totally covered with a layer of liquid that is later dried. The repeated formation of these layers makes the granule grow in size, and it ultimately looks like the typical layers in an onion.

Conventional Ammoniation-Granulation

Conventional granulation consists of the conversion of the liquid and fine sized raw materials into homogeneous granules. These granules are normally between 6 and 16 (Tyler) mesh in diameter. The two formulating parameters that can be adjusted to accomplish good conventional granulation are liquid phase and heat. The total liquid phase of the formulation is determined by multiplying the percent composition of each raw material by an empirical liquid phase factor. The chemical heat of reaction is calculated for ammonia reacting with phosphoric acid, sulfuric acid, and triple and normal superphosphates. Another source of both heat and liquid phase is steam. The average conventional formulation utilizes about 200 pounds of steam per ton. Fertilizer granules made by the conventional process have a moisture of 5 to 7 percent when they discharge from the granulator. Reduction of this moisture to less than 1 percent requires about 500,000 Btu's of fossil fuel heat input at the dryer. The product must be dried to this low moisture so it will not cake in bulk or bag storage.

These 100 regional ammoniation-granulation plants have a current replacement value of about 10 million dollars each although they cost much less when they were constructed. The production rate of these plants is 25-30 tons per hour with average annual production of 100,000 tons.

A typical regional granulation plant is shown in figure 1. The main rotating equipment consists of an ammoniator-granulator, a dryer, and a cooler. Typically the granulator is 8 feet in diameter and 16 feet long. The dryer and cooler are usually 8 feet in diameter and about 60 feet long. Also the plant includes classifying screens which separate the undersized and oversized material from the product sized fertilizer, normally -6 +16 mesh. Oversized material is crushed in chain or cagemills and rescreened. Usually four or five bucket elevators and several belt conveyors transfer the raw materials, product, recycle, and dust within the process. Exhaust airflows from the granulator, dryer, and cooler are scrubbed. About 5,000 cfm of exhaust gases and steam from the granulator are contacted with an acidified solution in a scrubber. The exhaust airflows from the dryer and cooler, normally each about 20,000 cfm, are passed through cyclones to remove larger dust particles and then through wet scrubbers or baghouses to catch the smaller particles.

New Pipe-Cross Reactor System

In the new TVA pipe-cross reactor process chemical heat of reaction between ammonia and phosphoric and sulfuric acids results in the production of a hot melt. This melt is used to cause granulation instead of the steam used in the conventional process. The pipe-cross reactor is a horizontal reaction tube mounted inside the rotary ammoniation-granulation drum. Details of the reactor and its location in the granulator are shown in figures 2 and 3. The tube is usually 5 or 6 inches in diameter and 10 to 12 feet long. Liquid feeds

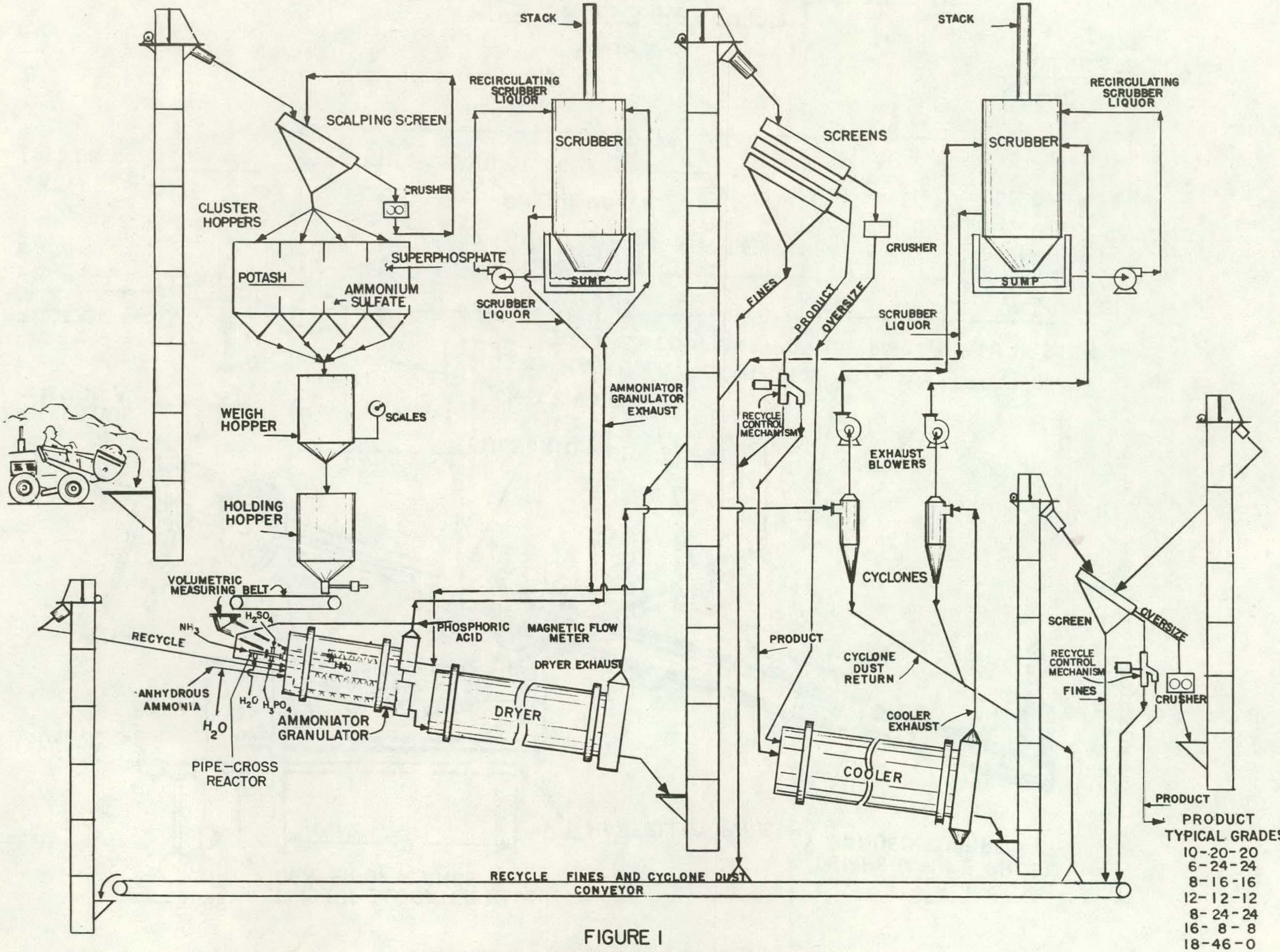


FIGURE I
AMMONIATION-GRANULATION PLANT WITH PIPE-CROSS REACTOR

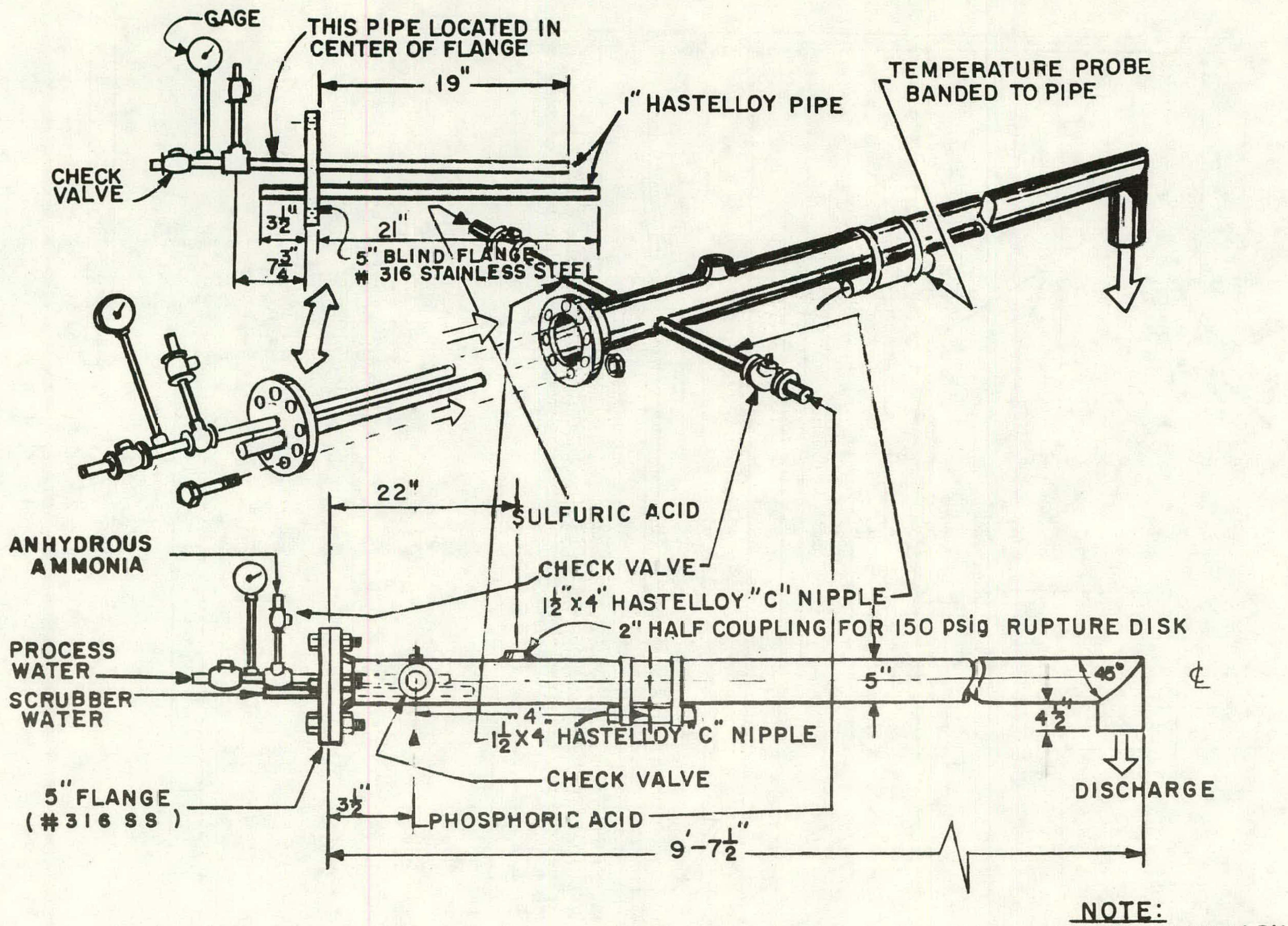
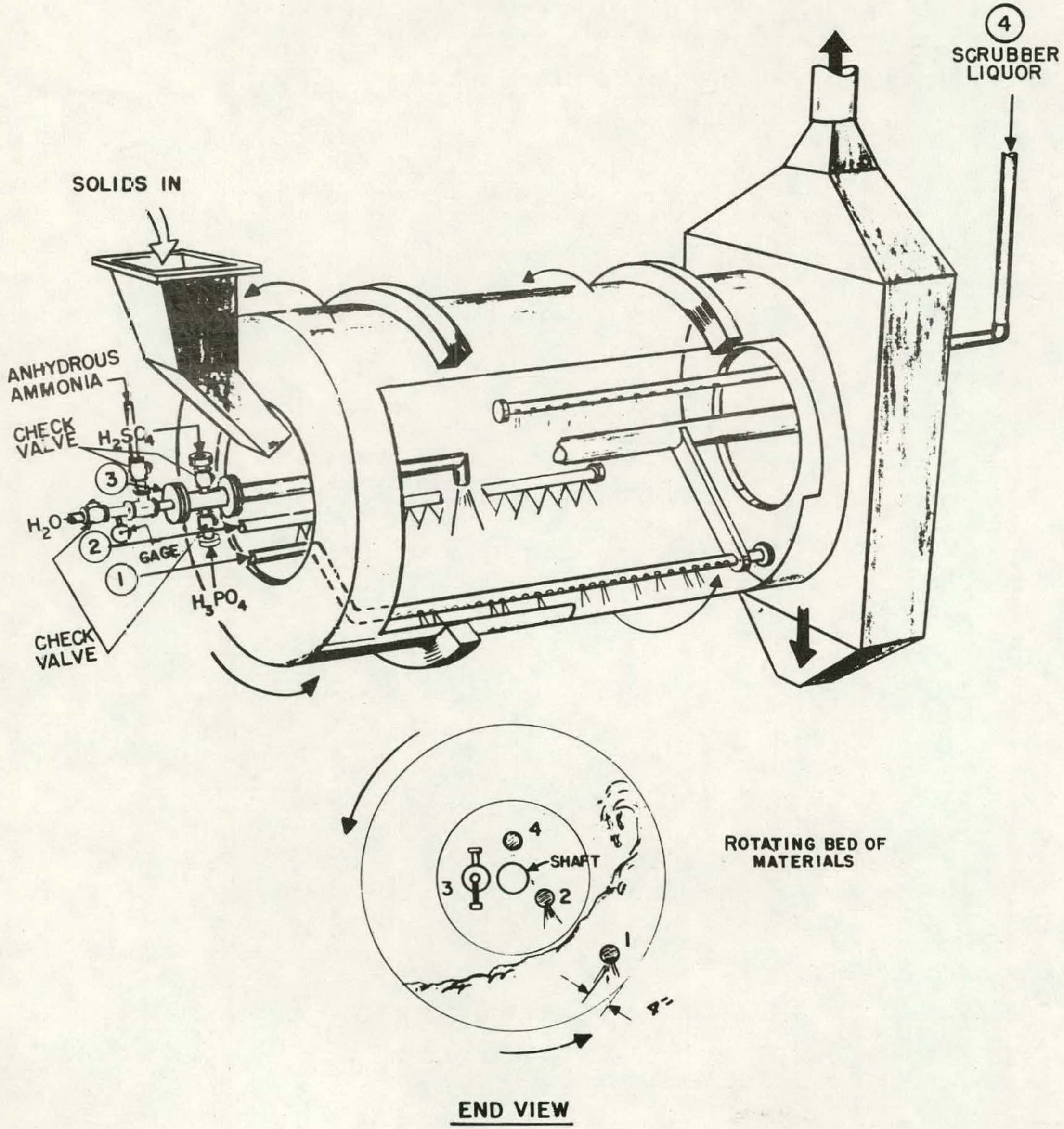


FIGURE 2

PIPE-CROSS REACTOR

5 INCH DIAMETER HASTELLOY "C" REACTOR TUBE



(1) AMMONIA SPARGER — LOCATED AT THE 4 O'CLOCK POSITION $4\frac{1}{2}$" FROM GRANULATION SHELL WITH HOLES FACING THE ROTATING STREAM OF MATERIALS. OVERALL LENGTH-12 FEET. ONE HUNDRED AND FORTY TWO $\frac{1}{16}$" HOLES ON ONE INCH CENTERS WITH SMALL QUANTITY OF WATER ADDED TO PREVENT CAKE AROUND SPARGER.

(2) PHOSPHORIC ACID SPARGER — LOCATED TO DISCHARGE PHOSPHORIC ACID ONTO THE TOP AND NEAR THE CENTER OF THE ROTATING BED OF MATERIALS. OVERALL LENGTH-8.9 FEET. SIXTEEN $\frac{3}{8}$ INCH HOLES ON THREE INCH CENTERS.

(3) PIPE-CROSS REACTOR — LOCATED TO DISCHARGE NEAR THE LONGITUDINAL CENTER OF THE BED AND AT A POINT ONE THIRD FROM THE BOTTOM EDGE OF THE BED OF MATERIAL IN THE GRANULATOR.

(4) SCRUBBER WATER — LOCATED ABOVE THE BED IN GRAN-ULATOR TO DRIBBLE SCRUBBER WATER ONTO BED.

FIGURE 3

LOCATION OF PIPE CROSS REACTOR IN ROTARY AMMONIATOR—GRANULATOR

enter the reaction tube outside the granulator and flow toward the discharge end. Ammonia enters through a smaller tube at the feed end of the reactor. It is centered in the reactor tube and discharges 19 inches from the feed end. Sulfuric and phosphoric acids are introduced through lines installed perpendicular to the reactor tube. These feed lines form a "cross" arrangement from which the name is derived. Water is added to the ammonia prior to its introduction into the reactor. This water induces a smoother reaction between the ammonia and acids. Reacting these materials inside a confined area retains much of the chemical heat of reaction. Water present in the reactor undergoes vaporization and flashes off at the pipe's discharge. This water vapor is removed in the exhaust gases from the granulator. The temperature of the essentially anhydrous melt is well above its melting point when it is discharged onto the rolling bed of the material in the granulator. Moisture removal from the product occurs during granulation and as the product is cooled from about 220°F to 120°F. The resulting product has a moisture of less than one percent; at this moisture, the product has excellent hardness and stores well in bulk or bag storage.

Because of the corrosive nature of the raw materials, reactor construction must be of Hastelloy C-276--a special alloy that is resistant to acid corrosion at temperatures up to 300°F. In some formulations it is desirable to install an insert into the discharge end of the reactor. This insert is shown in figure 4 and is used to improve melt spray characteristics from the reactor when relatively low reaction rates are used. It also causes intimate contact and complete reaction of ammonia and acids. It can be constructed of stainless steel (type 316).

Demonstration Plant Tests

In conventional granulation the amount of steam used to promote granulation is usually not measured; however, calculations and rough measurements have shown that the average conventional NPKS granulation plant consumes about 200 pounds of steam per ton of product to promote granulation. These data show the materials used in the formulation, the calculated amount of chemical heat per ton, estimated liquid phase, fossil fuel consumption, electrical consumption and energy required to transport the finished product 1,000 miles by railroad. These data are for 12-12-12 (table 1), 6-24-24 (table 2), and 8-32-16 (table 3) grades. Tables 4, 5, and 6 show data for these same grades produced in plants equipped with a TVA pipe-cross reactor. Where filler appears in the formulation, no energy considerations are made since sand obtained near the granulation plant is normally used for filler. Also the electrical consumption per ton of product is reported as a constant 210,000 Btu's of equivalent electrical energy. These examples of conventional and pipe-cross reactor granulation do not by any means cover all of the many ways these and other grades can be produced by either granulation process. They do, however, show representative energy savings that can be obtained through use of the PCR process. As noted in the tables, the energy required to produce the raw materials and transport them are about the same for either conventional or PCR granulation. If the 6-24-24 and 12-12-12 grades are compared, an average of 535,000 Btu's is saved. This saving occurs due to elimination of fossil fuel drying when the PCR is used; fossil fuel used to generate the steam is not included. This additional saving is estimated to be equivalent to 250,000 Btu per ton of product. Therefore, an average of 785,000 Btu's per ton of production is eliminated.

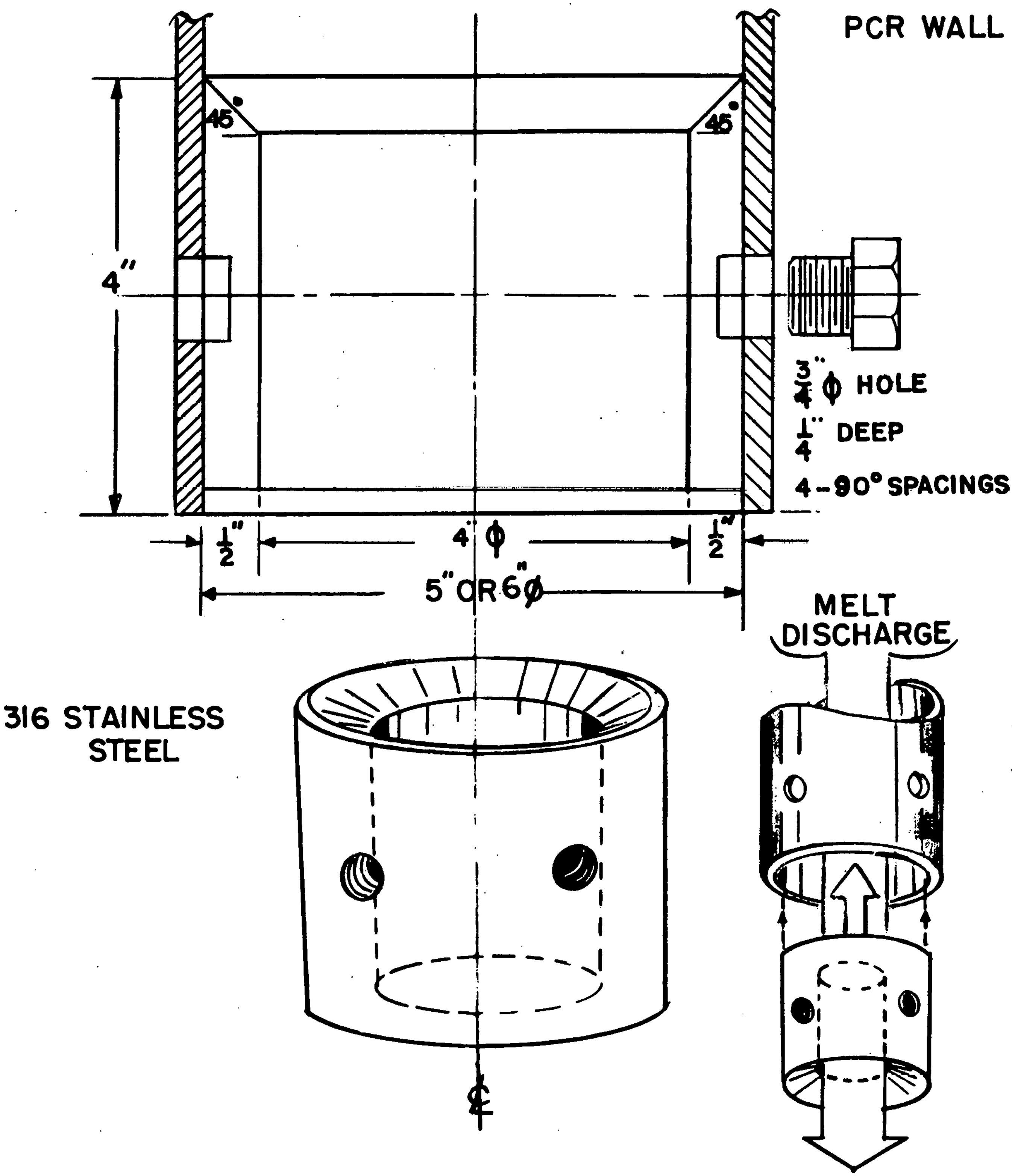


FIGURE 4

DISCHARGE NOZZLE FOR 5" OR 6" PCR.

The W. R. Grace plant at Columbus, Ohio, installed a PCR and obtained dramatic increases in production rates. Appendix 1 shows a letter from L. E. Ingram, Manager NPK Technical Service of this company, to Frank Achorn dated April 15, 1980, concerning the excellent results and savings his company has received with this new process. While they were only able to produce 6-24-24 at 25 tons per hour by conventional granulation, they are now able to produce this grade at almost 40 tons per hour using the PCR. Their electrical savings are quite substantial and a major contributor to their return on investment.

The previously discussed tables take no energy credit for the use of byproduct raw materials. In several instances major energy and raw material cost savings are obtained by use of byproduct ammonium sulfate or sulfuric acid. At a PCR installation in Missouri, byproduct sulfuric acid is obtained from another company only 125 miles from the plant. Their cost of this 60° Bé. sulfuric acid is extremely low. Before the sale of sulfuric acid was arranged, the acid producer was discharging the acid into the sewer and paying a $25,000 per month fine to the city. The savings on the use of byproduct acid such as this are several fold. In addition to savings in transportation, this sulfuric acid does not have to be produced in sulfuric acid plants and energy is saved by eliminating the waste treatment of the acid. Several plants with PCR's also use byproduct ammonium sulfate from the steel industry. We expect the use of such byproduct sulfur materials to increase in coming years as sulfur is removed in the coal burning process at electric generating stations. For example, TVA will be marketing about 100,000 tons per year of sulfuric acid recovered from its Johnsonville coal burning electric generating plant. Regional ammoniation-granulation plants, most of which are located in the eastern U.S., should be readily able to use sulfuric acid obtained from sources such as this, if they have installed a TVA PCR.

In the attached letter (appendix 2) from Gene Hale of Mid-Ohio Chemical, Washington Court House, Ohio, to Frank Achorn dated June 25 is a discussion of this firm's actual energy savings over a 3-month period. The PCR reduced their fossil fuel drying about 95 percent and also enabled them to use large quantities of byproduct sulfuric acid.

The attached figure in appendix 3 (Natural Gas Consumption for Fertilizer Drying) shows the effect of elimination of fossil fuel for drying at the MFA granulation plant in Palmyra, Missouri. Although this cooperator's cost of natural gas per ton increased by about 1,500 percent, the actual cost of fuel per ton of product for drying decreased to zero. This cooperator does not use fossil fuel now for the production of their granular NPKS products because of their efficient use of the PCR process.

In addition to the energy conservation aspects of the TVA PCR process, reduced atmospheric emissions have also been a major selling point. In conventional granulation there are more dust and fine particles moving through the processing equipment. Also a major problem has occurred when sulfuric acid, potash, and ammonia are introduced into a conventional bed formulation. The sulfuric acid reacts with the potash forming hydrochloric acid which in turn reacts with ammonia. An aerosol of ammonium chloride is produced. These very small particles are extremely difficult to scrub from the ammoniator-granulator exhaust gases. As the emission test results in table 7 indicate, particulate emissions from the ammoniator-granulator are almost nonexistent when using the PCR. It can also be noted that fluorine emissions are nil in the operation of this process. Recent emission sampling work in Ohio has shown that ammonia losses are even lower when all of the ammonia fed to the formulation is reacted with acids in the PCR. When the ammonia was split between the PCR and the bed of the granulator, about 4 percent of the ammonia fed to the process had to be scrubbed. But when all of the ammonia was reacted in the PCR, only 1 to 2 percent of the ammonia fed to the process had to be scrubbed. The only particulate emissions are contained in the dryer and cooler exhaust flows which normally pass through cyclones and then into either baghouses or wet scrubbers. In summary, the PCR process will in most cases reduce atmospheric emissions from these granulation plants.

Another Ohio granulation plant (Landmark, Incorporated at Mt. Gilead, Ohio) has experienced several advantages in the use of the PCR in addition to the energy savings. Landmark's list of advantages of the PCR process over the conventional bed granulation is included in appendix 4.

TVA engineers have been successful in demonstrating and commercializing the TVA PCR process, and this success has been due to TVA National Fertilizer Development Center's ongoing position of influence in the fertilizer industry. Appendix 5 lists the 22 installations of PCR's in the United States. About 8 more installations are being planned. Appendix 6 lists the engineering contractors TVA has worked with over the past several years. Another important part of NFDC's injection of technology into the fertilizer industry is conducting and participating in technical meetings. Appendix 7 lists recent publications and presentations on the pipe-cross reactor process.

Investment Cost and Payback

The installation of a TVA pipe-cross reactor in an existing regional NPKS granulation plant is extremely attractive economically. The replacement cost of a typical granulation plant is about $10,000,000, and almost $100,000 per year will be spent on equipment in a properly maintained plant. The cost of a typical PCR installation will be only $60,000 to $65,000. Thus, the investment to retrofit a PCR into one of these plants is relatively small.

Table 8 entitled "Economics for PCR Installation" (5) shows energy savings, investment costs, and payback times. The letter in appendix 8 from Joe Prosser to Gene Hale shows an engineering contractor's equipment list and quoted price for a PCR installation at Mid-Ohio Chemical Company, Incorporated, Washington Court House, Ohio, plant. Later discussions by TVA engineers with the Prosser Company and Mid-Ohio Chemical Company personnel resulted in the inclusion of an additional $13,000 for increased phosphoric acid pumping and piping capacity. This PCR installation contract totaled exactly $60,000. At late 1979-early 1980 prices, the PCR itself costs about $10,000. Normally an additional $50,000 is required for pumps, pipings, meters, and valves. Since these installations are retrofits, the exact equipment needed varies for each location.

Payback time will normally be less than one year as shown in table 8. This payback is calculated on the basis of the elimination of steam and the reduction of fossil fuel drying from the granulation process. A conservative natural gas price of $2.68 per 1,000 cubic feet was used. If increased production rates reduce electrical consumption per ton of product or cheap byproduct raw materials can be used with the PCR, payback times of 1/4 to 1/3 year are obtained. Under such circumstances, many of the companies choose to add other needed capital investment projects to the PCR projects. In a number of cases the PCR installation has significantly upgraded the overall condition of the granulation plant. With an average size plant of 30 tons per hour, the new investment in the PCR can be paid back in about 6 months. This payback period is very short for the fertilizer industry.

Computer Model of Pipe-Cross Reactor Process

Field operating experience at commercial pipe-cross (PCR) installations has been used by NFDC's computer system's analysts to develop a PCR model. This model formulates various fertilizer grades on a "least cost" basis. Separate ammoniation parameters are used for the PCR reactions and the reactions in the bed of the granulator. These parameters may be adjusted to achieve the desired degree of ammoniation. Typically, the original output is used to "fine tune" the raw material and operating conditions until a satisfactory formula is presented. Although the output is frequently adjusted by someone with a good understanding of the process, the computer model saves considerable time over hand calculated methods. Several industrial cooperators--Landmark, Incorporated, IMCC, and W. R. Grace--are using this computer model in their PCR operations. Information from actual industrial users is considered essential to the further development of this model.

Future efforts will be made to model granulation predictability by modifying existing conventional granulation theories to describe PCR operating experience. Currently, no theory exists to quantitatively describe PCR melt granulation.

Summary

At this time (fall of 1980), 22 pipe-cross reactors have been installed in regional granulation plants in the United States. There are a total of about 100 such plants which means that about 22 percent of the market has been penetrated under this DOE contract. About 9 more PCR installations are in the planning stages at this time. Under our new DOE contract, which is mainly concerned with implementation of the PCR's in DAP granulation plants, we will also be continuing to promote the use of the PCR in regional NPKS granulation plants.

These PCR's have been retrofitted into granulation plants which have replacement values of about $10,000,000. The average PCR installation costs $60,000 and takes less than a year to pay for itself. In addition, energy savings, easier plant operation, reduced air pollution, and improved fertilizer product quality also result from its use. We estimate that the 22 installed PCR's are saving about 9 million gallons of fuel oil per year. It is estimated that by 1985 about 80 percent penetration of the market will be realized with an energy saving equivalent to about 35 million gallons of fuel oil.

Table 1

Conventional 12-12-12 Grade
Energy Inputs from Production and Transportation
of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Anhydrous NH_3 (82.2% N)[a]	139	2,429	48.65	
Ammonium sulfate (20.5% N)	490	2,281	171.5	
Triple superphosphate (46% P_2O_5)	218	409	76.3	
Diammonium phosphate (18% N, 46% P_2O_5)	200	1,251	70.0	
Phosphoric acid (54% P_2O_5)	89	225	31.15	
Potash (60% K_2O, standard size)	400	228	140.0	
Sulfuric acid (60° Bé.)	384	81	134.4	
Filler	173	-	-	
Granulation Conditions				
Steam (lb/ton product)	unknown			
Chemical heat per ton (10^3 Btu)[b]	347			
Liquid phase (without steam)	686			
Fuel consumption by dryer, per ton[c]				546
Electrical consumption, per ton				210
Energy Input, per ton of product		6,900	672	756

[a]Degrees of ammoniation - Phosphoric acid = 7.2 lbs NH_3/20 lbs P_2O_5
TSP = 3.8 lbs NH_3/20 lbs P_2O_5
Sulfuric acid = 0.347 lbs NH_3/lb 100% H_2SO_4

[b]Chemical heat of reaction - Btu/lb NH_3 for TSP = 1,643 Btu/lb NH_3 for H_2SO_4 = 2,696 Btu/lb NH_3 for H_3PO_4 = 2,220

[c]From actual fuel consumption

[d]Railroad, use 700 Btu/ton mile

Table 2

Conventional 6-24-24 Grade
Energy Inputs from Production and Transportation
of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Anhydrous NH_3 (82.2% N)[a]	122	2,132	42.7	
Ammonium nitrate (33.5% N)	72	720	25.2	
Byproduct phosphate (42% P_2O_5)	357	611	125.0	
Phosphoric acid (54% P_2O_5)	630	1,594	220.5	
Potash (60% K_2O, standard size)	800	456	280.0	
Filler	85	-	-	
Granulation Conditions				
Steam (lb/ton product)	unknown			
Chemical heat per ton (10^3 Btu)[b]	272			
Liquid phase	716			
Fuel consumption by dryer, per ton[c]				587
Electrical consumption, per ton				210
Energy Input, per ton of product		5,510	693	797

[a]Degrees of ammoniation - Phosphoric acid = 7.2 lbs NH_3/20 lbs P_2O_5

[b]Chemical heat of reaction - Btu/lb NH_3 for H_3PO_4 = 2,220

[c]From actual fuel consumption

[d]Railroad, use 700 Btu/ton mile

Table 3

Conventional 8-32-16 Grade
Energy Inputs from Production and Transportation of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Solution 530 {53.0% N (49% NH_3, 36% NH_4NO_3)}[a]	115	1,440	40.25	
Triple superphosphate (46% P_2O_5)	815	1,530	285.25	
Diammonium phosphate (18% N, 46% P_2O_5)	580	3,630	203.00	
Potash (60% K_2O, standard size)	335	191	117.25	
Potash (60% K_2O, coarse)	200	141	70.0	
Sulfuric acid (66° Bé.)	30	9	10.5	
Granulation Conditions				
Steam (lb/ton product)	96			
Chemical heat per ton (10^3 Btu)[b]	107			
Heat supplied as steam per ton	93			
Fuel to boiler (80% efficiency) per ton				120
Liquid phase (without steam)	444			
Liquid phase (with steam)	636			
Fuel consumption by dryer, per ton[c]				300
Electrical consumption, per ton				210
Energy Input, per ton of product		6,940	726	630

[a] Degrees of ammoniation - TSP = 2.5 lbs NH_3/20 lbs P_2O_5
Sulfuric acid = 0.347 lbs NH_3/lb 100% H_2SO_4

[b] Chemical heat of reaction - Btu/lb NH_3 for TSP = 1,643 Btu/lb NH_3 for H_2SO_4 = 2,696

[c] From actual fuel consumption or calculated from moisture content in and out of dryer

[d] Railroad, use 700 Btu/ton mile

Table 4

Pipe-Cross Reactor 12-12-12 Grade
Energy Inputs from Production and Transportation
of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Pipe-cross reactor				
Ammonia[a]	184	3,215.0	64.4	
Sulfuric acid (66° Bé.)	456	132.0	159.6	
Phosphoric acid (54% P_2O_5)	456	1,154.0	159.6	
Ammoniator-Granulator				
Ammonia[a]	23	402.0	8.05	
Ammonium sulfate	400	1,862.0	140.0	
Potassium chloride	400	228.0	140.0	
Filler	176	-	-	
Granulation Conditions				
Steam (lb/ton product)	none			
Chemical heat per ton (10^3 Btu)[b]	530			
Fuel consumption, per ton[c]				none
Electrical consumption, per ton				210
Energy Input, per ton of product		6,990	672	210

[a]Degrees of ammoniation - Phosphoric acid = 4.9 NH_3/20 lbs P_2O_5
Sulfuric acid = 0.347 lbs NH_3/lb 100% H_2SO_4

[b]Chemical heat of reaction - Btu/lb NH_3 for H_3PO_4 = 2,220 Btu/lb NH_3 for H_2SO_4 = 2,696

[c]Actual fuel consumption, dryer burner off

[d]Railroad, use 700 Btu/ton mile

Table 5

Pipe-Cross Reactor 6-24-24 Grade
Energy Inputs from Production and Transportation of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Pipe-cross reactor				
Ammonia[a]	83	1,450	29.05	
Sulfuric acid (66° Bé.)	142	38	49.7	
Phosphoric acid (53% P_2O_5)	330	835	115.5	
Ammoniator-Granulator				
Ammonia[a]	67	1,171	23.45	
Phosphoric acid (53% P_2O_5)	600	1,518	270.0	
Potassium chloride	800	456	280.0	
Filler	144			
Granulation Conditions				
Steam (lb/ton product)	none			
Chemical heat per ton (10^3 Btu)[b]	355			
Fuel consumption, per ton[c]				none
Electrical consumption, per ton				210
Energy Input, per ton of product		5,468	708	210

[a]Degrees of ammoniation - Phosphoric acid = 4.3 lbs NH_3/20 lbs P_2O_5
Sulfuric acid = 0.347 lbs NH_3/lb 100% H_2SO_4

[b]Chemical heat of reaction - Btu/lb NH_3 for H_3PO_4 = 2,220 Btu/lb NH_3 for H_2SO_4 = 2,696

[c]Actual fuel consumption, dryer burner off

[d]Railroad, use 700 Btu/ton mile

Table 6

Pipe-Cross Reactor 8-22-11 Grade
Energy Inputs from Production and Transportation
of Raw Materials and Granulation of Product

Formulation	Raw Material Lb/ton Product	Energy to Produce Raw Material 10^3 Btu	Energy to Transport 1,000 miles[d] 10^3 Btu	Energy to Granulate 10^3 Btu
Pipe-cross reactor				
Ammonia[a]	89	1,555.0	31.15	
Sulfuric acid (66° Bé.)	124	66.9	43.4	
Phosphoric acid (54% P_2O_5)	200	506.0	70.0	
Ammoniator-Granulator				
Ammonia[a]	64	1,119.0	22.4	
Ammonium sulfate	200	931.0	70.0	
Phosphoric acid (54% P_2O_5)	565	1,430.0	197.75	
Triple superphosphate (0-46-0)	106	199.0	37.1	
Potassium chloride	312	178.0	109.2	
Micronutrients	159	-	-	
Filler	327	-	-	
Granulation Conditions				
Steam (lb/ton product)	none			
Chemical heat per ton (10^3 Btu)[b]	424			
Fuel consumption, per ton[c]				none
Electrical consumption, per ton				210
Energy Input, per ton of product		5,980	581	210

[a]Degrees of ammoniation - TSP = 0.0 lbs NH_3/20 lbs P_2O_5
Phosphoric acid = 4.3 lbs NH_3/20 lbs P_2O_5
Sulfuric acid = 0.347 lbs NH_3/lb 100% H_2SO_4

[b]Chemical heat of reaction - Btu/lb NH_3 for TSP = 1,643 Btu/lb NH_3 for H_2SO_4 = 2,696 Btu/lb NH_3 for N_3PO_4 = 2,220

[c]Actual fuel consumption, dryer burner off

[d]Railroad, use 700 Btu/ton mile

Table 7

Emission Test Results, 4-Inch Pipe-Cross Reactor
Granulation Plant, Alabama

Emission Test	Date	Grade	Ammonia[a] Lb/Hour Out of Scrubber	Stack Temp. °F	Actual Gas Flow ft^3/min	Stack Loss Rate – Lb/Hour: Fertilizer Particulate	Free NH_3	NH_4Cl	NH_4F	$(NH_4)_2SO_4$
A	6/21	8-24-24	–	132	5340	Nil	84	1.4	Nil	0.4
B	6/22	8-24-24	–	146	5340	Nil	138	0.4	Nil	0.3
C	6/23	11-44-0	20	145	5340	Nil	10	Nil	Nil	0.3
D	6/23	12-48-0	60	150	5340	Nil	94	Nil	Nil	0.1
E	6/24	8-24-24	30	150	5340	Nil	45	0.3	Nil	Nil

[a] Rapid hand-pump test

Table 8

ECONOMICS FOR PCR INSTALLATION

Plant Size Ton/Hr.	Plant Energy Costs $/Yr.		Energy Savings $/Yr.	Total Installed Investment	DCF RATE OF RETURN (Escalation of Energy)		Payback Time Yrs.
	CONVENTIONAL	PIPE-CROSS REACTOR			0%	10%	
15	197.000	82,000	115,000	55,000	116%	126%	.9
20	263,000	109,000	154,000	60,000	142%	152%	.7
30	394,000	164,000	230,000	68,000	187%	197%	.5
40	526,000	219,000	307,000	75,000	226%	235%	.4

REFERENCES

1. Achorn, F. P., D. G. Salladay and Jeffery L. Greenhill. "Effects Of Energy Costs On Fertilizer Costs," For Presentation at the TVA Fertilizer Conference, Kansas City, Missouri. August 5-6, 1980.

2. Bouldin, D. R., N. Herendeen, and W. S. Reid, "Methods of Application of Phosphorus and Potassium Fertilizers for Corn in New York," New York State College of Agriculture, Ithaca, New York. March 1968. p 1.

3. 1979 Cornell Recommends for Field Crops, New York State College of Agriculture and Life Sciences, Ithaca, New York. pp 11 and 46.

4. 1979 Agronomy Guide, Pennsylvania State University, College of Agriculture, Extension Service, University Park, Pennsylvania. p 6.

5. "Energy Conservation in Ammoniation-Granulation Plants," Centec Corporation, Reston, Virginia, and Fort Lauderdale, Florida. 1980.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Appendix 1

GRACE

Agricultural Chemicals Group

W. R. Grace & Co
100 N. Main Street
P.O. Box 277
Memphis, Tennessee 38101

(901) 522-2000

April 15, 1980

Mr. Frank Achorn
Tennessee Valley Authority
402 Chemical Engineering Bldg.
Muscle Shoals, Ala. 35660

Dear Frank:

As you know, we installed the TVA cross pipe reactor system in our Columbus, Ohio, granular plant last fall. The startup went smoothly and there have been no major operational problems. We have encountered significant reductions in energy consumption through the use of the cross pipe system.

We have evaluated its use in our other plants due to the success at Columbus. Although the projects have not yet been approved, we are planning to install cross pipe reactor systems in two more plants this summer. Also, we will probably budget to install the fourth cross pipe reactor in 1981.

The original Columbus installation was based on design data provided by TVA. Your review of the process design and technical assistance on startup was very helpful.

Frank, the cross pipe reactor system will definitely result in conservation of energy and help us minimize our production costs. These are two extremely important goals in today's tight energy and money markets.

Your group has done an excellent job in designing the system and communicating with industry. Again, thanks for your help.

Very truly yours,

W. R. Grace & Company
AGRICULTURAL CHEMICALS GROUP

L. E. Ingram, Manager
NPK Technical Services

LEI/jnm

Appendix 2

Mid-Ohio Chemical Terminals, Inc.

Box 280, Washington C. H., Ohio 43160

June 25, 1980

Mr. Frank Acorn
Tennessee Valley Authority
National Fertilizer Development Center
Muscle Shoals, Alabama 35660

Dear Frank:

I want to take this opportunity to tell you how much I appreciated the help your staff extended me during the past year. You certainly have a group to be proud of.

With the help of your staff, The Prosser Company installed our Pipe Cross Reactor in February. In checking our records, I find that during February, March and April of 1979 we produced 14,580 tons of finished mixed fertilizer. During this time, we used 67,609 cubic feet of gas at a cost of $16,442.62. During the same period of 1980 with the PCR, we produced 14,754 tons of finished product while consuming 3,226 cubic feet of natural gas at a cost of $980.74.

In addition to the above savings, I estimate that we will consume between 8,000 and 10,000 tons of spent sulphuric acid at a savings of approximately $15.00 per ton. Also in addition, the product that we are producing is much superior to the product we were manufacturing prior to the PCR.

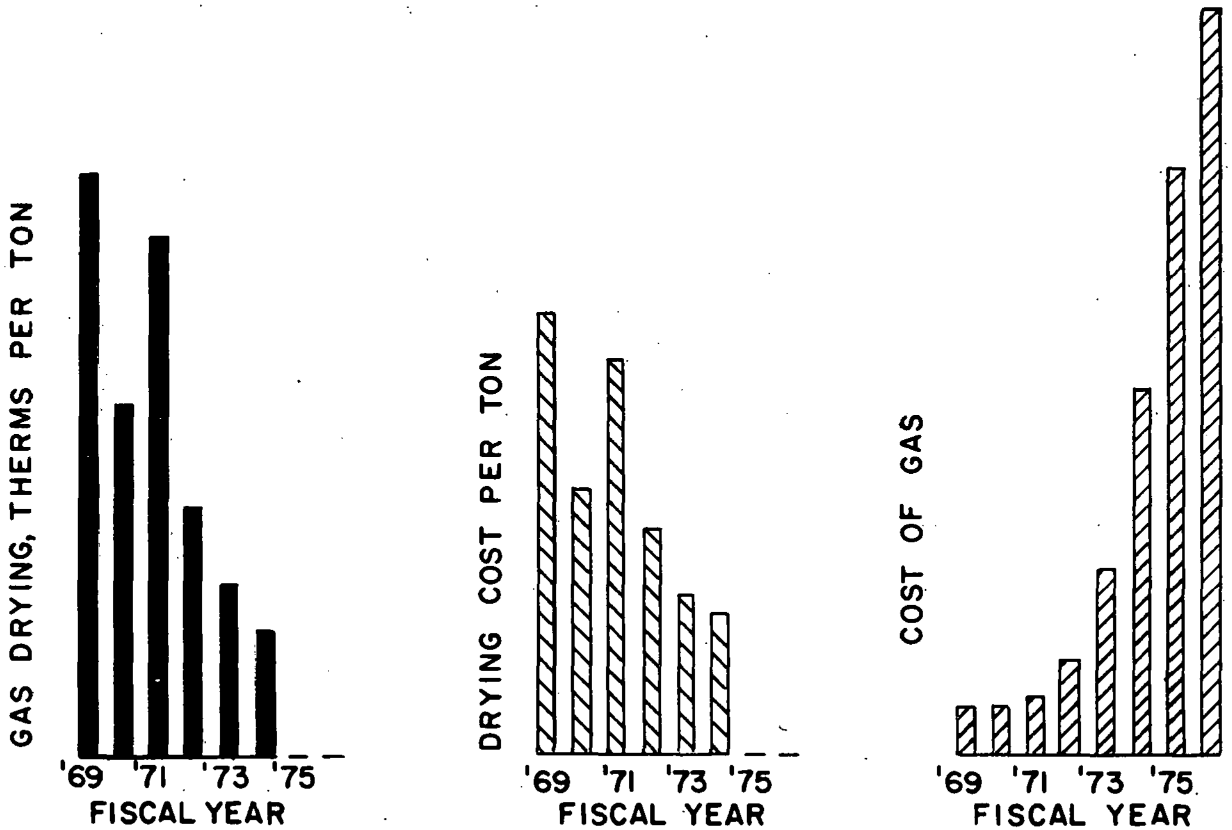
In summary, it is obvious that we are tremendously happy with the economic savings the PCR has given us and are very happy with the product it is producing. If we can be of any assistance to you in providing you with data from this equipment, please do not hesitate to call upon us.

Sincerely,

Gene C. Hale

GCH/dr

NATURAL GAS CONSUMPTION FOR FERTILIZER DRYING



METHOD OF OPERATION

'72,'73,'74
USE OF SOME SUPERPHOSPHORIC ACID AND CHANGED OPERATIONS FROM A 1.4 MOLE RATIO TO 1.0

'74
BEGAN USE OF TVA PIPE-CROSS REACTOR

'75,'76
FULL USE OF PCR-- NO HEAT USED IN FERTILIZER PRODUCTION OTHER THAN THE HEAT OF REACTION OF THE CHEMICALS THEMSELVES.

Appendix 4

Advantages of PCR Process over Conventional Bed Granulation

1. The pipe-cross reactor process gives a much more homogenous chemical blend and uniform appearance thus restoring the traditional superiority of granulated fertilizer over blends which gradually eroded as we have substituted high analysis materials such as DAP in our formulation.

2. Large amounts of acids can be used in formulations. This is an advantage when acids are relatively cheap. Large volume acid use is also desirable when tank car demurrage becomes threatening.

3. Metering liquids is simpler, more precise, and allows better fine tuning of the process than is possible when weighing and handling dry materials.

4. A further advantage that follows item #3 is that dry material shrinkage is reduced because less dry material is handled.

5. Because there is less dry material handling, labor costs will be decreased and maintenance costs on handling equipment such as elevators and tractors should likewise be reduced.

6. When all the anhydrous ammonia enters via the pipe, N losses are significantly less than losses incurred during conventional granulation.

7. There is decreased use of fuel for drying when grades are properly formulated.

8. Chute plugging, caused by tacky ammoniated material (conventional bed formula), has been essentially eliminated because of flash drying of the product in the ammoniator during the PCR process.

9. The final product is harder and, therefore, not as dusty.

10. Increased production rates, in some cases, are possible.

11. Baghouse leakage of sub-micron particles is less than half that occurring during non-pipe runs.

Appendix 5

Installation of Pipe-Cross Reactor
In Fertilizer Granulation Plants
To Conserve Energy

Installed

Company	No. of Reactors
Missouri Farmers Association: Palmyra, Missouri	1
W. R. Grace: Columbus, Ohio	1
Landmark, Incorporated: Mt. Gilead, Ohio	1
IMCC: Florence, Alabama; Americus, Georgia; Winston-Salem, North Carolina; and Spartanburg, South Carolina	4
Gold Kist: Hanceville, Alabama	1
Mobil Chemical Company: (Formerly Olin Co.), Pasadena, Texas	2
Lebanon Chemical Company: Baltimore, Maryland	1
J. R. Simplot Company: Pocatello, Idaho	1
Swift Ag. Chemicals: East St. Louis, Illinois	1
Smith-Douglass, Div. of Borden Chemical: Norfolk, VA; Streator, IL; Saginaw & Holland, MI	4
USS Agr. Chemicals: Cherokee, Alabama	1
Mid-Ohio Chemical Company: Washington Court House, Ohio	1
Valley Nitrogen Cooperative: Helm, California	1
Texas Farm Products Company: Nacogdoches, Texas	1
Kaiser Agricultural Chemical: Wilmington, North Carolina	1
Total	22

Planned Installations

Kaiser Agricultural Chemical	2
W. R. Grace	5
Beker Industries	1
Royster Company	1
Total	9

Overseas Installations

Japan	1
Brazil	1
Colombia	1
Netherlands	1
Australia	1
Total	5

Appendix 6

TVA'S INTRODUCTION OF THE PIPE-CROSS REACTOR PROCESS

TVA engineers have worked with the following engineering contractors on the design of pipe-cross reactors.

Firm	Contact
The Prosser Company, Inc. Glen Arm, Maryland 21057	Joe Prosser, President FTS: 8-920-3311 301-592-6271
A. J. Sackett and Sons Company 1701 South Highland Avenue Baltimore, Maryland 21224	Walter J. Sackett, Jr., President FTS: 8-920-3311 301-276-4466
Feeco International, Inc. 3913 Algoma Road Route 1 Green Bay, Wisconsin 54301	Glen Wesenberg Vice President Process Engineering FTS: 8-362-1012 416-468-1000
The D. M. Weatherly Company 1800 Peachtree Road, N.W. Atlanta, Georgia 30309	Desmond J. Byrne Vice President Engineering FTS: 8-404-355-5323 (direct dial)

TVA Publications
Pipe-Cross Reactor Process

1. Salladay, D. G., Cole, C. A., and Greenhill, J. L. "Improving Quality And Grade Control In NPKS Granulation Plants." For Presentation at Fertilizer Industry Round Table, Washington, DC, October 30 - November 1, 1979.

2. "Pipe-Cross Reactor." Technical Update June 1979, Tennessee Valley Authority, Reprint Z-95.

3. Parker, B. R., Norton, M. M., McCamy, I. W., and Salladay, D. G. "Pilot- And Demonstration-Scale Developments In Production Of Ammonium Phosphate-Based Fertilizers Using The Pipe And Pipe-Cross Reactors." For Presentation at 1978 International Superphosphate and Compound Manufacturer's Association Limited Technical/Economic Conference, Orlando, Florida, October 22-27, 1978.

4. Salladay, D. G. and Myers, E. D. "Use Of TVA's Pipe-Cross Reactor To Conserve Energy In Fertilizer Granulation Plants." For Presentation at Fifth National Conference on Energy and the Environment, Cincinnati, Ohio, November 1-3, 1977.

5. Achorn, F. P. and Salladay, D. G. "TVA's New Pipe-Cross Reactor Process For Granular Ammonium Phosphates." For Presentation at American Chemical Society Meeting, San Francisco, California, August 29 - September 3, 1976.

6. Achorn, F. P. and Salladay, D. G. "Production Of Monoammonium Phosphate In A Pipe-Cross Reactor." For Presentation at Annual Meeting of the Fertilizer Industry Round Table, Washington, DC, November 4-6, 1975.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Appendix 8

THE PROSSER COMPANY, INC.

GLEN ARM, MARYLAND 21057

TELEX
87-967

TELEPHONE
301 592-6871

October 5, 1979

Mr. Gene C. Hale, Vice President
MID-OHIO CHEMICAL COMPANY, INC.
Box 280
717 Robinson Road
Washington Court House, Ohio 43160

Dear Gene:

This letter is written in confirmation of discussions held in your office during our visit there this past Tuesday, October 2nd.

At that time you ordered from us, a T.V.A. type pipe cross reactor system to be furnished and installed in the ammoniator of your Washington Court House Plant.

This unit is to be complete within itself, but will depend upon receiving all liquid materials at the ammoniator floor from Mid-Ohio Chemical. In other words, we include no piping except short runs to the meter and all piping from the meters to the pipe cross.

Specifically, what we propose to furnish is:

One T.V.A. type pipe cross reactor, fabricated from 6" diameter Hastelloy C276 pipe and complete with separate mixing tee for receipt of phosphoric acid, sulfuric acid, anhydrous ammonia and water. We include a water jacket fabricated of type 3/16" stainless steel.

One Lot of internal supports for the pipe cross.

Appendix 8

Mr. Gene C. Hale, Vice President
MID-OHIO CHEMICAL COMPANY, INC. October 5, 1979

One Fischer & Porter magnetic flow meter for phosphoric acid with remote indicating, recording and controlling cabinet and with control valve.

One Fischer & Porter magnetic meter for sulfuric acid, all as described for meter above.

One Fischer & Porter armored variable area rotometer for anhydrous ammonia with magnabond indicating, recording and controlling cabinet and control valve.

One Fischer & Porter variable area rotometer for water - - indicating only.

One Lot of piping materials, valves, fittings, etc.

Further, we agree to deliver the equipment to Washington Court House, install it and to supervise the whole job, as well as to perform the office engineering necessary for the design.

For the above equipment our price is . . . .$47,000.00, which will be billed in monthly segments as work progresses, always subject to a 10% retainer which is to be held by Mid-Ohio until the pipe cross reactor is placed into service.

We thank you very much for this order and are proceeding with it. We have ordered the pipe and the flow meters and expect to receive materials in time to make the installation in the second half of January 1980.

In accordance with your request, we have checked the phosphoric acid supply system and find that the existing pump will be adequate if you insulate the storage tanks and maintain the acid

Mr. Gene C. Hale, Vice President
MID-OHIO CHEMICAL COMPANY, INC. October 5, 1979

at a temperature of 30° F. minimum. It will, however, be necessary to install a 3" Schedule 5 stainless steel pipe line from the tank to the pump and from the pump to the ammoniator floor. This pipe line will cost about $20.00 per foot installed and insulated, but not traced. We have determined that tracing will not be necessary if the tank and pipe line are insulated and if the acid is kept warm.

If you want more details on the piping materials and the recommended insulation, please contact us.

Yours very truly,

THE PROSSER COMPANY, INC.

Joseph L. Prosser

JOSEPH L. PROSSER
President

JLP:es

☆U.S. GOVERNMENT PRINTING OFFICE. 1980-740-145/990