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PRODUCTION OF GRANULAR UREA BY THE TVA FALLING CURTAIN-EVAPORATIVE COOLING PROCESS

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INTRODUCTION

The TVA falling curtain-evaporative cooling process for melt granulation (1, 2, 3, 4, 5, 6) is an outgrowth of TVA technology developed for spray coating sulfur onto a granular substrate, such as urea or other fertilizer material, to obtain a controlled-release fertilizer (7, 8, 9, 10, 11, 12). In that work, unusually efficient coating of granules was obtained through use of a specially designed coating drum that allowed spraying of molten sulfur on a single falling curtain of granules. In the new melt granulation process, essentially the same technology is used except that melt of urea or other fertilizer material is sprayed onto seed granules of the same composition as the melt; thus the granules are built up to the desired size. Another pertinent feature of the new process is that a significant portion of the heat given up by the solidification of the melt and further cooling of the solidified material in the granulation drum is removed by evaporative cooling. That is, heat is absorbed by the evaporation of a fine mist of water sprayed into air that is passed through the granulation drum.

TVA's first experimental work that combined falling-curtain granulation with evaporative cooling was in the fall of 1976. In this work, sulfur was granulated in a 1.2-meter-diameter by 1.8-meter-long rotary drum at a rate of 0.9 tonne per hour. The process and product were very promising, which prompted a private company to build an 18-tonne-per-hour sulfur granulation plant based on the TVA process. Operation of this plant was successful, and the company later built a three-train 54-tonne-per-hour plant. This second plant was started up in the fall of 1979 (13).

In December of 1978, TVA modified an existing sulfur-coated urea pilot plant to study production of granular urea by the falling curtain-evaporative cooling process. In that modified plant, the process and product were very promising; granular urea of good quality was produced at rates up to 500 kilograms per hour. Now, TVA has built a larger pilot plant of 1.8-tonne-per-hour (2 ton/h) capacity to develop the process further. Work is continuing in this plant to maximize the efficiency and operability of the process and to develop the necessary scale-up data for transfer of the technology to the fertilizer industry.

THE PROCESS

The basic process for granulation of urea by the falling curtain-evaporative cooling process is shown in Figure 1. Granulation occurs in a rotary drum with specially designed internals. In this drum, granules are elevated by lifting flights as shown in Figure 2; the lifted granules discharge from the flights before reaching the apex of the drum and a large number of the granules are directed by inclined collecting pans into the form of a curtain of rapidly falling material. Sprays of molten urea are directed onto this curtain of falling granules. Then, with the cooling provided by airflow through the drum, melt on the coated granules solidifies and thus builds the granules in size. There is almost no agglomeration between granules in this process. The air flowing through the drum is cooled by the evaporation of water mist sprayed into the drum through nozzles as shown in Figure 2.

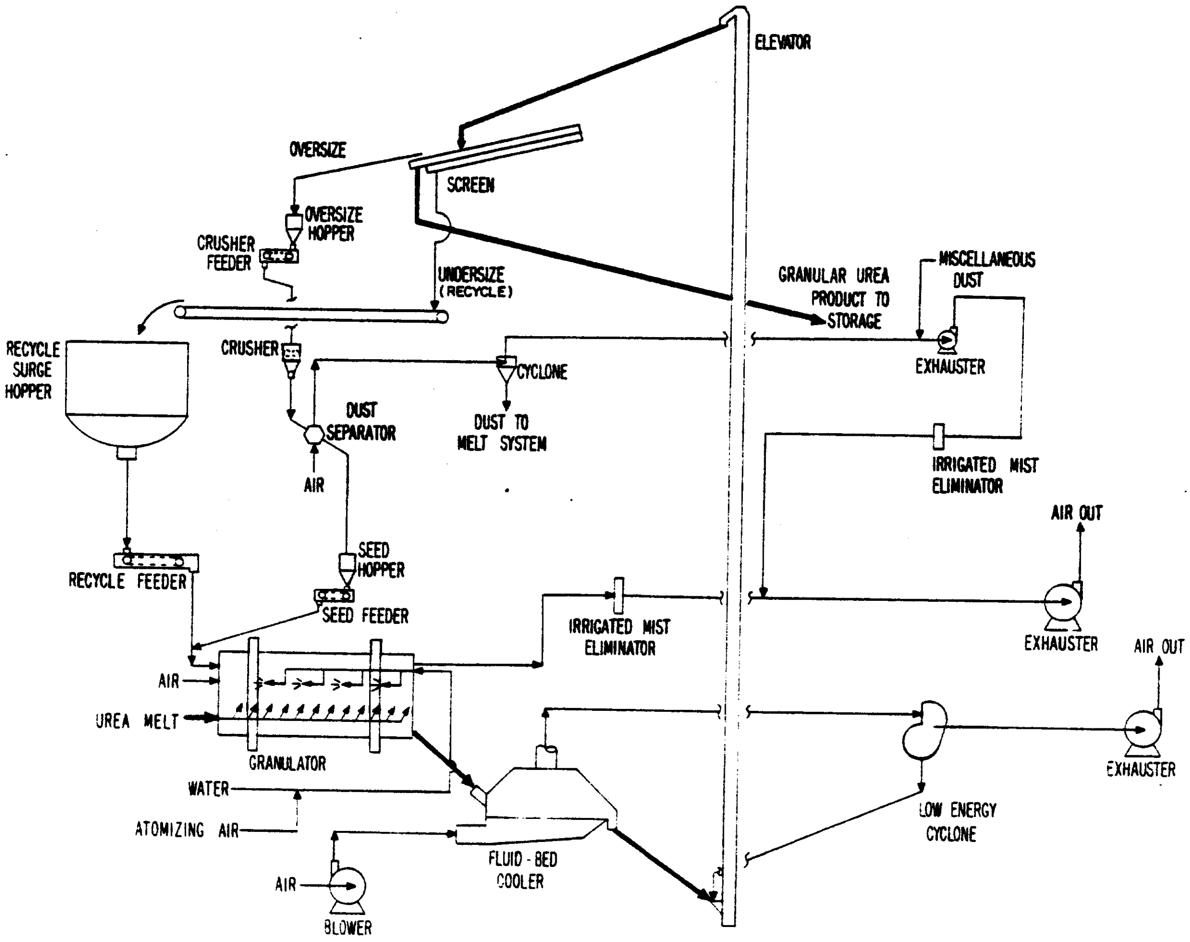
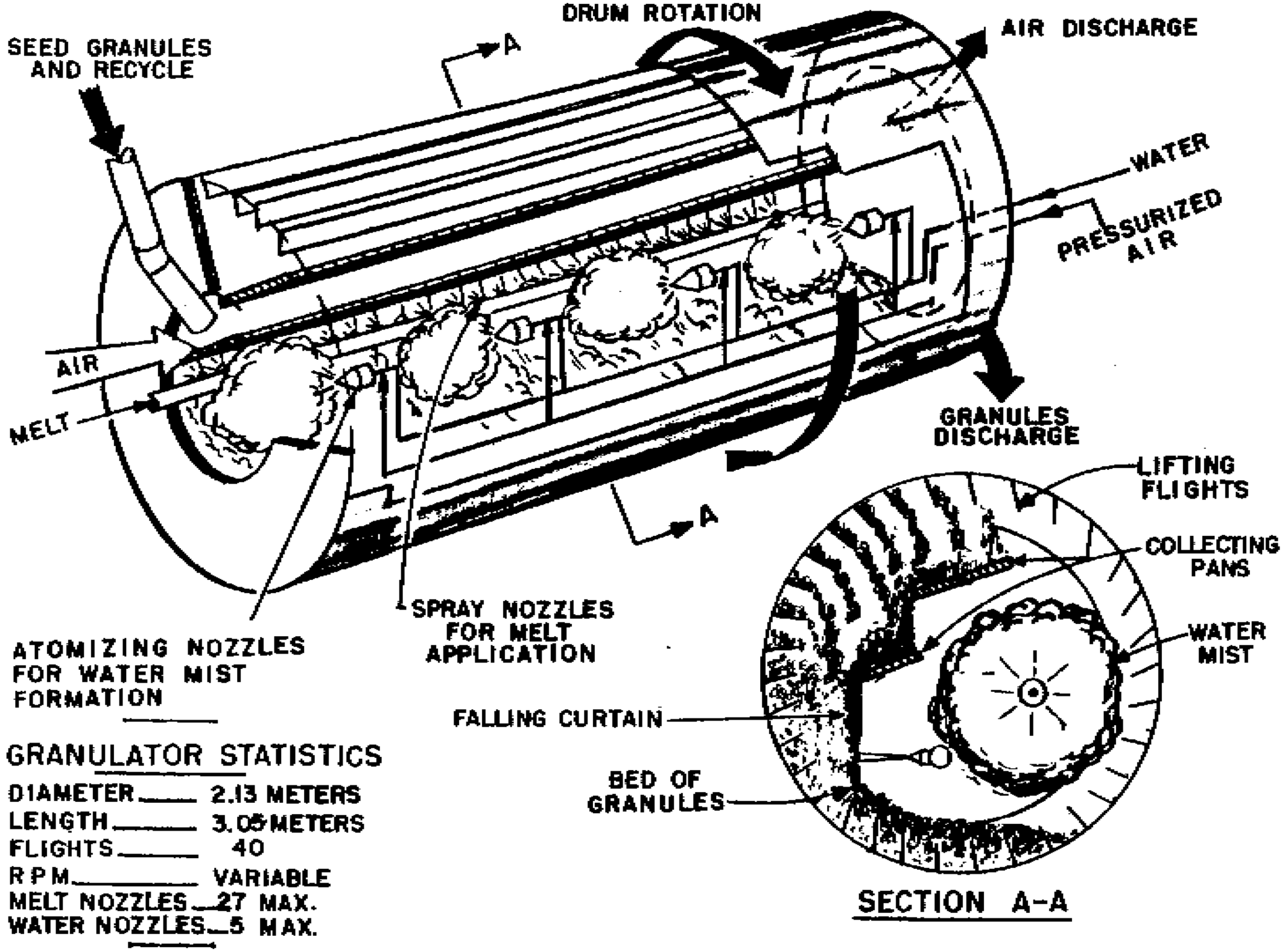


Figure 1. Flowsheet of TVA Pilot Plant for Granulation of Urea by the Falling Curtain-Evaporative Cooling Process



GRANULATOR STATISTICS

DIAMETER	2.13 METERS
LENGTH	3.05 METERS
FLIGHTS	40
RPM	VARIABLE
MELT NOZZLES	27 MAX.
WATER NOZZLES	5 MAX.

Figure 2. Granulation Drum in Pilot Plant for TVA Falling Curtain-Evaporative Cooling Process

Granules discharge from the drum to a fluid-bed unit where they are cooled further. The granules then are elevated and screened to remove oversize and undersize material from the product stream. The undersize material is collected in a surge hopper and recycled to the granulator at a metered rate. Small seed granules also are metered to the granulator to replace granules discharged as product and thus maintain approximately a constant number of granules per unit of weight in the process streams. Seed granules used have been predominately in the size range of 0.4 to 0.8 millimeter in diameter and are obtained by crushing oversize and product-size material. Most particles smaller than 0.4 millimeter in diameter are purposely blown out of the crushed seed urea in a fluidized-bed separator and normally are remelted. If urea microprills are available, they can be used as seed. The size of product can be varied from that of large prills to that of very large granules by changing screen sizes and making necessary adjustments to seed feed rates. When producing granules with average granule diameter of 2.4 millimeters, the weight ratio of seed granules to product is about 1:50. If sufficient seed are not obtained as crushed oversize, some product-size material can be crushed.

The urea melt usually is at a temperature between 135 and 149 °C when it is sprayed onto the granules in the granulator. The granules exiting from the granulator are usually at a temperature between 82 and 99 °C, and they normally exit from the cooler at a temperature between 49 and 60 °C. For the condition in which melt is sprayed at 149 °C and granules exit the cooler at 60 °C, about 98 gram-calories of heat per gram of urea granulated is released. This includes a heat of fusion, which is 57.8 gram-calories per gram, and heat released in cooling of melt and subsequent cooling of granules. The pilot-plant design is based on the preceding values and specifies that about 68% (129,000 kg-cal/h) of the released heat is to be removed from the granulator by water evaporation plus an increase in the temperature of the air stream passing through the granulator plus losses through the shell of the drum. The remaining 32% (60,500 kg-cal/h) is to be removed in the fluid-bed cooler. This relatively large transfer of heat in the granulator is possible while still maintaining relatively low airflow rates (100 m^3/min at the design production rate) because of the very finely atomized water that is evaporated in the airstream. At the temperatures involved, water absorbs about 590 gram-calories for each gram evaporated and heated to the temperature of the air leaving the granulator, which is about 49 °C. Approximately 71 liters of water is evaporated for every 907 kilograms of granular urea produced, and in evaporating, the water removes about 45% of the heat released in the process or about 84,500 kilogram-calories per hour.

Urea granules are hygroscopic; therefore, the water is atomized in the granulator in sectors free from falling urea granules to prevent direct contact of water mist and urea. Also, humidity in the air is controlled to avoid exceeding the critical humidity of the urea with which air comes in contact. When granules are at the granulator discharge temperature of 97 °C, they would start absorbing moisture if the water content in the air in contact with them reached an absolute humidity of about 0.27 gram of water per gram of dry air (34% relative humidity for air at 97 °C). The undersize granules recycled to the granulator are at a temperature of about 60 °C, and they would start absorbing moisture if they contacted air with absolute humidity greater than 0.08 gram of water per gram of dry air (58% relative humidity for air at 60 °C). The air absorbs moisture as it passes through the granulator and thus exits with higher moisture concentration than it enters; therefore, the air is passed through the granulator cocurrently with the urea in order to reduce the chance of moisture absorption by the recycle urea in the feed end of the granulator. Design of the pilot plant is for moisture concentrations in the air leaving the granulator to be 0.03 gram of water per gram of dry air (40% relative humidity for air at 49 °C). Airflow through the fluid-bed cooler is designed to be about 90 cubic meters per minute.

Pilot-plant work has shown that the uniformity of size of the final product can be controlled by the ratio of the recycle feed rate to the melt spray rate. The recycle consists only of undersize granules, and the rate at which recycle granules are fed to the granulator is controlled by a belt feeder. The feeder is mounted on a scale to allow the determination of feed rates, which can be adjusted. As the amount of recycle is increased for a given spray rate, the size of product becomes more uniform. Data from the small pilot plant indicated that very little oversize is produced at recycle-to-melt ratios of about 1:1. Higher recycle rates make the product extremely uniform in size, which is undesirable for some uses such as for size matching with other materials in bulk blending. Lower recycle rates increase oversize production--beyond that needed for seed generation. Any excess oversize must be remelted and regranulated, which requires additional energy consumption and increases biuret content of the final product; both are undesirable.

The air leaving the granulator is washed with recycled scrubber solution and the resulting spray particles are collected in an irrigated mist eliminator. Work in the small pilot plant showed dust formation in the process to be less than 2% of the urea granulation rate. Particles emitted from the fluidized-bed cooler are relatively large and are collected in a low-pressure-drop horizontal cyclone which feeds them back into the elevator. Dust generated in the seed system is recovered by a cyclone. Dust collected from miscellaneous points in the system is washed out of the air by a system similar to that used to remove particulates in the air leaving the granulator.

The pilot-plant tests of urea granulation have shown that the process can be used to consistently produce urea that is hard and spherical. Typical particles of 2.4 to 2.8 millimeters in diameter have a bulk density of 770 kilograms per cubic meter, a crushing strength of 3.2 kilograms, and a sphericity of about 80%. Although water is sprayed in the granulator for cooling, the moisture content of the granules is normally between 0.1 and 0.3%. The process appears to be easy to control and man-power requirements in a large plant should be commensurate with those of other granulation processes. Overall energy consumption and initial capital expenditures for this process should be lower than those for other processes.

PILOT-PLANT EQUIPMENT

The granulation drum (Figure 2) is 2.1 meters in diameter and 3.1 meters long and has a 12.7-centimeter-high retaining ring at the discharge end. Forty lifting flights are installed in the drum at 9-degree intervals. The flights are straight with flat surfaces 7.6 centimeters wide and 2.7 meters long. They are installed parallel to the axis of the drum and they are canted 15 degrees forward from the perpendicular with the shell of the drum. Two collecting pans are installed parallel to the axis of the drum. The top pan is about 65 centimeters wide and 2.8 meters long. The lower pan is about 55 centimeters wide and 2.9 meters long. Both pans are sloped counter to the direction of the rotation of the drum at an angle such that the granules will cascade down them. Each pan catches some of the material discharged from the lifting flights. All granules discharging from the top pan fall to the bottom pan. Besides providing a curtain of falling granules on which the urea can be sprayed, the collecting pans catch the granules after only a short fall, thus breaking the momentum of the granules before they can develop enough force to shatter on impact and create dust. In addition, the pans provide a large sector of the granulator in which heat transfer can occur by air-to-granule contact but without allowing the granules to pass through the water sprays located underneath the pans. The double-pan configuration is designed to increase airflow between the water-evaporation sector of the granulator and the sector where the most air-to-granule contact occurs.

Molten urea is distributed in the granulator under gage pressures up to 70 kilograms per square centimeter through a steam-heated header that can contain up to 27 spray nozzles 9.7 centimeters apart. For convenience in the pilot plant, the urea melt is obtained by melting urea prills. The melt passes through a bag filter made of Nomex (a heat-resistant aromatic polyamide fiber) before being pumped to the header. The filtration removes particles larger than 10 micrometers and prevents stoppages in the nozzles; the nozzle orifices vary in size from an equivalent diameter of 0.53 millimeter to 0.91 millimeter. The molten urea supplied from the melter is collected in a small pump tank. This tank and the melt piping are designed to minimize biuret formation by retaining urea in the molten state less than 30 seconds. The molten urea is supplied to the header from the pump tank by a double-acting piston pump driven by a piston-type air motor. The air motor allows pressure control of melt in the spray system because the pressure it develops is in direct proportion to the air pressure supplied. The flow rate of urea is indicated by a turbine flowmeter and is manually controlled by changes in pneumatic pressure to the air motor or by changes in size or number of spraying nozzles. The pump and all high-pressure valves are submerged in a constant-temperature oil bath. All molten urea piping is steam jacketed and all equipment in contact with molten urea is made of Type 316L stainless steel except the pump; the pump is made of Type 303 and 304 stainless steels. The water for evaporative cooling is metered to pneumatic atomizing nozzles in the granulation drum where it is atomized in wide-angle, round spray patterns countercurrent to the air being pulled through the drum.

The fluid-bed cooler has a bed area of 0.93 square meter and a stainless steel fluidizing screen that contains a large number of holes 0.036 centimeter in diameter for a screen open area of 8.2%. Air for fluidization and cooling is provided by two centrifugal fans (a blower and an exhauster). The ductwork and damper arrangement allows close control of airflow into the cooler. The horizontal cyclone removes any seed-size particles entrained by air leaving the cooler and they are returned through a rubber, sock-style airlock to the elevator. The elevator is a continuous discharge-type unit and runs at the slow speed of about 41 meters per minute. Both features help prevent breakage (thus seed generation) of the material being handled. The screen is a double-deck, gyrating-type unit. Screen sizes are changed as necessary to obtain the size of product desired. To facilitate pilot-plant operation, a cone-bottom product hopper with a capacity of about 1.7 tonnes of urea is provided. Undersize leaving the screen is transported by a cleated belt conveyor to the recycle surge hopper which has a capacity of about 2.9 tonnes of urea.

All oversize material and some product, if needed, is fed on an interim basis to a thin-bladed hammer mill. The speed of the mill can be adjusted to optimize the efficiency of seed formation. The crushed material is fed to the dust separator which separates the dust from the seed-size particles using the principle of air classification. The dust separator is a small fluid-bed unit with a screen area of 0.19 square meter. It is designed to operate at an airflow of about 14 cubic meters per minute. At the resultant air velocity, the dust is entrained and the seed is left in the fluid bed.

Usually about 50% of the feed to the hammer mill is retained as seed granules. The dust separated from the seed is collected in a cyclone which has a diameter of about 31 centimeters and operates at a pressure drop of about 10 centimeters of water. The crusher feeder and seed feeder, like the recycle feeder, have variable-speed belt control and are mounted on scales for rate determination. The wire-mesh mist eliminators have a pressure drop of about 2.5 centimeters of water and are mounted in tanks 0.91 and 0.76 meter in diameter. The vessels, mist eliminators, centrifugal exhaust fans which handle air to them, and the inline centrifugal pump used for pumping scrubber solution are all constructed of Type 304 or 316 stainless steel.

All rotary equipment is driven by totally enclosed fan-cooled motors. Instruments and access points are provided throughout the plant to facilitate the taking of data and samples.

DISCUSSION

At the time of the present writing, the large pilot plant (1.8-tonne-per-hour capacity) has not yet been operated. Immediate operation is planned, however, to find optimum values for the various process variables. In TVA's earlier work using the small (500 kg/h) modified sulfur-coated urea pilot plant, several important variables were identified as affecting the physical properties of the product, the capacity of the plant, and the operability of the process. However, the very limited volume of the granulator and problems in obtaining a steady supply of molten urea to the granulator prevented defining the optimum conditions, range limits, or the magnitude of the effects of these variables under realistic conditions of water atomization and steady operation. Researchers were able to determine that the process has considerable operational latitude, because wide fluctuations in operating conditions caused very few product-quality or operational problems.

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DISCUSSION : (Rapporteur K.C. Knudsen, Superfos, Denmark)

Q - Mr. J.P. MAZAUD, Heurtey Industries, France

What is the increase in the biuret content in the granulation equipment?

A - The residence time is only 15-30 seconds, and the increase in biuret content is about 0.3%.

Q - What is the concentration of the urea melt (96% or 99%) at the inlet of the granulator?

A - Up till now we used a pure urea melt. We plan to make experiments using solutions of urea. At lower concentrations you might expect some dust formation.

Q - Mr. B.K. JAIN, F.A.I., India

What is the largest size plant which can be built in a single train?

A - We anticipate a capacity of 30 t/h in a granulator of 12 feet diameter and 30 feet long. Based on the latest successful experiments, it might be expected that it will be possible to reach 50 t/ha.

Q - How would the cost of an installed plant and operating cost compare with a similar size prilling plant (say for a 500 t/d plant)?

A - I have no comparable figures, but I am quite sure that this process will be very competitive with other processes.

Q - Mr. G. PAGANI, Montedison SpA, Italy

It is our experience that, with the granulation of melted solutions (as NH_4NO_3 and urea), every section of the granulator gets easily dirty. Does it happen in the TVA process too?
In the case of a positive answer, I should like to know the frequency of manual cleaning. Or is it likely that a continuous cleaning is used during the run?

A - So far, we have little operating experience. Indications are that the drum does not get dirty, and we do not expect that a continuous cleaning will be necessary.

Q - Mr. R. van HARDEVELD, D.S.M., Netherlands

To what capacity can your process be scaled up?
Do you agree that the heat-transfer between the cooling air and the falling curtain will be limiting? If so what are your ideas to increase the heat transfer?

A - Yes, heat transfer is a limiting factor. Therefore, it is important that the air passes several times through the curtain of granules and through the cooling section, and we have installed air interchange equipment in the drum in order to obtain that effect.

Q - Mr. C. KELETI, UNIDO, Austria

Is the urea drum granulator horizontal or is it rotating at an angle to facilitate discharge of product?

A - The drum is almost horizontal having a slope of about 1/16 of an inch per foot.

Q - Mr. P. MORAILLON, Générale des Engrais, France

Do the inventors hope to employ their new process for the granulation of ammonium nitrate in spite of the fact that it has a higher hygroscopicity than urea?

A - We do not expect that the higher hygroscopicity of ammonium nitrate will be a problem. However, we would be hesitant to use a pressure as high as 500 pounds/sq. inch when spraying an ammonium nitrate melt into the granulator. Experiments using a lower pressure are considered.