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Alternative Process for Urea Supergranules

BRIQUETTING

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Abstract

Results of tests by the International Fertilizer Development Center (IFDC) and other organizations show that considerable improvement is achieved in the agronomic efficiency of urea in wetland rice production by deep placement of urea supergranules compared to broadcast application of urea prills. The physical and chemical characteristics of urea make the material well suited for production of urea supergranules by briquetting, which is an agglomeration process using the application of pressure to powdered dry materials. Urea briquettes of 0.8 to 2.0 grams produced by IFDC in a small briquetting machine were of a good quality.

Conceptual process designs were developed for the manufacture of 1- to 2-gram urea briquettes considering different types of urea feed material. The conceptual designs were used for developing cost estimates for the production of urea briquettes. For briquetting plants added to an existing urea complex, the estimated production cost premium for urea briquettes is $14.5 to $20.3 per metric ton, depending upon plant capacity and type of feed material. For a unit at a separate site, the estimated premium is $36.8 per metric ton.

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Units Used in This Bulletin

cm	centimeters
cm^3	cubic centimeters
g	grams
g/cm^3	grams per cubic centimeter
hp	horsepower
kg/hour	kilograms per hour
kWh	kilowatt-hours
m	meters
m^2	square meters
mm	millimeters
m/second	meters per second
m^3/second	cubic meters per second
mt	metric tons
mt/cm	metric tons per centimeter
mtpd	metric tons per day
mtpy	metric tons per year
psig	pounds per square inch gauge
rpm	revolutions per minute
$/$m^3$	U.S. dollars per cubic meter
$/mt	U.S. dollars per metric ton
$/year	U.S. dollars per year

Summary

Deep placement of spherical urea supergranules has been extensively tested in wetland rice production by the International Fertilizer Development Center (IFDC) and other organizations. Test results indicate that urea supergranules offer considerable improvement in agronomic efficiency over prilled urea by broadcast application. Deep-placed urea briquettes also provided high agronomic efficiency under limited testing. This bulletin analyzes the technical and economic aspects of using the briquetting process for the production of urea supergranules. Briquetting is a process in which dry powdered materials are agglomerated by the application of pressure. The process has been in commercial application in nonfertilizer industries for many years.

The physical and chemical characteristics of a material determine the degree of its suitability for briquetting. The characteristics of powdered urea, particularly its plasticity and softness, make the material well suited for briquetting. Feed materials for briquetting must have good flow characteristics so that the material can be fed into the nip area of the briquetting machine rolls. Thus, the moisture level should be low enough to avoid bridging in the feed system.

There are several important design parameters for briquetting machines. The principal parameter is the roll pressure. The power or energy required for converting a powdered material into briquettes is directly related to the roll pressure required. However, the pressure requirement to produce high-quality briquettes must be determined experimentally for a particular material. For example, the roll pressure required for urea is relatively low compared to that for many materials that are briquetted. In addition to roll pressure, other principal design parameters for briquetting machines are (1) roll dimensions—diameter and width, (2) roll gap, (3) roll speed, and (4) roll pocket size. The experience of briquetting machine manufacturers should be considered in determining the optimum design parameters.

To test the production of urea briquettes, IFDC used a small laboratory-scale briquetter (12.5-cm diameter rolls 5.1 cm wide). Three sets of rolls with nominal pocket sizes of 0.5, 0.8, and 1.0 cm^3 were used. The weight of the urea briquettes for the respective pocket sizes was approximately 0.8, 1.1-1.3, and 1.6-2.0 g. Both urea prills and urea fines were used as feed materials, and all the tests were made with a roll pressure of about 1.5 mt/cm of roll width. In all tests good-quality briquettes were produced. The specific gravity of the briquettes ranged from 1.31 to 1.33 compared with about 1.34 for solid urea. The yield of briquettes, as a percentage of feed material, was about 83%-87%. A rotary drum was used for tumbling the briquettes discharged from the briquetting machine to separate the briquettes and to remove webbing. Weight variation of the briquettes was less than 10% for all tests.

On the basis of this small-scale test work and large-scale testing by briquetting machine manufacturers, IFDC developed a conceptual process design for the manufacture of urea briquettes of 1- to 2-g size. In addition to the basic briquetter, the conceptual design included elevators/conveyors, bins, dust collectors, screens, recycle-material crusher, tumbling drum, and other supporting equipment. Two plant capacities and different urea feed materials were considered.

The conceptual process design provided the basis for preliminary investment and conversion cost estimates for the production of urea briquettes in developing countries. Cost estimates were developed for the following three production schemes:

Scheme Number	Description
I	125-mtpd briquetting unit at an existing urea plant using only recycle material.
II	250-mtpd briquetting unit at an existing urea plant using 50% recycle material and 50% crystals or prills.
III	250-mtpd briquetting unit at a new site using urea prills.

Feed material credits relative to urea prills were also estimated for the urea recycle material and crystals under Schemes I and II corresponding to the variable conversion costs for producing urea prills from the materials.

The total investment cost estimates including allowances for working capital for the three schemes were as follows:

Scheme I	$4.0 million
Scheme II	$6.3 million
Scheme III	$12.6 million

The conversion cost estimates for Schemes I, II, and III were $32.3, $27.5, and $36.8/mt, respectively. The conversion cost estimate less feed material credit for Scheme I was $20.3/mt. For Scheme II the conversion cost estimates less feed material credits were $16.5/mt and $14.5/mt for urea prills and crystals, respectively, as supplemental feed materials. These conversion cost estimates were based on mid-1983 costs and assumed a 100% capacity utilization. They did not include allowances for bagging costs.

The net conversion cost estimates were analyzed on the basis of additional costs for briquetted urea as compared with prilled urea. For this purpose delivered costs for bulk prilled urea of $150/mt, $200/mt, and $250/mt were assumed. A bagging cost of $15.0/mt was assumed for both urea prills and briquettes. On these bases the premiums for urea briquettes compared with urea prills were estimated as follows:

Scheme	$/mt	Premium for Briquettes $150/mt[1]	$200/mt[1]	$250/mt[1]
		------	%	------
I	20.3	12.3	9.4	7.7
II (Prills)	16.5	10.0	7.7	6.2
II (Crystals)	14.5	8.8	6.7	5.5
III	36.8	22.3	17.1	13.9

1. Delivered cost for bulk prilled urea.

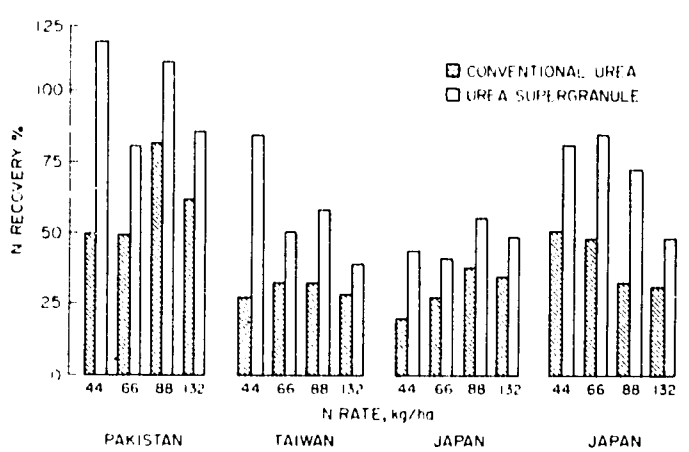
Introduction

The International Fertilizer Development Center (IFDC) and other organizations are devoting considerable effort to improve nitrogen fertilizer use efficiency. Nitrogen fertilizers have contributed significantly to an increase in food and fiber production and are a key input where nitrogen-responsive crops are grown. One of the most important food crops of Asian countries is rice, and it requires substantial quantities of nitrogen. The major nitrogen fertilizer used on rice at present and probably for the remainder of the century is urea. When urea is applied to flooded rice, however, nitrogen use efficiency is low because of loss mechanisms such as ammonia volatilization, nitrification-denitrification, runoff, and leaching. Any loss of nitrogen applied to the soil is also a loss of energy.

One of the techniques under study for improvement of nitrogen use efficiency for wetland rice production in developing countries is the deep placement of large urea particles, commonly referred to as urea supergranules (USG). In 1974 IFDC proposed using a large particle of urea fertilizer instead of a deep-placed mudball (soil + fertilizer). Molten urea was cast into cylinders weighing up to 3 g each and tested in Asia. Subsequently, 1- to 2-g spherical particles supplied by Norsk Hydro from a high-temperature pan-granulation process were used in many tests sponsored by IFDC. The results indicate that considerably greater agronomic efficiency is achieved by using USG than by broadcast application of prilled urea. The percentage of fertilizer nitrogen recovered from deep-placed USG was much higher than that from conventional urea at different sites and various nitrogen levels (Figure 1). For proper economic assessment of deep placement of USG, better estimates are needed for the cost of USG relative to current forms of urea (prills) used for rice.

There are several processes for the production of urea granules, and they produce particle sizes ranging from 2-4 mm (standard grade) up to 8 mm (forestry grade) from urea melt. Most of the USG used for experimental purposes has been produced by modification of these conventional granulation processes. However, supergranules have been produced only on a small scale, and there is no information on large-scale commercial production. Briquetting, which does not require urea melt, is an alternative process for the production of USG.

Briquetting is a process in which dry solid materials are agglomerated by the application of pressure alone, and it has been used for many years in the ceramics, pharmaceutical, and metallurgical industries. The objective of this bulletin is to provide a preliminary technical and economic assessment of the briquetting process for the production of USG. This assessment involves a consideration of the principles of briquetting, a conceptual process design based on test results, and estimates of investment and production costs for either adding a briquetting plant to an existing plant or establishing a new briquetting plant.



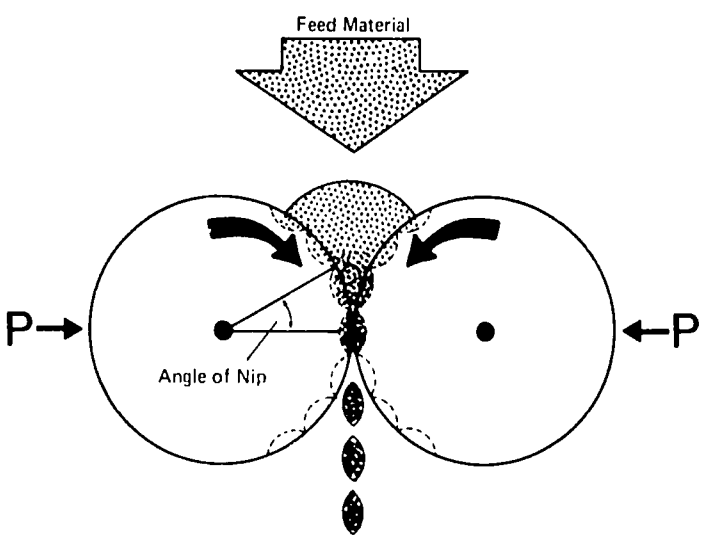
Source: Yamada et al. (17)

Figure 1. Crop Recovery of Fertilizer-N by Rice as Affected by N Sources.

Description of the Briquetting Process

Principles

Briquetting has been known for many years. The coal industry, for example, has been converting fines into briquettes since the 1840s. The basic principle of agglomeration by briquetting is the application of pressure to a fine powder as it flows between two rolls rotating at the same speed but in opposite directions as shown in Figure 2. The nip area is the area between the rolls where the compaction (densification) takes place, and the nip angle depends on the material being compacted. The effect of the applied pressure is to remove the air between the particles of the powder and thereby densify the material. The resulting close contact between individual particles leads to the formation of a very dense, strong agglomerate in which the forces holding the particles together may be molecular forces of attraction (Van der Waals), adsorption forces, solid bridges, or mechanical interlocking. The formation of solid particles by such a roll-pressing process using indented pocketed rolls is normally referred to as briquetting. This process is only suitable for producing particles greater than 8-10 mm in diameter. A related process is tableting: Pressure is applied to a powder in a die to make individual large particles, and these compressed tablets are then ejected. This process is widely used in the pharmaceutical industry.



Source: Pietsch, W. (10).
Figure 2. Schematic Diagram of a Briquetter.

The briquetting process has been used for several industrial applications where the addition of a binder or a lubricant is sometimes required. However, in the case of urea briquetting for the fertilizer industry, the addition of such additives is not necessary because urea crystals are soft and plastic and form very cohesive agglomerates under pressure.

Factors Affecting Briquetting

The factors that affect the roll briquetting process can be related to the nature of the material being briquetted or to the equipment used.

Feed Characteristics

As mentioned previously, in the briquetting process pressure is applied to remove air from the feed powder particles to form a strong, hard, enlarged particle. Feed material characteristics, such as shape, size, plasticity, hardness, and moisture content, as well as temperature, are parameters that affect the compactibility of the product. The feed material must have good flow characteristics so that it can be fed into the nip area of the rolls. The size and shape of the feed material have a direct relationship with the compaction efficiency. Small-size material contains large quantities of entrapped air that needs to be removed. The shape of particles also influences the packing characteristics of the powder. Plasticity and hardness are important parameters that influence the ease with which the briquetting is accomplished and the pressure required to form the briquette. Urea has good plasticity and is easy to briquette. However, when the material is fed into the nip area and passes through the rolls, it increases in temperature because of the heat generated by frictional forces. This may cause excessive plasticity and sticking to the rolls, especially with urea. It is possible to control the temperature increase by internally cooling the rolls.

The moisture content of the feed material determines its flow characteristics and should be low enough to avoid bridging in the feed system. This does not mean that the material needs to be completely dry. A small amount of moisture may be beneficial to the briquetting process. The strength of the briquette is enhanced by the formation, under pressure, of new crystalline bridges which result from evaporation of the water from the thin aqueous film between the crystals.

Machine Characteristics

The principal parameter that affects briquetting is pressure. In roll briquetting the pressure required to make good strong briquettes is calculated as the total force applied to the roll divided by the roll width and is expressed in tons per linear centimeter of roll width. The total force applied by the roll press is divided by the roll width to determine the pressure. The briquetting pressure is also a function of the roll diameter; higher pressure can be obtained with large-diameter rolls than with small-diameter rolls.

Roll Briquetting Design

Several factors have to be considered in the design, manufacture, and operation of large roll presses for commercial production of urea briquettes.

An integral part of the roll briquetter is the system that introduces the feed material into the nip area of the rolls. One way of introducing the feed is by gravity, using the pressure differential of the head in the feed bin above the briquetter; however, a force-feed system is preferred in order to obtain uniform feed needed to achieve a good compacted material. The force feeder has the advantage of effecting some predensification and thus removing some of the air trapped in the material.

The capacity of the roll press is determined by the roll dimensions. The roll diameter fixes the size of the machine and is a parameter that cannot be adjusted. The roll width will depend on the pressure required to briquette the material under consideration. Typically, roll width will be in the range of 15-150 cm. The roll gap is the distance between the two rolls. The webbing holding the briquettes will not have the same thickness as the gap between the rolls because the webbing expands as the elastically deformed particles recover their shape and because a small amount of compressed air is trapped in closed pores of the compacted material. Another factor that affects the design and operation of the machine is the roll speed, which is directly related to the production rate. Normally the circumferential speed of the rolls should not exceed 1 m/second to provide good deaeration of the material.

Test Work at IFDC

In 1981 IFDC purchased a small two-roll laboratory-scale briquetter/compactor (Figure 3), and this machine has been used to study the production of urea supergranules by the briquetting process. The rolls (diameter 12.5 cm; width 5.1 cm) are arranged vertically and are fed by an auger feeder from a hopper at the side. A maximum force of 10 tons can be applied to the rolls. Three sets of rolls with different sized pockets are available and are easily interchangeable. One set of rolls has four rows of pockets producing briquettes with a nominal volume of 0.5 cm^3; the second set of rolls has three rows of pockets producing briquettes with a nominal volume of 0.8 cm^3; the third set of rolls has two rows of pockets producing briquettes with a nominal volume of 1.0 cm^3. The rolls and briquettes made from each set of rolls are shown in Figure 4.

Manufacturer; Ferro-Tech, Wyandotte, Michigan, U.S.A.
Figure 3. IFDC Laboratory-Scale Briquetter.

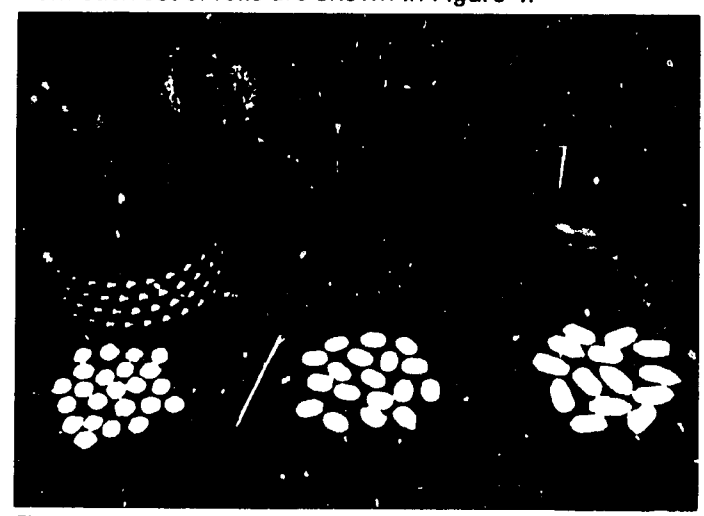


Figure 4. Briquetting Rolls and Briquettes.

Tests were performed on a batch basis as shown in Figure 5. The briquettes left the rolls joined together by webbing and were first screened on a coarse screen. This step was used to evaluate the amount of fines remaining after briquetting and would not be necessary in commercial operation.

The webbing holding many of the briquettes together was a thin sheet of compacted urea formed by compaction of the material between the indented pockets on the roll faces. This area between the pockets is known as the land area. The webbing was formed because the rolls had to be kept a minimum distance apart: Normally this distance was 1-2 mm, and it could not be less than 1 mm.[1] The briquettes were separated and webbing removed by tumbling the briquettes in a rotating drum. This ensured that

1. For this reason the actual volume of the briquettes is greater than the nominal volume by the thickness of the web.

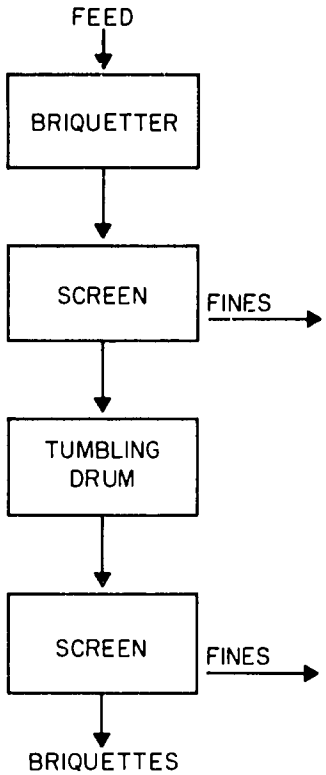


Figure 5. Batch Procedure for Briquetting Urea.

no briquettes remained joined together and that the individual briquettes were of fairly uniform weight.

The material fed to the briquetter was either urea fines from the TVA granulation plant or prills (technical or agricultural grade) from commercial sources. Screen analyses for the feed materials are given in Table 1. All the tests were performed with fresh feed only, because the fines separated in the two screening stages were not recycled in these batch tests. Results of the briquetting test are summarized in Table 2. The pressure applied to the rolls was the same for all tests, and the briquettes obtained in all cases were of good quality as shown by their density (specific gravity of urea, 1.335). Roll and auger speeds could be varied, within limits, to give different size (weight) briquettes from the same rolls without affecting the briquette quality (see, for example, runs 4 and 5, Table 2). The amount of fines from the briquettes, as separated in the first screening stage, was in the range of 5%-8%, while fines generated in the tumbling stage and separated in the second screening stage were in the range of 6%-9%. The overall yield of briquettes after both screening steps was 82%-87%. Feed rates were in the range of 45-55 kg/hour with higher feed rates obtained

Table 1.
Sieve Analyses of Feed Materials for Urea Briquetting Tests

	Cumulative Percentage Retained on Indicated Screen		
Mesh (Tyler)	Fines	Prills (Technical Grade)	Prills (Agricultural Grade)
8	-	0.2	0
10	4.3	9.0	5.6
14	12.2	75.0	75.0
20	-	99.0	98.5
35	42.4	99.4	99.5
65	58.1	99.8	-
150	64.6	-	-
325	88.7	-	-

Table 2.
Test Results for Urea Briquetting

	Runs					
Operating Conditions	1	2	3	4	5	6
Size of roll pocket (nominal), cm^3	0.5	0.8	0.8	1.0	1.0	1.0
Feed material	Fines	Fines	Prills[a]	Fines	Fines	Prills[b]
Feed rate, kg/hour	47.6	45.5	47.2	55.6	53.0	54.0
Pressure, psig	2,000	2,000	2,000	2,000	2,000	2,000
Pressure, mt/cm	1.49	1.49	1.49	1.49	1.49	1.49
Roll speed, rpm	9.4	9.1	9.3	7.7	9.1	7.6
Auger speed, rpm	50	50	84	77	62	79
Webbing thickness, mm	1.5	1.0	2.4	2.0	1.5	2.0
Briquette Product						
Yield before tumbling, %	94.9	94.3	91.5	91.4	92.2	91.9
Yield after tumbling, %	87.2	85.7	84.9	83.6	84.3	82.7
Weight, g	0.78±0.07	1.10±0.03	1.27±0.06	1.89±0.03	1.64±0.03	1.96±0.06
True density	1.32	1.33	1.31	1.33	1.33	1.33
Bulk density, g/cm^3	0.71	0.71	0.68	0.70	0.73	0.71
Production rate, kg/hour	41.5	39.0	40.1	46.5	44.6	44.7

a. Agricultural grade (formaldehyde added), Mississippi Chemical Corporation.
b. Technical grade (no formaldehyde added), Mississippi Chemical Corporation.

with the largest pocket size. Briquette production rates were about 40 kg/hour for the two rolls with smaller size pockets and about 45 kg/hour for the roll with the largest size pocket.

No significant differences were observed in briquette yield with either fines or prills as the feed material. However, prills did give larger (heavier) briquettes than did fines. Briquettes from agricultural-grade prills (with formaldehyde) had a slightly lower density than briquettes from technical-grade prills (without formaldehyde) or fines (with formaldehyde added). Bulk density of the briquettes produced was 0.7 g/cm^3. The weight variation of the briquettes produced in these tests, expressed as the standard deviation, was between 2%-9% of the briquette weight and was largest for the smallest briquettes.

From tests made by equipment manufacturers on large-diameter rolls, a weight variation of about 10% would be expected for 1-g briquettes. This variation stems from the need to keep the rolls further apart on a large machine; it would be less for larger sized briquettes.

Aqueous dissolution studies in stirred or static systems showed a considerable difference in rate of dissolution of urea prills compared with urea briquettes (supergranules). However, little difference was found in the rate of dissolution of different-sized briquettes (0.78, 1.10, 1.64 g). These results are shown in Figures 6 and 7 as percentage of urea dissolved against time for 10-g samples in 100 ml of water. These results should be taken into consideration when procedures for deep placement of urea of varying particle sizes are being developed.

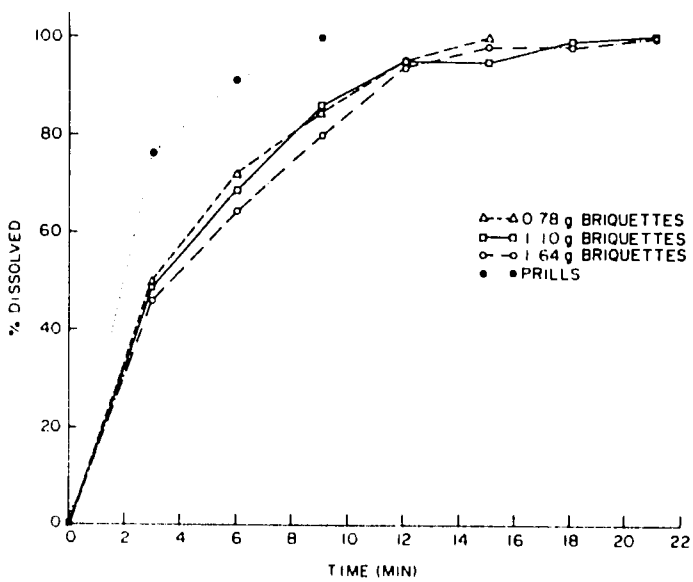


Figure 6. Dissolution Studies for Urea in a Static System.

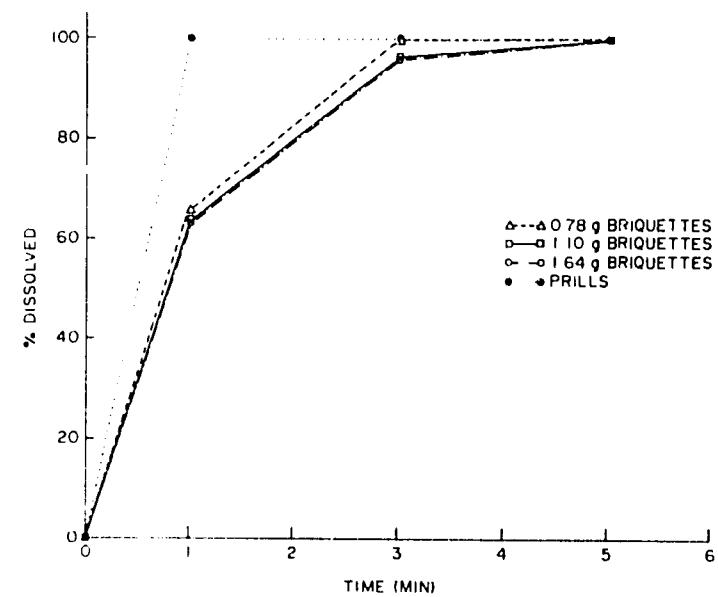


Figure 7. Dissolution Studies for Urea in a Stirred System.

Urea Briquetting Process Design

The basic process steps required for urea briquetting are shown in Figure 8. They include mixing of recycle material with fresh feed, briquetting, separation of individual briquettes, and screening. A typical flow diagram for a continuous, full-scale production plant is shown in Figure 9. The fresh feed, which can be urea dust, prills, or crystals from the fresh feed bin, is transferred by a weigh belt conveyor into a paddle mixer where it is mixed with the recycle material. The mixture is then sent via an elevator into the briquetter feed bin, and from there it is fed to the briquetter. As the material is forced between the two counter-rotating rolls under pressure, it is converted into a solid string of briquettes. In order to break this string of briquettes and produce individual particles, a rotary drum tumbles the string where the webbing is broken off the briquettes. The briquettes are separated from pieces of webbing by a screen. The product briquettes are sent to storage, and the webbing is returned to the process via the paddle mixer. If the webbing pieces are too large, a crusher may be required to reduce their size before mixing with the fresh feed in the paddle mixer.

A dry dust collection system is required and may be a cyclone or bag filter or a combination of both. Dust is collected mainly from the crusher, screen, and the elevator and is returned to the briquetter via the paddle mixer. All equipment is closed, and all dust is collected and returned to the system, thereby ensuring minimum losses of material. With this arrangement the process presents no pollution problems.

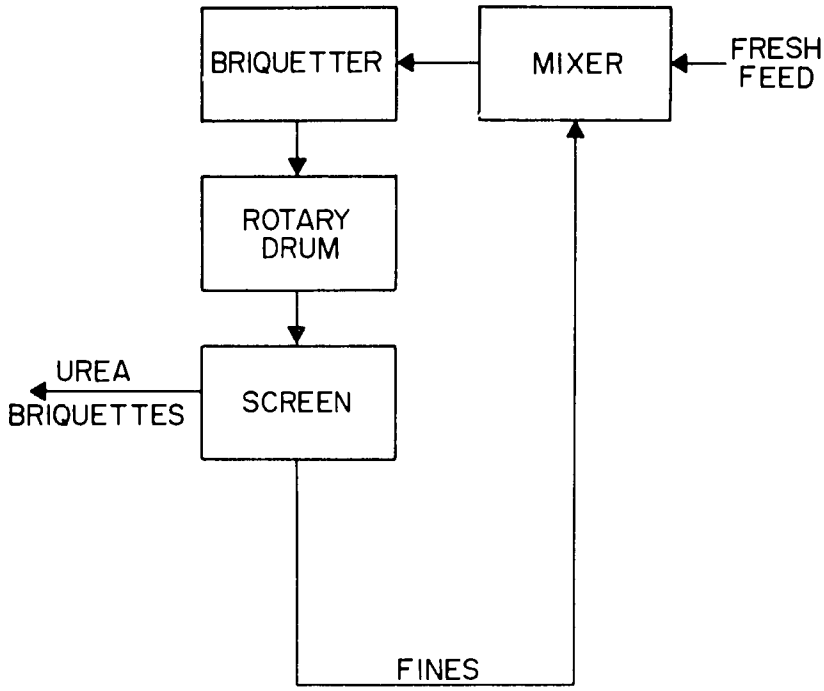


Figure 8. Schematic Diagram for Continuous Briquetting Process.

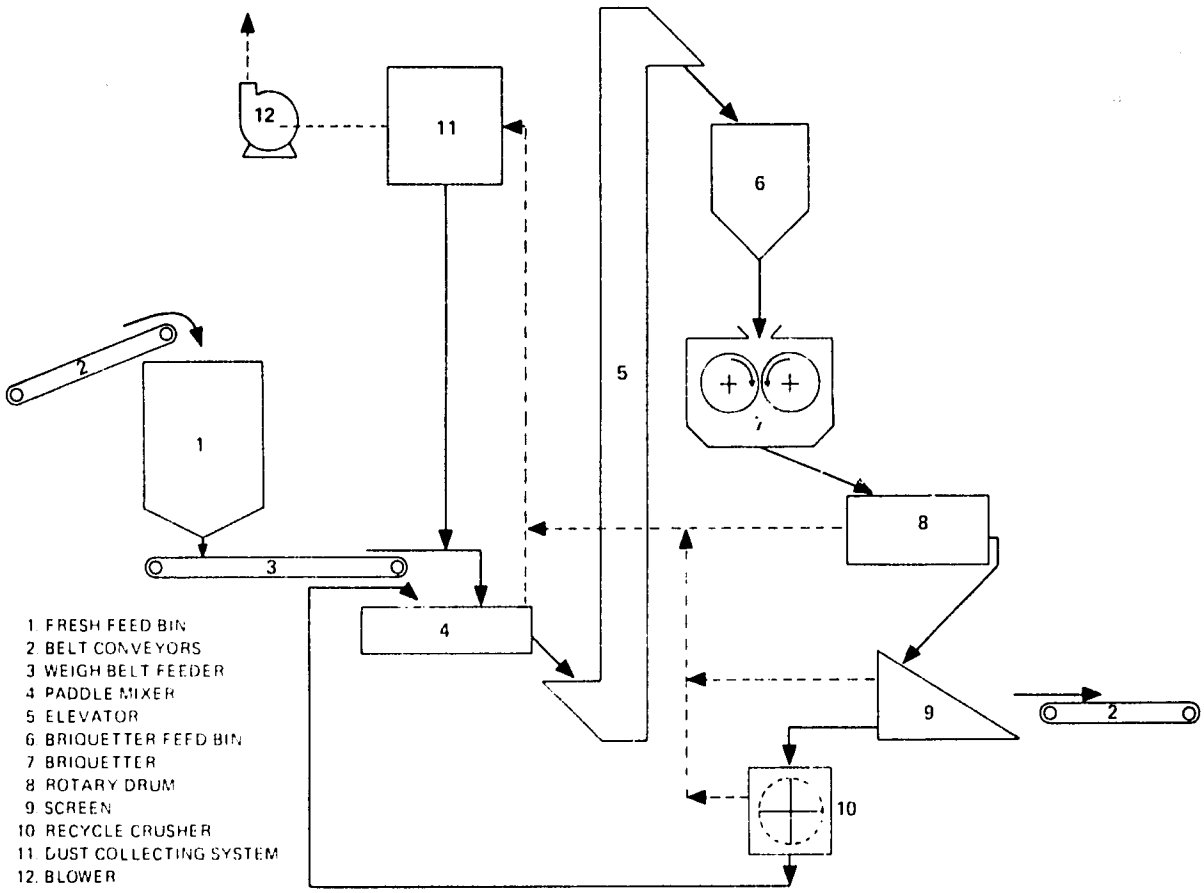


Figure 9. Briquetting Process Flow Diagram.

Process Economics

In this section, the process economics of producing USG by the briquetting process for developing countries are evaluated. Preliminary investment and conversion cost estimates were developed for the briquetted product under different conditions of plant capacities, plant site, and urea feed materials. The credits for using urea recycle materials and urea crystals instead of urea prills were evaluated. The effects of capacity utilization on the economics of urea briquetting process were also covered.

Premises and Scopes of Studies

Detailed premises and assumptions for the cost estimates involve consideration of various production schemes. They are explained as follows.

Selected Production Schemes

The urea briquetting unit can be added to an existing urea plant using urea recycle materials,[2] crystals, and/or prills as feed materials. It also can be built at a new site using purchased urea prills. To evaluate the effects of plant site, plant capacity, and urea feed materials on the economics of the process, the following schemes were studied.

Scheme Number	Description
I	125-mtpd briquetting unit at an existing urea plant using only recycle material.
II	250-mtpd briquetting unit at an existing urea plant.
II-A	Using 125-mtpd recycle material and 125-mtpd product prills.
II-B	Using 125-mtpd recycle material and 125-mtpd crystals.
III	250-mtpd briquetting unit at a new site using urea prills.

Scheme II-B is similar to Scheme II-A except that urea prills are replaced with urea crystals. Scheme II-B is only applicable to urea plants using the crystallization process for urea concentration. The other schemes are applicable to both evaporation and crystallization processes for urea concentration.

Investment and conversion cost estimates for urea briquettes were developed for each of the schemes. For Schemes I and II, estimates of feed material credits were developed on the basis of cost estimates for reprocessing the recycle materials and for converting the crystals into prills. The recycle material rate of 125 mtpd is typical for 1,000- to 1,500-mtpd urea plants. The same investment and conversion cost estimates were used for Schemes II-A and II-B; however, the feed material credits were different for the two schemes.

Premises and Assumptions for Cost Estimates

An itemized summary of the principal premises and assumptions for the investment and conversion cost estimates is presented in Appendix A. The premises, assumptions, and methodology for the cost estimates are discussed in the following sections.

The cost estimates were based on mid-1983 costs, and a plant location in a developing country was assumed. As mentioned previously, two plant sites (one at an existing urea complex and one at a new site) and two plant capacities of 125 mtpd and 250 mtpd were considered. Single briquetting machines were used for both capacities. The briquettes were assumed to be in the range of 1-2 g. The design for the briquetting process was discussed in a previous section of this bulletin. The schematic diagram for the process is shown in Figure 8, and the equipment flow diagram is presented in Figure 9. Process equipment specifications for a typical 250-mtpd briquetting plant are given in Appendix B.

For the same design capacity, the fixed investment for the battery-limits briquetting process unit was assumed to be the same for the two plant sites, with only the fixed investment for the auxiliary and support facilities being different. At an existing urea plant site, additions of auxiliary and support facilities were assumed to be minor, and allowances were not included for raw materials and product storage buildings. At a new site, allowances were included for raw materials and for such facilities as product storage buildings, mobile equipment, truck scales, utilities supply, and maintenance and administrative buildings.

Fixed investment estimates for the 250-mtpd briquetting process unit (battery-limits) were developed by estimating the delivered process equipment costs and then estimating the other direct and indirect costs on the basis of the equipment cost. Equipment cost estimates were developed on the basis of the equipment specifications given in Appendix B and preliminary proposals and published cost data. Cost estimates for equipment installation and other direct costs (material and labor) were estimated as percentages of the equipment cost. Indirect cost items were estimated as percentages of the direct cost estimates. This technique for estimating fixed investment is commonly used for preliminary estimates.

2. Urea recycle materials include urea fines collected from the bottom of the prilling tower, the screens, the warehouse and bagging area, as well as solids collected from the dust recovery system.

The fixed investment for the 125-mtpd briquetting plant (battery-limits basis) was estimated from that for the 250-mtpd plant by using the following formula:

$$\frac{I_2}{I_1} = \left(\frac{C_2}{C_1}\right)^x$$

where: I_2 = Investment for plant of capacity C_2
I_1 = Investment for plant of capacity C_1
x = Exponential scale factor.

The exponential scale factor, x, was assumed to be 0.6 in this study.

Other fixed investment costs included project management cost, preoperational and startup expenses, and interest during construction. The interest during construction was added to represent the cost of money regardless of whether the funds for the investment were borrowed or represented the owner's equity.

The working capital estimates were developed by using the inventory method and include allowances for inventories of raw materials, products, spare parts, and miscellaneous supplies. Assumptions for these inventories are shown in Appendix A.

Conversion cost is defined as the production cost excluding the raw materials and bagging cost. Conversion cost estimates include allowances for raw material and product handling cost, interest on working capital, and fixed capital recovery.

Conversion cost estimates were developed on a mid-1983 cost basis and for various capacity utilizations. The annual production rate at 100% capacity utilization corresponds to the daily design capacity multiplied by 330 operating days/year. The fixed capital recovery (capital charges) was based on a 12% annual interest rate and a 15-year time period. The fixed capital recovery, which corresponds to an annual charge of 14.7%[3] of the total fixed investment, covered depreciation and interest charges. The conversion cost was broken down into variable and fixed costs to facilitate the cost evaluation of different levels of capacity utilization. Conversion cost items that remained constant on an annual basis over the likely range of capacity utilization—i.e., 50%-100%—were treated as fixed costs. Conversion cost items that essentially vary in direct proportion to operating rate on an annual basis were treated as variable costs; on a per-unit-of-product basis, they were constant.

For those production schemes that used urea recycle material and/or crystals as feed materials, estimates of feed material credits relative to urea prills were developed and subtracted from the corresponding conversion cost. The feed material credits were estimated on the basis of the cost for reprocessing the recycle material and for converting the crystals to prills. In estimating these credits, only variable costs such as materials handling and utilities (electricity, steam, cooling water, etc.) were considered; other fixed costs such as maintenance, operating labor, and fixed capital recovery were not considered because they were assumed to be borne by the existing urea plant.

3. Based on formula: $\frac{i(1+i)^n}{(1+i)^n-1}$ with i = 0.12 and n = 15.

Investment Cost Estimates

Preliminary investment estimates were prepared on the basis of the premises and scopes of studies discussed above. The process equipment cost estimate for a typical 250-mtpd plant was about $1.2 million as shown in Table 3. The preliminary fixed investment estimates for 125-mtpd and 250-mtpd briquetting process units (battery-limits) were $2.5 million and $3.8 million, respectively, as presented in Table 4.

The total fixed investment estimate for the addition of a 125-mtpd briquetting plant to an existing urea plant (Scheme I) was $3.3 million. A summary of the cost estimate is shown in Table 5.

The total fixed investment estimate for the addition of a 250-mtpd briquetting plant to an existing urea plant (Scheme II) was $5.0 million as shown in Table 6.

The total fixed investment estimate for a 250-mtpd briquetting plant at a new site (Scheme III) was $8.0 million as presented in Table 7.

By using the inventory method discussed previously, the working capital estimates were calculated as $0.7 million, $1.3 million, and $4.6 million, respectively, for Schemes I, II, and III.

Table 3.
Delivered Process Equipment Cost Estimate for 250-mtpd Briquetting Plant.

Major Premises: 1. Cost basis: 1983 US $
2. Developing-country location

Process Equipment Item	US $ '000
Briquetter and stuffer	520
Rotary drum	35
Mixer and crusher	45
Screen	25
Dust collection system	70
Elevators and conveyors	130
Bins and hoppers	65
Weigh-belt feeders	25
Bagging system	50
Total, U.S. basis	965
Total, developing-country basis (U.S. x 1.25)	1,205

Table 4.
Battery-Limits Fixed Investment Estimates for Briquetting Plants

Major Premises: 1. Cost basis: 1983 US $
2. Developing-country location

I. Battery-Limits Fixed Investment for 250-mptd Briquetting Plant

	'000 US $
A. Direct Cost	
1. Delivered process equipment cost (Table 3)	1,205
2. Process equipment installation (45% of item 1)	545
3. Instrumentation—installed (10% of item 1)	120
4. Electrical—installed (15% of item 1)	180
5. Piping/ducts—installed (15% of item 1)	180
6. Buildings and structure (40% of item 1)	485
Total Direct Cost	2,715
B. Indirect Cost	
1. Engineering and supervision (12% of item A)	325
2. Construction overhead and expenses (10% of item A)	270
3. Contractor's fee and contingency (18% of item A)	490
Total Indirect Cost	1,085
C. Total Battery-Limits Fixed Investment (A + B)	3,800

II. Battery-Limits Fixed Investment for 125-mtpd Briquetting Plant

$$\$3{,}800{,}000 \times \left(\frac{125}{250}\right)^{0.6} = \$2{,}500{,}000$$

Table 5.
Fixed Investment Estimates for 125-mtpd Briquetting Plant as an Addition to Existing Urea Complex (Scheme I)

Major Premises: 1. Cost basis: 1983 US $
2. Developing-country location

	Investment Estimates ('000 US $)
A. Briquetting plant battery limits (Table 4)	2,500
B. Auxiliary and support facilities[a]	250
C. Other costs	
1. Preoperational, startup expenses, and project management[b]	140
2. Interest during construction[c]	410
D. Total fixed investment	3,300

a. Based on 10% of battery-limits cost (item A).
b. Based on 5% of item A + B.
c. Based on 15% of sum of items A + B.

Table 6.
Fixed Investment Estimates for 250-mtpd Briquetting Plant as an Addition to Existing Urea Complex (Scheme II)

Major Premises: 1. Cost basis: 1983 US $
2. Developing-country location

	Investment Estimates ('000 US $)
A. Briquetting plant battery limits (Table 4)	3,800
B. Auxiliary and support facilities[a]	380
C. Other costs	
1. Preoperational, startup expenses, and project management[b]	200
2. Interest during construction[c]	620
D. Total fixed investment	5,000

a. Based on 10% of battery-limits investment cost (item A).
b. Based on 5% of item A + B.
c. Based on 15% of sum of items A + B.

Table 7.
Fixed Investment Estimates for 250-mtpd Briquetting Plant at a New Site (Scheme III)

Major Premises: 1. Cost basis: 1983 US $
2. Developing-country location
3. Bulk storage capacity: 15,000 mt
4. Bagged storage capacity: 5,000 mt

	Investment Estimates ('000 US $)
A. Briquetting plant battery limits (Table 4)	3,800
B. Auxiliary and support facilities	
1. Bulk handling and storage building[a]	1,260
2. Bagged product storage building[b]	660
3. Pallets	150
4. Truck scales	50
5. Mobile equipment	150
6. Utility equipment, maintenance shop laboratory, administrative office[c]	380
7. Site development and miscellaneous	220
Subtotal	2,870
C. Other costs	
1. Preoperational, startup expenses, and project management[d]	330
2. Interest during construction[e]	1,000
D. Total fixed investment	8,000

a. Based on 3,000 m² @ $420/m².
b. Based on 2,000 m² @ $330/m².
c. Based on 10% of battery-limits cost (item A).
d. Based on 5% of item A + B.
e. Based on 15% of sum of items A + B.

The total capital estimates were $4.0 million, $6.3 million, and $12.6 million for Schemes I, II, and III, respectively.

Conversion Cost Estimat

Preliminary conversion cost and feed material credits were developed for the four production schemes on the basis of the preliminary investment estimates and the previously discussed premises.

Conversion cost estimates,[4] excluding feed material credits, for Schemes I, II, and III are presented in Table 8. The variable conversion cost was the same for all schemes—$2.5/mt. The annual fixed conversion costs were approximately $1.2 million, $1.6 million, and $2.8 million, respectively, for Schemes I, II, and III. These fixed costs corresponded to $29.8, $20.0, and $34.3/mt at 100% capacity utilization for Schemes I, II, and III, respectively. The estimated bagging cost for each scheme was $15/mt, which included the cost of bags. As shown in Table 8, the conversion cost estimates for bulk products were $32.3, $22.5, and $36.8/mt, respectively, for Schemes I, II, and III. The conversion costs plus bagging costs were $47.3, $37.5, and $51.8/mt, respectively, for Schemes I, II, and III.

Cost estimates for converting urea recycle materials and crystals to urea prills were $12.0 and $4.0/mt, respectively, as indicated in Table 9. On the basis of these cost estimates, the feed material credits relative to urea prills were estimated as $12.0, $6.0, and $8.0/mt for Schemes I, IIA, and IIB, respectively, as shown in Table 10. No feed material

Table 8.
Conversion Cost Estimates for Briquetting Plants

Major premises: 1. Cost basis: Mid-1983 US $
2. Developing-country location
3. 100% capacity utilization

	Scheme I		Scheme II		Scheme III	
	125 mtpd Existing site		250 mtpd Existing site		250 mtpd New site	
Fixed investment, $ million	3.3		5.0		8.0	
Working capital, $ million	0.7		1.3		4.6	
Production rate, mtpy	41,250		82,500		82,500	
Conversion Cost Items	**'000 $/yr**	**$/mt**	**'000 $/yr**	**$/mt**	**'000 $/yr**	**$/mt**
Variable costs						
Electricity (30 kWh @ $0.045)		1.4		1.4		1.4
Fuel for mobile equipment		0.6		0.6		0.6
Miscellaneous supplies		0.5		0.5		0.5
Subtotal		***2.5***		***2.5***		***2.5***
Fixed costs						
Operating labor and supervision	240		240		300	
Administrative and general expense[a]	240		240		450	
Maintenance[b]	155		236		284	
Insurance[c]	27		42		66	
Fixed capital recovery[d]	485		735		1,176	
Interest on working capital[e]	84		156		552	
Subtotal	***1,231***	***29.8***	***1,649***	***20.0***	***2,828***	***34.3***
Total conversion cost, bulk product		32.3		22.5		36.8
Bagging cost[f]		15.0		15.0		15.0
Conversion cost plus bagging cost		47.3		37.5		51.8

a. Based on 100% and 150% of operating labor and supervision for existing and new site, respectively.
b. Based on 6% of battery-limits plant cost plus 2% auxiliary and support facilities cost.
c. Based on 1% of battery-limits plant cost plus auxiliary and support facilities cost.
d. Based on 14.7% of total fixed investment.
e. Based on 12% of working capital.
f. Includes the cost of bags.

4. All conversion costs from this section were for 100% capacity utilization except where specifically mentioned otherwise.

Table 9.
Cost Estimates[a] for Converting Urea Recycle Materials and Crystals to Prills

Cost basis: 1983 US $

	Recycle Materials[b] to Prills		Crystals to Prills	
	Basis	$/mt	Basis	$/mt
Material handling		1.0		-
Steam @ $12/mt	0.75 mt	9.0	0.25 mt	3.0
Electricity @ $0.045/kWh	30 kWh	1.4	15 kWh	0.7
Cooling water and miscellaneous		0.6		0.3
Total		**12.0**		**4.0**

a. Variable cost only.
b. Urea recycle materials are dissolved with water to give about 75% urea solution and returned to the urea finishing section.

Table 10.
Feed Material Credits Relative to Urea Prills

Cost basis: 1983 US $

Scheme Number	Urea Feed	Feed Credit ($/mt)
I	100% recycle material	12.0
IIA	50% recycle material, 50% product prills	6.0[a]
IIB	50% recycle material, 50% crystals	8.0[b]
III	100% prills	0.0

a. Based on 50% of $12.0/mt credit for recycle material.
b. Based on average credit of $12.0/mt and $4.0/mt for recycle material and crystals, respectively.

credits were applied to Scheme III, which uses urea prills as feed material.

Conversion cost estimates, including feed material credits, are presented in Table 11. The net conversion cost estimates for bulk product after allowing for feed material credits were $20.3, $16.5, $14.5, and $36.8/mt, respectively, for Schemes I, IIA, IIB, and III. Net conversion plus bagging costs were $35.3, $31.5, $29.5, and $51.8/mt, respectively, for Schemes I, IIA, IIB, and III.

The conversion cost estimates, with and without feed material credits, versus capacity utilization from 60% to 100% are shown in graphic form in Figure 10. The conversion cost estimates, without feed material credits, at 60%, 80%, and 100% capacity utilizations are presented below in tabular form.

Scheme	Conversion Cost at Indicated Capacity Utilization 60%	80%	100%
	($ mt)		
I	52.2	39.7	32.3
IIA/B	35.8	27.5	22.5
III	59.7	45.4	36.8

Table 11.
Conversion Cost Estimates Including Feed Material Credits

Major premises: 1. Mid-1983 cost basis
2. Developing-country location
3. 100% capacity utilization

Item	Cost, $/mt Scheme I	Scheme IIA	Scheme IIB	Scheme III
Conversion cost estimate	32.3	22.5	22.5	36.8
Feed material credit	12.0	6.0	8.0	0
Net conversion cost, bulk product	20.3	16.5	14.5	36.8
Bagging cost	15.0	15.0	15.0	15.0
Net conversion cost plus bagging cost	35.3	31.5	29.5	51.8

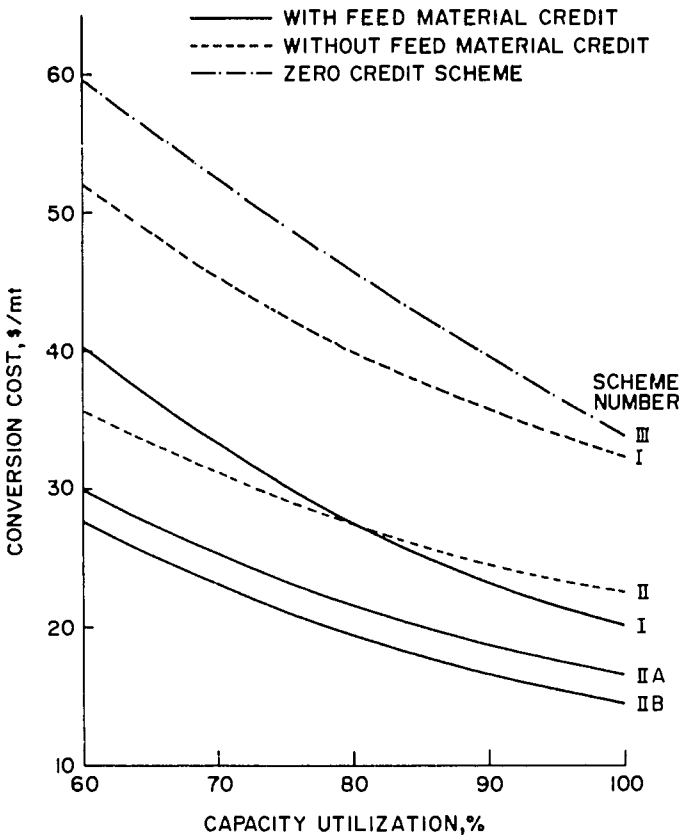


Figure 10. Conversion Cost Versus Capacity Utilization, Bulk Product.

Summary and Analysis of Cost Estimates

A summary of the investment and conversion cost estimates is presented in Table 12. The conversion cost estimates assumed 100% capacity utilization. These cost estimates are analyzed in the following paragraphs.

By comparing Schemes I and II, the impact of plant capacity on investment and conversion costs can be analyzed. The plant capacities for Scheme I and II are 125 mtpd and 250 mtpd, respectively. The increase in plant capacity from 125 mtpd to 250 mtpd increased the fixed investment from $3.3 million to $5.0 million or a 52% increase. The increase in capacity resulted in a decrease in conversion cost, excluding allowances for feed material credits, from $32.3/mt to $22.5/mt or a reduction of about 30%.

A comparison of Schemes II and III shows the effect on investment and conversion cost estimates of adding the briquetting plant to an existing urea complex versus building the plant at a new site. In both cases the plant capacity was 250 mtpd. As a result of greater requirements of auxiliary and support facilities, including storage facilities, the fixed investment estimate for a new site was $8.0 million versus $5.0 million for an existing plant site. Because of the greater inventory requirements the working capital estimate for the new site was $4.6 million versus $1.3 million for the existing plant site. Thus, the total capital investment estimate of

Table 12.
Summary of Investment and Conversion Cost Estimates

Major premises: 1. Mid-1983 cost basis
2. Developing country location
3. 100% capacity utilization

Item	Production Scheme			
	I	II	IIB	III
Plant capacity, mtpd	125	250	250	250
Annual production, '000 mt	41.25	82.5	82.5	82.5
Investment cost estimates, US $ million				
Fixed	3.3	5.0	5.0	8.0
Working	0.7	1.3	1.3	4.6
Total	4.0	6.3	6.3	12.6
Conversion cost, bulk material, $/mt				
Gross	32.3	22.5	22.5	36.8
Feed material credit	12.0	6.0	8.0	0
Net	20.3	16.5	14.5	36.8
Bagging cost, $/mt	15.0	15.0	15.0	15.0
Net conversion cost plus bagging cost, $/mt	35.3	31.5	29.5	51.8

$12.6 million for a new site was 100% higher than the estimate of $6.3 million for an existing plant site. The conversion cost estimate for the new site was $36.8/mt compared with $22.5/mt, excluding feed material credit, for an existing plant site. The conversion cost estimate for the new site was about 64% higher.

The impact of feed material credits on the conversion costs can be analyzed from the summary in Table 12. For Scheme I, which utilized only recycle material, the feed material credit of $12.0/mt reduced the conversion cost estimate from $32.3/mt to $20.3/mt or about 37%. For Scheme IIA, which utilized 50% recycle material and 50% product prills, the feed material credit of $6.0/mt reduced the conversion cost estimate from $22.5/mt to $16.5/mt or about 27%. For Scheme IIB, which utilized 50% recycle material and 50% urea crystals, the feed material credit of $8.0/mt reduced the conversion cost estimate from $22.5/mt to $14.5/mt or about 36%. Since Scheme III utilized all purchased urea, no feed material credits were applicable.

It is important to compare the conversion cost estimates or added costs for briquetted urea with those for prilled urea. For this purpose delivered costs for bulk prilled urea of $150/mt, $200/mt, and $250/mt were assumed. A bagging cost of $15.0/mt was assumed for the prilled urea and for the briquetted urea. On this basis the total product cost estimates for bagged urea briquettes produced by the different schemes and for bagged urea prills were as follows:

Scheme	Bulk Prills	Bagged Urea Briquettes	Bagged Urea Prills	Premium for Briquettes ($/mt)	Premium for Briquettes (%)
	- - - - - -($/mt)- - - - -				
I	150.0	185.3	165.0	20.3	12.3
	200.0	235.3	215.0	20.3	9.4
	250.0	285.3	265.0	20.3	7.7
IIA	150.0	181.5	165.0	16.5	10.0
	200.0	231.5	215.0	16.5	7.7
	250.0	281.5	265.0	16.5	6.2
IIB	150.0	179.5	165.0	14.5	8.8
	200.0	229.5	215.0	14.5	6.7
	250.0	279.5	265.0	14.5	5.5
III	150.0	201.8	165.0	36.8	22.3
	200.0	251.8	215.0	36.8	17.1
	250.0	301.8	265.0	36.8	13.9

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Appendix A

Premises and Assumptions for Investment and Conversion Cost Estimates

1. Cost estimates are based on a mid-1983 cost basis and for a developing country location where the investment cost is assumed to be approximately 25% higher than for the U.S. Gulf Coast.
2. The investment costs do not include costs for land, infrastructure (housing, access roads, docks, etc.) and support facilities located outside the plant site boundary. Allowances are not included for escalation during construction.
3. The investment costs for raw material and product storage buildings are included for a new site but excluded for an existing site.
4. Interest during construction is on the basis of 15% of fixed investment which corresponds to a 3-year project with a typical disbursement rate and a 12% interest rate.
5. Working capital estimates include allowances for the following inventories:
   a. Raw material: Existing site—negligible
      New site—60 days
   b. Product: 20 days
   c. Cash: 30 days of conversion cost
   d. Spare Parts: 4% of process unit plant cost
   e. Miscellaneous Supplies: Annual production at $1/mt
6. Conversion costs include allowances for raw material and product handling, interest on working capital, and fixed capital recovery.
7. Bagging cost includes the cost of bags, bagging labor, product handling, and related general expenses.
8. Annual maintenance cost is based on 6% of the briquetting process plant cost and 2% of auxiliary and support facilities cost.
9. Annual insurance cost is based on 1% of the process plant cost plus auxiliary and support facilities cost.
10. Administrative and general expenses for existing and new sites are based on 100% and 150% of operating labor and supervision cost, respectively.
11. Annual interest on working capital is based on 12% of the working capital.
12. Fixed capital recovery is based on 14.7% of the fixed investment. This is the capital recovery factor corresponding to a 12% interest rate and a 15-year period. The capital recovery covers depreciation and interest and/or return on investment.
13. Estimates of feed material credits relative to urea prills (for Schemes I and II) are developed on the basis of cost estimates for reprocessing the recycle materials and for converting the crystals to prills. Only variable costs are charged to these costs because the fixed costs are assumed to be borne by the existing urea plant.
14. Utility costs are as follows:

Electricity, $/kWh	0.045
Steam, $/mt	12.0
Cooling water, $/m^3	0.04

15. Other premises and assumptions are discussed in the report.

Appendix B

Process Equipment Specifications for a Typical 250-mtpd Briquetting Plant

Equipment Name	Quantity	Specifications
Briquetter and stuffer	1	Double roll press, 12.5 mtph, Press drive: 300 hp Feeder drive: 40 hp
Rotary drum	1	Diameter 1.5 m, length 5 m, carbon steel, 5 hp
Paddle mixer	1	0.7 m x 5 m, 25 hp, 12.5 mtph
Recycle crusher	1	Hammer mill, 5 mtph, 30 hp
Vibrating screen	1	2 m x 3 m, 12.5 mtph, 10 hp
Dry dust-collection system	1	Filter air, baghouse type 7 m^3/sec, 60 hp blower
Mixer discharge bucket elevator	1	20 mtph, 15 m high, 4 hp
Bagging system bucket elevator	1	40 mtph, 15 m high, 4 hp 1 shift/day
Feed belt conveyor	1	15 mtph, length = 100 m, width = 70 cm, 2 motors of 1 hp each
Recycle material belt conveyor	1	5 mtph, length = 20 m, width = 70 cm, 1 hp
Bulk product belt conveyor	1	15 mtph, length = 100 m, width = 70 cm, 3 motors of 1 hp each
Bagged product belt conveyor	1	40 mtph, length = 20 m, width = 1 m, 3 hp motor
Weighbelt feeder	1	15 mtph
Fresh feed bin	1	200 m^3, 87-mt capacity, equipped with bin activator and rotary air lock
Briquetting feed bin	1	14 m^3, 6-mt capacity equipped with bin activator and rotary air lock
Bagging storage bin	1	14 m^3, 6-mt capacity, equipped with bin activator and rotary air lock
Bagging unit	1	40 mtph, 1 shift/day