GRANULAR FERTILIZER COOLERS

Cost Comparisons

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Introduction

Before we start discussing some of the different fertilizer coolers used in the international industry, it would seem appropriate to briefly explain the need for cooling of these products.

After the drying and screening stage, the temperature of the fertilizer granules can range from 175°F to 250°F. Most fertilizer products would be subject to "caking" (agglomeration or lumping) if they were shipped or sent to the storage pile at these temperatures. The cause of this caking is the growth of crystal bonds between the individual granules. Drying and cooling of the different fertilizer products minimizes thermal effects and chemical reactions which can result in the creation of crystals from minute amounts of salt solutions present in the granules[1]. Figure 1 shows (left) the formation of surface crystals growth responsible for caking in a fertilizer granule (12-12-12) that had been stored for 3 months. This crystals were identified as a Urea-Ammonia Chloride Complex. The picture at the right of this figure shows how drying and cooling (lower granules) can reduce the extent of surface crystals that promote bonding between the particles[2].

The maximum product temperature that can be allowed depends on various factors including:

- Type of product (chemical composition)
- Particle size and hardness of the granules
- Product moisture
- Amount and type of conditioning agent
- Storage pressure (pile or bag height)

With some ammonium nitrate grades safety is a major factor as "smoldering" (slow burning) is possible in piles of fertilizers. The oxidizing action of the nitrates on the organic content of the granules is the main reason for the smoldering. These reactions are accelerated at higher temperatures.

Some DAP producers operate plants that were built without a product cooler. As a result, they are forced to keep the product in the warehouse until it is sufficiently cold to ship. Their only alternative to increased product inventory is to accept higher product caking complaints from their customers. Breaking of the caked product piles results in a significant amount of fines removed by the shipping screens. Recycling of these fines increases the cost of production and also reduces the net production rate from the granulation plant.

It is worthwhile noting that too much cooling can also create caking problems caused by water being absorbed by the granules from the atmosphere. Low product temperatures can lower the water vapor pressure below that of the atmosphere. As a result moisture is absorbed by the granules as they try to reach equilibrium with the surrounding air. This moisture absorption is sometimes displayed as a moist outer layer in older (cooler) granular fertilizer piles.

Cooler Designs

Product coolers typically used in the fertilizer industry include:

- Cascading tray
- Rotary flighted drum
- Fluid bed
- Plate Exchanger

Cascading Tray

The tray cooler was used for the design of DAP plants by various engineering companies in the early to middle sixties. It consists of a series of perforated plates mounted horizontally, and separated vertically by about 3 to 4 feet, within a square stationary carbon steel shell. Ambient air aspirated through openings at the bottom of the shell flows through 5/8" - 1" holes in the trays. In theory these perforated plates would distribute the air to maximize contact with the granules as they fell by gravity through the holes in the different trays. The cooled product was discharged at the bottom of the cooler to a belt conveyor or elevator that carried the product to storage. Most of the units installed in Florida and Louisiana experienced problems with channeling of the air and granules through opposite sides of the perforated plates and failed to perform as expected. Typical tray loading have been reported as high as 0.8 stph / ft^2 with exit air velocities of 500 - 650 ft/min based on the cross sectional area of the shell. The pressure drop normally ranged from about 5 to about 9.5 in WC[3]. Producers that have had these coolers in service have either replaced them or are considering their replacement with more efficient/reliable units.

Rotary Flighted Drum

The cooler usually found in fertilizer plants throughout the world is the countercurrent flighted rotary type. While the cost of this equipment is relatively high, it is very reliable and has more or less been the standard at least in the U.S. The showering action promotes product dedusting and it does not require washing or periodic removal of lumps to maintain its performance. This unit (Fig.2) is designed with spiral flights at the feed end, followed by alternating lifting flights of various designs. Most plants designed or visited by the authors have bucket flights at the discharge end that lift and discharge the material near the top side of the revolving shell. The point of discharge is sufficiently high and the boot end of the product elevator does not have to be installed in a hole. On a reference 12' diameter x 55' long unit the spiral, cascading, and bucket flights occupy respectively about 9%, 87% and 4% of the shell length. The diameter of this cooler is fixed by the air flow calculated by a heat and material balance. Air discharge velocities of 500 ft/min have been used without any problems caused by surging of the solids flow. Heat transfer coefficients encountered by the authors have varied from about 10 to about 23 BTU/h ft^3 °F depending on the cascading flight arrangement and the air velocity or mass flow in effect. Curves have been published [4,5] confirming that heat transfer coefficients increase with increasing air flux.

Fluid Bed Coolers

To our knowledge there are no fluid bed coolers being used in DAP, MAP, or NPK plants in this country. Nonetheless, they are commonly used in fertilizer plants in countries such as Norway, England, France, Germany, Romania, Hungary, Nigeria and will be used in a DAP plant designed by Jacobs that is expected to start in Huangmailing, China later this year.

Fluid bed coolers will usually occupy less space and have a lower capital cost than the rotary drum cooler. These advantages may have been decisive in making them the the equipment of choice in European plants that have exceeded their original cooling capacities.

On the negative side, these units usually require more air flow at a higher pressure drop than rotary drums. Fluid beds cannot move large pieces of scale and can be affected by pluggage of the fluidizing plate due to dusty inlet air.

There are three main types of fluid bed coolers:

- Static deck
- Vibrating deck
- Hybrid or heat exchanger

The static deck fluidized bed (Figure 3) consists of a closed chamber separated into two parts by a fluidization bottom plate. This plate may be a perforated plate or a porous plate made of agglomerated or sintered metal. The air inlet box under this plate is used to distribute the air flow. As the air volume is increased a velocity is reached at which the air flow just fully supports the weight of the granules on top of the fluidizing plate. This is the point of incipient fluidization. When the velocity is increased beyond this point the bed starts to "bubble" and particles approach a state of individual suspension within the air stream. This is the practical operating point that ensures excellent contact and heat exchange between the granules and the air.

In the heat exchanger (H.E.) fluid bed, (Figure 4) plate or tube exchangers are immersed in the fluidized bed. This type of unit reduces the air flow required and therefore the surface area and size of the cooler and of the equipment required to clean the gases. The H.E. fluid bed has beds that are normally 600 to 1800 mm deep and therefore higher air pressure drops than static bed coolers.

Vibrating deck coolers can transport the material with lower air flow as they do not require full fluid conditions to transport the material. They are also best suited to handle sticky materials that could exhibit wide fluctuations in their behavior (due to variations in particle size) with respect to fluidization velocities. This arrangement would appear to have a greater turndown and therefore be more flexible.

Plate Exchanger

The plate exchanger cooler is a rather new application in the phosphate fertilizer field. One design that has been getting some attention in Canada, Brazil and now in the US is the "Bulk Flow Heat Exchanger". This indirect heat exchanger consists of a vertical bank of 304 ss plates which are water cooled. Heat transfer is achieved by direct contact of the plates and granules. Product to be cooled is fed at the top of the unit and flows down through the bank of plates. A gate at the bottom of the cooler is activated by a level indicating controller. The latter regulates the rate at which the granules discharge from the cooler and insures that the plates remain covered with material at different product feed rates.

A simplified flow diagram of this unit is included in Fig. 5. Up to now the cooling medium has been water as shown. Anhydrous ammonia could probably be utilized to enhance energy efficiency by removing heat from the product and maintaining it within the DAP plant. This may however require thicker, more expensive plates.

We should point out that there are other types of indirect cooler that could probably be used to cool fertilizer products, but have not been included in this paper. These include the MULTIDISK ® thermal processor from the Renneburg Division of Heyl and Patterson Inc. and well as the water cooled Cylindrical coolers manufactured by F. L. Smidth and Co. These units include the advantage of the plate exchangers in that minimum gas volumes are required to cool the product.

Installation Costs

Jacobs examined the cost of installing fertilizer coolers into existing plants. The required modifications were sized for plants that produced 50 stph, 100 stph and 150 stph of DAP, and that required product cooling from 190 °F to 130 °F. Ammonia chillers were included in the rotary and fluid bed coolers to minimize the size of the gas cleaning equipment and to optimize the heat recovery of the plants. An ambient air temperature of 90 °F (at 85% R.H.) and a cooling water temperature of 85 °F was the starting point for the cooling medium for the air or indirect cooled units. Ammonia chillers reduce the temperature of the air entering the cooler to about 40 °F.

Table 1 is a list of the equipment, respective prices and total capital required to retrofit the different types of coolers into an existing 50 stph DAP plant. This retrofit assumes that the plants had been designed with coolers that were not performing, but that included cyclones, scrubbers and fans that could be utilized. This scenario has been encountered in some of our projects. Tables 2 and 3 lists the same information but in this case it is for plant producing 100 stph and 150 stph of DAP respectively.

The layout reviewed for this study required a bucket elevator and a longer belt conveyor for the rotary cooler case than would be required with either of the two fluid bed coolers. As shown in tables 1 through 3 the rotary cooler had the highest equipment and total installation cost of any of the four alternates. The plate exchanger had the lowest cost for the 50 stph case but lost this advantage for the 100 stph and 150 stph plants where two of these units were required to handle the cooling load. For these large capacity plants the H.E. fluid bed cooler showed the lowest installed cost. The installed cost of these cooler alternates is plotted against the plants' production rate in Figure 6.

Electrical Energy Requirements

The additional and total electrical energy requirements for all of the mechanical equipment associated with these three cases are listed in Table 4. The annual energy cost at $0.07 per kWh is listed in Table 5. The numbers under the additional columns represent energy consumed above that required by the original gas handling system.

The lowest energy cost are those of the plate exchanger followed by the rotary drum. The static and H.E. fluid beds had the highest energy cost due to the combination of higher air flow and/or pressure drop. The total electrical cost to operate either of the four coolers is plotted in Figure 7 as a function of the DAP plant production rate. These costs range from $6552/year for the plate exchanger at 50 stph to $430,416/year for the H. E. fluid bed at 150 stph rate.

Advantages and Disadvantages

The plate exchanger or "Bulk Flow" unit has a definite cost advantage particularly in plants having a capacity of 70 - 75 stph or less. For larger size plants present designs require more that one cooler and the capital cost advantages start to disappear. This type of cooler the advantage of requiring an air flow of only about 150 ft^3/st product versus 23,000 to 30,000 ft^3/st product respectively for the rotary and static fluid bed types. This provides substantial energy savings. On the negative side, there is little track record for these units. Due to their design these coolers could have some difficulty handling large pieces of scale, and will require cleaning about every one to two weeks to keep the plates clean. Ammonia could probably be used as a coolant, but careful evaluation of the dew point would be required to avoid condensation at the lower plate temperatures. Use of ammonia will probably require use of thicker wall plates to withstand higher operation pressures and will increase the cost of the unit. This units warrant close examination particularly for increases in original cooling capacity where only one unit is required to lower the product temperature to acceptable levels

Fluid bed coolers have a lower initial cost than the rotary units and in higher capacity plants can compete in terms of cost with the plate exchanger. These units require a higher air pressure which increase the electrical operating costs of the fans to the point of eliminating their initial capital cost advantage over the counter current rotary drum coolers. Lower air flows can be obtained with the H.E. fluid bed but at the expense of a higher air pressure drop.

Rotary drum coolers continue to be the standard at least in the US, fertilizer granulation plants. These units offer performance reliability as they are not subject to the material flow/cooling problems that can be caused by large pieces of scale falling on the fluidizing plates or obstructing the material flowing through the plates and gates of the fluid bed and plate exchanger design. The product dedusting capabilities and additional water evaporation obtained in these (and also the fluid bed) units cannot be accomplished by the plate exchangers. The energy required to move the cooling air is lower than that of the fluid bed cooler but significantly higher than required for the plate exchangers.

In conclusion we would like to close this presentation by recognizing that there are different ways to design or debottleneck the cooling section of granulation plants. Coolers such as the fluid bed have been successfully used in numerous fertilizer plants and do appear to have an advantage in initial capital cost over the more standard rotary drum. The latter's lower operating costs would be expected to eliminate this initial advantage. The plate exchanger has a definite cost advantage for the smaller plants where only one unit is required. This advantage will be more pronounced in plant modifications or new plants that require additional gas cleaning equipment to handle the gases from the rotary and the fluid bed units.

REFERENCES

1. "The Fertilizer Manual" by International Fertilizer Development Center.

2. "Microscopic Studies of the Mechanism off Caking and Its Prevention on Granular Fertilizers" by Silverberg, Julius, J.R. Lehr and George Hoffmeister, Jr., Journal of Agricultural and Food Chemistry.

3. Private communications with coworkers.

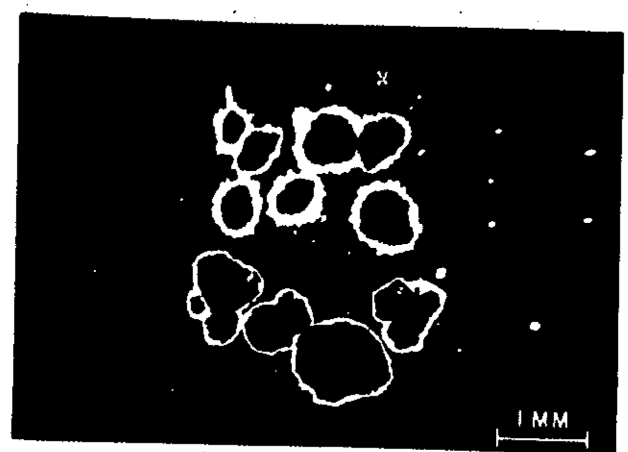
4. " Granular Fertilizer Cooling Theory and Practice", by A.T. Nogueira, 1989 Joint Meeting AICHE, Clearwater, Florida

5. "Air - Solids Interaction in Rotary Dryers and Coolers", by W.C. Saeman, Chemical Engineering Progress, (Vol. 58, No. 6) June 1962.

Figure 1

Surface Crystals Responsible for Caking

Closeup of surface crystal growth responsible for caking during 3 months' storage



Effects of drying (lower set of granules) in reducing extent of caking-bond growth during storage

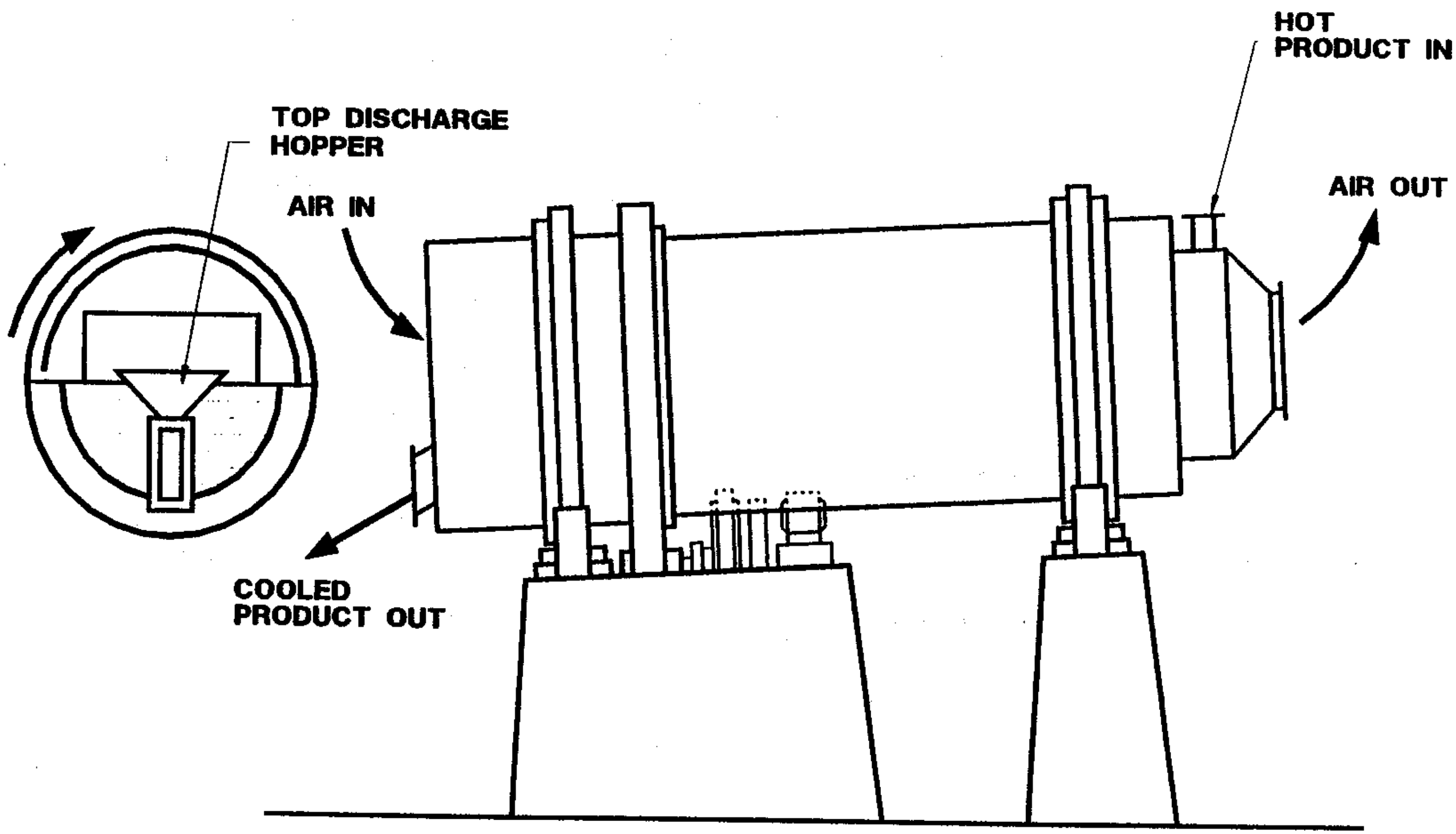


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FIGURE 2

COUNTERCURRENT ROTARY COOLER

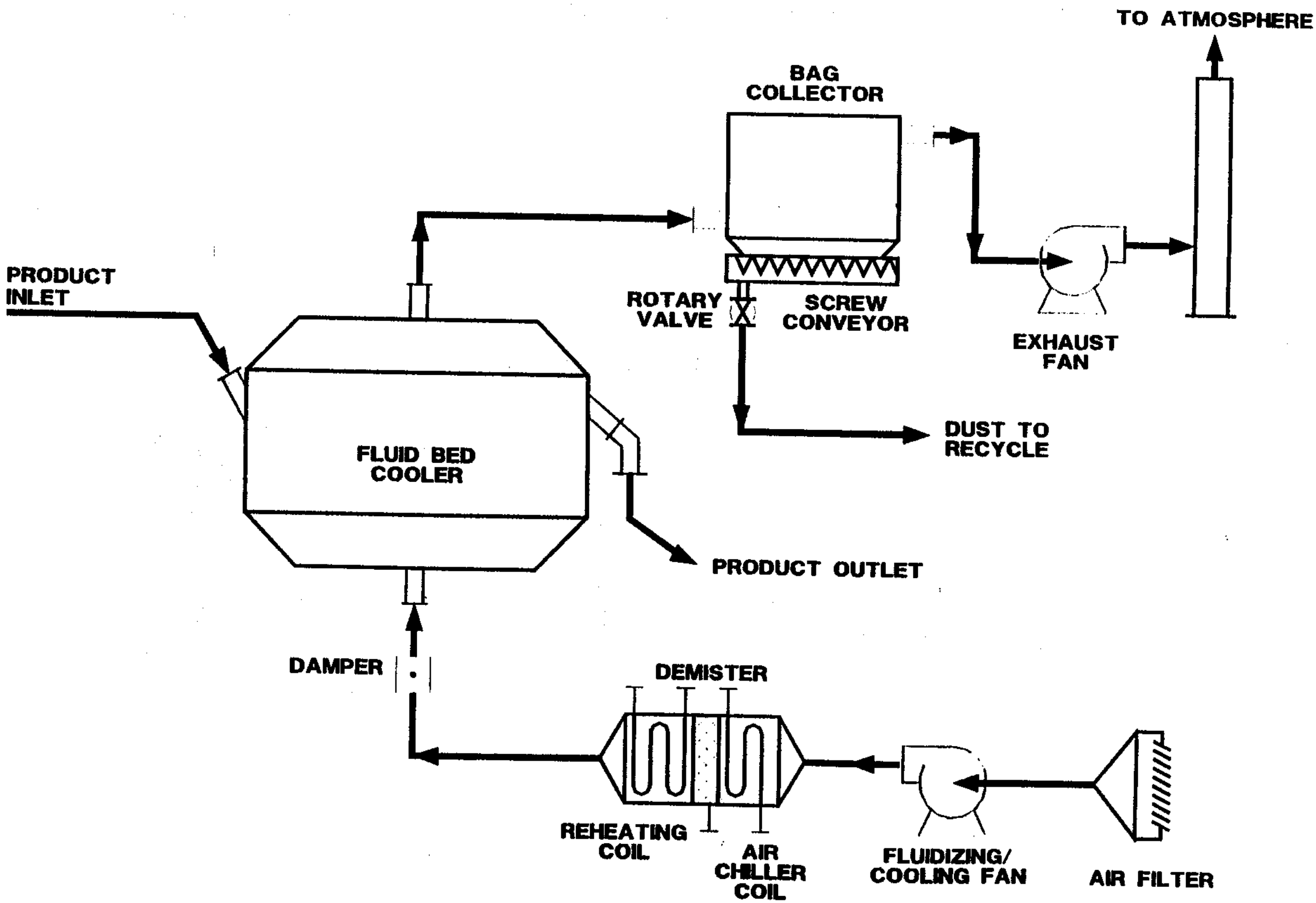

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FIGURE 3

FLUID BED COOLER

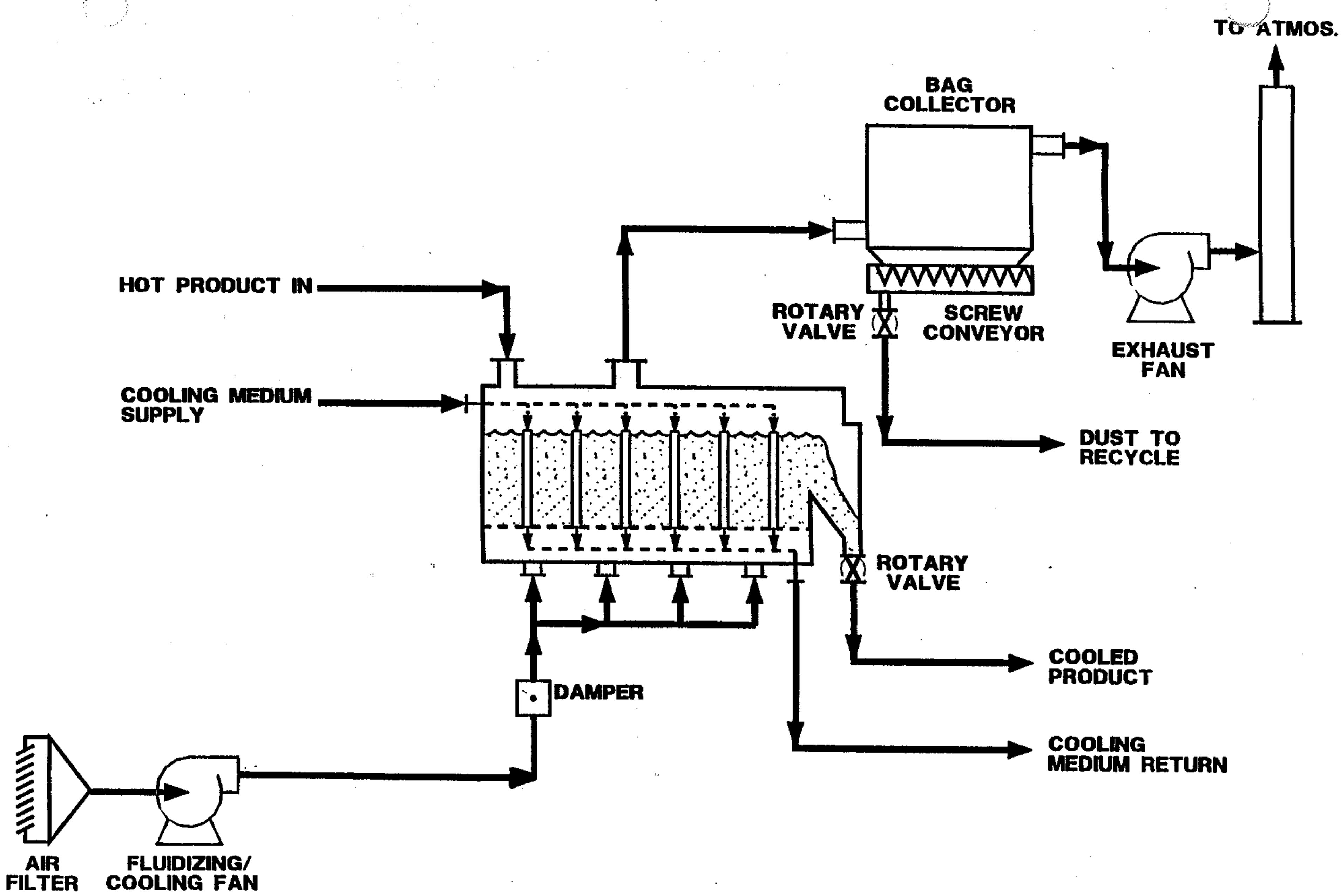

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FIGURE 4

HEAT EXCHANGER FLUIDIZED BED

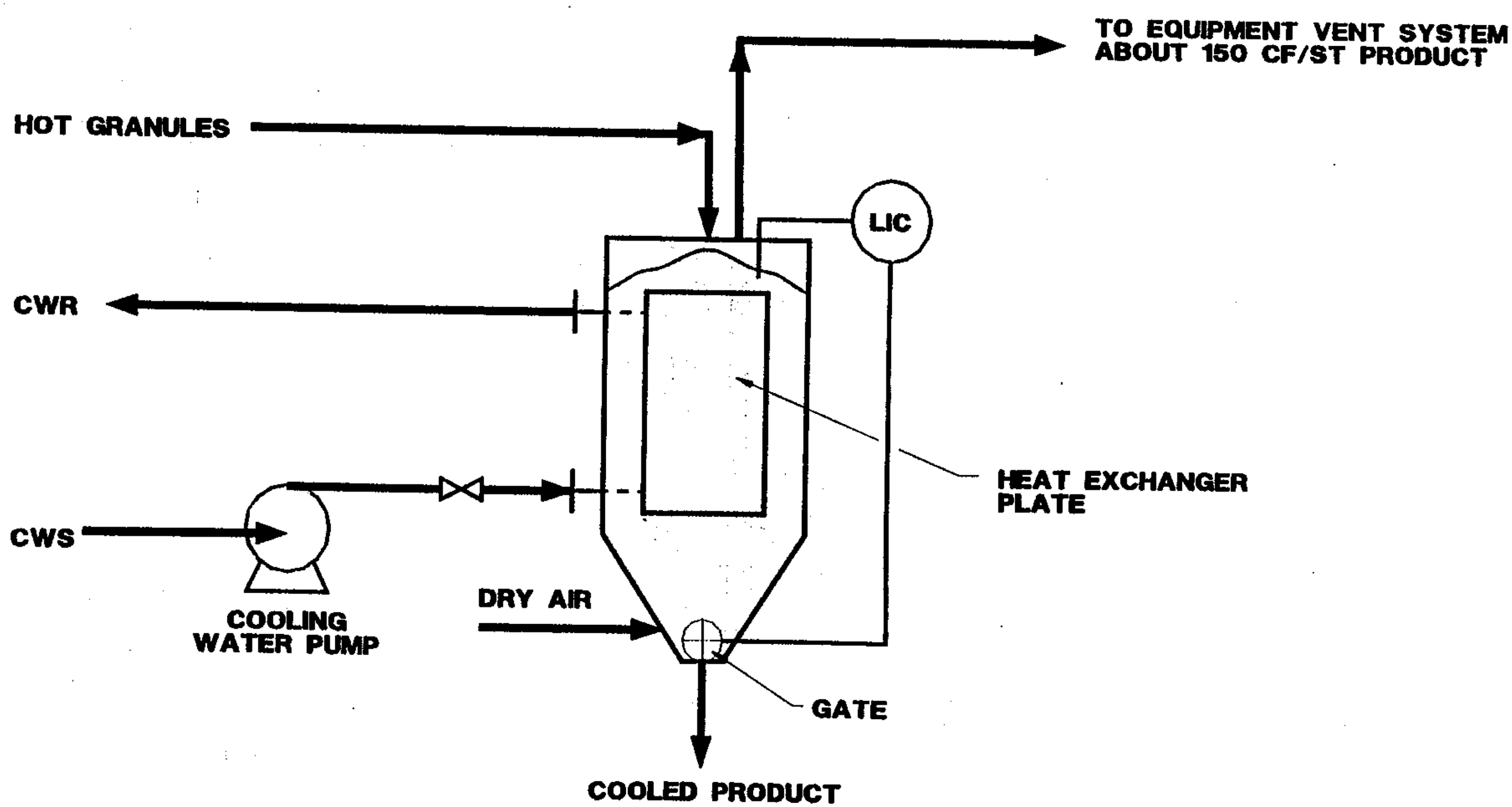

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FIGURE 5
"BULK FLOW" PLATE EXCHANGER
TYPICAL PFD

TABLE 1 - Cost of Plant Modification for 50 stph DAP

Equipment	Rotary	Fluid Bed	H.E. Fluid Bed	Plate Exchanger
Cooler	$300,000	$111,000	$195,600	$220,000
Cooling Water Pump	NA	NA	NA	$3,700
Air Chiller	$78,000	$78,000	NA	NA
Ammonia Separator	$2,400	$2,400	$2,400	NA
Belt Conveyor	$11,000	$9,000	$9,000	NA
Bucket Elevator	$15,800	NA	NA	NA
Forced Draft Fan	NA	NA	$63,200	NA
Induced Draft Fan	NA	$68,000	NA	NA
Air Locks	NA	$7,800	$7,800	NA
Total Equipment Price	$407,200	$276,200	$278,000	$223,700
Others (1)	$546,800	$402,000	$290,800	$233,200
Total Installed Cost	**$954,000**	**$678,200**	**$568,800**	**$456,900**

TABLE 2 - Cost of Plant Modification for 100 stph DAP

Equipment	Rotary	Fluid Bed	H.E. Fluid Bed	Plate Exchanger
Cooler	$360,000	$168,000	$296,400	$410,000
Cooling Water Pump	NA	NA	NA	$7,200
Air Chiller	$118,000	$118,000	NA	NA
Ammonia Separator	$3,300	$3,300	$3,300	NA
Belt Conveyor	$11,000	$9,000	$9,000	$11,000
Bucket Elevator	$24,000	NA	NA	NA
Forced Draft Fan	NA	NA	$95,800	NA
Induced Draft Fan	NA	$103,000	NA	NA
Air Locks	NA	$7,800	$7,800	NA
Total Equipment Price	$516,300	$409,100	$412,300	$428,200
Others (1)	$696,700	$593,900	$430,300	$458,800
Total Installed Cost	**$1,213,000**	**$1,003,000**	**$842,600**	**$887,000**

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TABLE 3 - Cost of Plant Modification for 150 stph DAP

Equipment	Rotary	Fluid Bed	H.E. Fluid Bed	Plate Exchanger
Cooler	$550,000	$214,000	$378,000	$620,000
Cooling Water Pump	NA	NA	NA	$8,200
Air Chiller	$151,000	$151,000	NA	NA
Ammonia Separator	$4,200	$4,200	$4,200	NA
Belt Conveyor	$11,000	$9,000	$9,000	$11,000
Bucket Elevator	$30,600	NA	NA	NA
Forced Draft Fan	NA	NA	$122,000	NA
Induced Draft Fan	NA	$131,000	NA	NA
Air Locks	NA	$7,800	$7,800	NA
Total Equipment Price	$746,800	$517,000	$521,000	$639,200
Others (1)	$1,003,200	$752,000	$545,000	$672,800
Total Installed Cost	**$1,750,000**	**$1,269,000**	**$1,066,000**	**$1,312,000**

Notes: 1. Includes bulk commodities,freight, labor, professional sevices, sales tax at 7% of material cost, 2% construction fee and 15% allowance for unforseen conditions.

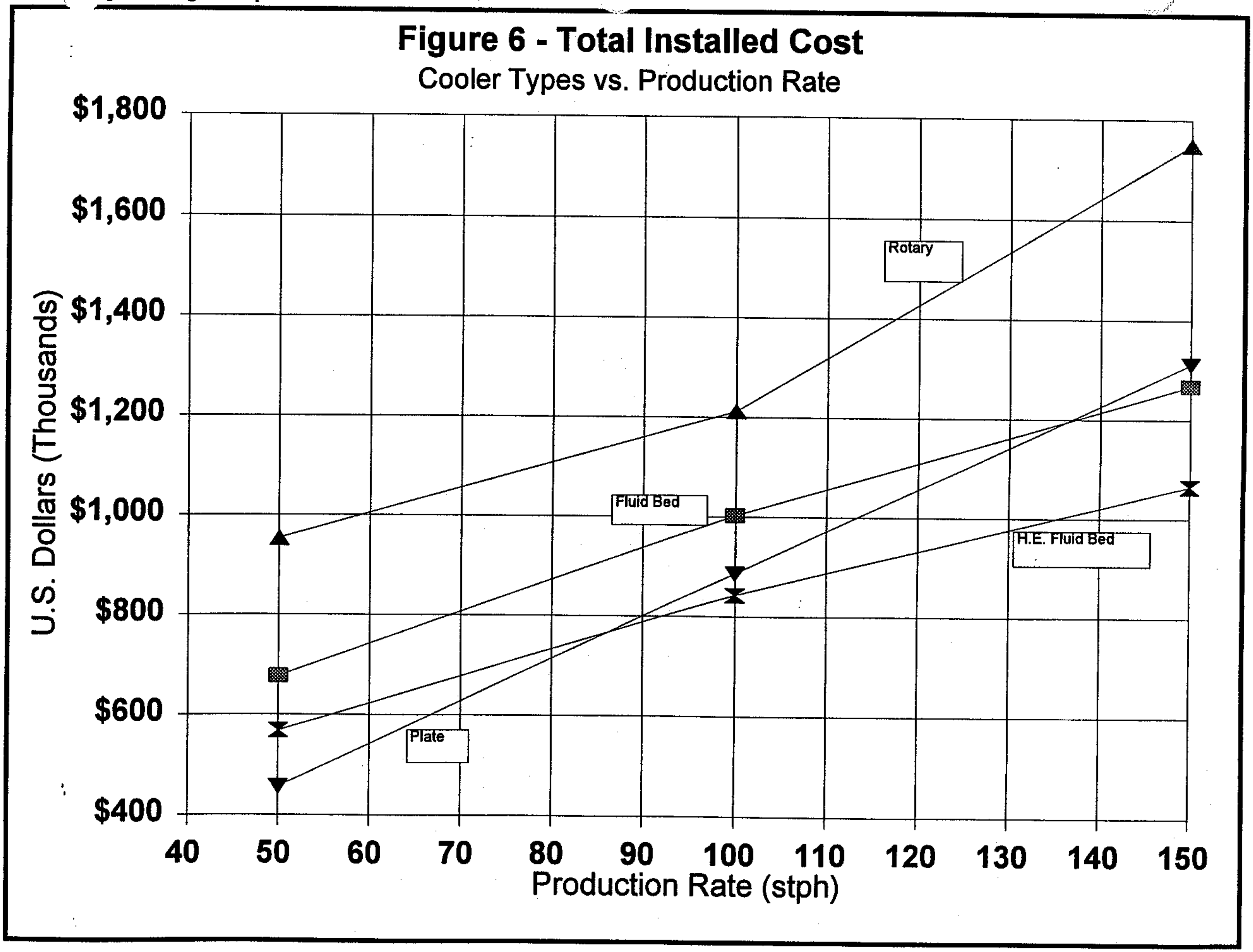
Figure 6 - Total Installed Cost
Cooler Types vs. Production Rate
U.S. Dollars (Thousands)
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
40
50
60
70
80
90
100
110
120
130
140
150
Production Rate (stph)
Rotary
Fluid Bed
H.E. Fluid Bed
Plate

Table 4 - Electrical Energy Requirements (kW)

Plant Capacity	Rotary Drum		Static Fluid Bed		H. E. Fluid Bed		Plate Exchanger	
	Additional	Total	Additional	Total	Additional	Total	Additional	Total
50 stph	41	158	125	242	189	306	-103	13
100 stph	78	303	250	475	353	578	-241	27
150 stph	115	444	374	703	525	854	-353	39

Table 5 - Annual Electrical Costs (US $)

Plant Capacity	Rotary Drum		Static Fluid Bed		H. E. Fluid Bed		Plate Exchanger	
	Additional	Total	Additional	Total	Additional	Total	Additional	Total
50 stph	$20,664	$79,632	$63,000	$121,968	$95,256	$154,224	($51,912)	$6,552
100 stph	$39,312	$152,712	$126,000	$239,400	$177,912	$291,312	($121,464)	$13,608
150 stph	$57,960	$223,776	$188,496	$354,312	$264,600	$430,416	($177,912)	$19,656

Figure 7 - Total Electrical Costs/Year

Cooler Types vs. Production Rate