GRANULAR FERTILIZER COOLING

Theory and Practice

by

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INTRODUCTION

General

Although there is general consensus that granular fertilizer products should be cooled prior to storage, bagging or shipping, there is no generally accepted temperatures to which a product must be cooled. Perhaps this lack of agreement is because products are cooled for different reasons:

1. To prevent caking in storage, in transit, in bags or at customer's facilities.

2. To prevent moisture migration to the surface of the pile, followed by winter freezing of the product and product decrepitation or break-up.

3. To prevent damage to bags or bagging equipment.

A popular TVA publication "Physical Properties of Fertilizers and Methods for Measuring Them" gives the following recommendations for "well-dried" products:

Ammonium Nitrate	54°C	(130°F)
Superphosphates-Urea	54°C	(130°F)
DAP, MAP, NPK	71°C	(160°F)
Prilled Urea	82°C	(180°F)
Bagged Products	54°C	(130°F)

The complete text of the recommendations is displayed in Figure 1.

Caking

With regards to MAP and NPK, the experience of most producers seem to verify TVA recommendations, and even with relatively hot products relatively low rates of complaints are received from terminals and customers even when product is handled and stored at fairly high (70-75°C) temperatures.

In regards to DAP, however, operating experiences indicate the following:

1. DAP's manufactured with low impurity acids have a much higher tendency to cake in storage than DAP manufactured with Florida acids. Lower moistures (about 1%), thorough cooling (less than 130°F) and organic coatings are usually necessary to assure a free flowing material.

2. For Florida acids, DAP or for formulations which contain

large proportions of iron, aluminum and magnesium sludges, a reasonable set of recommendations would be as follows: A product temperature of 150°F should be considered marginally acceptable, 130°F is thought as highly desirable and a temperature of 120°F or less could be described as ideal. At 120°F, product can be shipped anywhere during any season of the year without fear of complaints.

Moisture Migration

Moisture migration and the formation of "wet caps" is a problem which occurs when fairly warm product is stored for long periods of time (generally more than 30 days) at generally cool to cold temperatures. Figure two shows the moisture variation and product hardness from the surface of a 20 foot MAP pile which had been in storage for about 5 weeks at air temperatures 60 to 70°F. The samples where taken at the top of the pile. As can be seen in the fiqure, there was definitely moisture migration to the apex of the pile, even though the bulk product moisture was well within acceptable ranges. In Figure two the corresponding temperature profile is shown for two locations. Again the temperature was well within the guidelines for preventing caking; moisture migration was not prevented, however.

It appears, therefore, that the prevention of loss of hardness, followed by product decrepitation may be a more stringent criteria in terms of product cooling, especially, if the product is to be stored for long periods of time or is to undergo a long voyage.

PERFORMANCE OF COOLERS

From the point of view of the user, performance is measured by final product temperature. This, in turn is the result of the interaction of a number of factors listed in Table 1:

TABLE 1

Factors Which Determine Final Product Temperature

- Initial Product Temperature
- Temperature of the Air Used for Cooling
- Specific Heat of Product Being Cooled
- Mass Ratio of Cooling Air to Product Flow
- Equipment Type Size and Design Features

The initial product temperature has a direct relation to the final product temperature. Figure 4 shows a typical relationship. In general, a variation in the temperature entering the cooler will be reflected in a similar but smaller variation in the final product temperature. A primary consideration in obtaining a cooler product is, therefore, whether the granular product temperature entering the cooler can be reduced by operating the dryer at a lower temperature.

Figure 5 shows the typical effect of the cooling air temperature on final product temperature. Again, there is a direct but not a one-to-one relationship between these two temperatures.

Currently accepted design values for the specific heat of commercial fertilizer are listed below:

TABLE 2

Specific Heat of Commercial Fertilizer, 55°C to 90°C Range

Product	Specific Heat, BTU/lb°F or Kcal/Kg°C
DAP	0.34
MAP	0.31
16-20-0	0.36
9-25-25	0.26
Ammonium Sulfate	0.39
KCl (MOP)	0.169

As with most solid materials, the specific heat of fertilizer increases with temperature. For example, for pure MAP the reported relationship is as follows:

$$Cp = 0.2773 + 7.30 \times 10^{-4} t \text{ BTU/lb°F or Kcal/Kg°C}$$

where t is the temperature in degrees centigrade

And for potassium chloride:

$$Cp_{molar} = 10.93 + 0.00376T \text{ Cal/deg gmol}$$

where T is the temperature in degrees Kelvin

Obviously, the heat duty of a cooler will vary with the product being cooled. <u>Other things being equal</u>, the product with the higher specific heat will have a higher final temperature.

The amount of air utilized for each unit of product has a profound effect on final product temperature. This ratio of air to product exerts its effect in two ways:

1. By changing the logarithmic temperature difference.
2. By changing the heat transfer coefficient for the cooler.

The effect on the log-mean-delta T of either increasing or decreasing the air flow is a rigorous, straight forward consequence of the heat balance and needs very little discussion.

The effect of air flow, on the heat transfer coefficient, however, has been and probably remains, the subject of some controversy. Most designers and cooler suppliers agree that the volumetric heat transfer coefficient for a cooler increases with air flow. Nevertheless, there is no general agreement on the extent of this effect. Recently collected data is presented later on this paper and the reader can reach his own conclusions.

The equipment type, size and design features are, of course very important in determining performance. In the fertilizer industry the most common type of cooler is the rotary cooler. This type is probably followed by tray or Buell coolers. Another type less frequently used is the fluidized bed cooler. All three types will be discussed below.

ROTARY COOLERS

General

As mentioned earlier, rotary coolers are most frequently utilized for phosphate based granular fertilizers. The frequency of their use is undoubtedly based on tradition, partly in the simplicity of their design and operating features and probably also on plant layout convenience and construction costs.

Typical Dimensions

Typical proportions for a rotary cooler are a length to diameter ratio of 3.2 to 6.0 and a slope of 0.03125 - 0.0625 ft per ft or meters per meter. Typical diameters in the newer granulation plants are between 10 and 14 feet (3 to 4.25 meters) and lengths between 40 and 60 feet (12.2 to 18 meters). The speed of rotation is generally between 3 and 5.5 RPM with, as usual, the larger diameter units rotating at the slower RPMs, to correspond roughly with peripheral or shell speeds of 125 to 175 ft/mm (38 to 53 Meters/min).

Arrangement of Flights

Inside the cylindrical shell the feed section is usually occupied by feed or spiral flights. The purpose of these spirally arranged flights is to move the product away from the end-seal and thus prevent product spillage. This is important when the cooler is heavily overloaded in terms of product throughput viz-a-viz the diameter, RPM and slope. Unfortunately, in many designs, these "take-away" flights occupy too much of the useful length (sometimes 15%) of the cooler even though this is not necessary to move the product into the "lifting" flights.

The middle section of a cooler will consist of lifting flights. This section occupies most of the cooler length and constitutes the useful or effective volume area of the the cooler. The purpose of the lifting flights is to spread the material across the air flow in a uniform shower or curtain. Visual observations of many coolers, confirmed by simple calculations, indicate however, poorly designed flights which empty either too early or too soon to provide a reasonably uniformly curtain across the cooler. This is an unfortunate and unnecessary situation. Lifting flights come in many sizes and shapes which can be individually tailored to the requirements of each cooler and product to achieve the best results. Furthermore, when compared to changes in the physical dimensions, RPM, slope and air flow, replacement of the lifting flights may be a rather economical, although generally small, improvement.

Discharge Arrangements and Hold-Up

The discharge end of the cooler can consist of a simple overflow dam (bottom discharge) into a hopper (Fiq 6a) or modified lifting flights or buckets which discharge into an overhead hopper (Fig 6b).

Coolers are normally designed to hold granular material in 10% of their volume with a "calculated" maximum of 15%. To calculate the volume held in the cooler a number of equations have been proposed, as shown in Table 3. None of these formulas make an allowance for the height of the discharge dam on bottom discharge units or the capacity of the flights and hopper on top discharge coolers.

Because coolers are generally shorter than dryers and much shorter than kilns, with generally lower length to diameter ratios and lower throughput per unit of cross sectional area, the discharge arrangements from the cooler are overwhelmingly important in determining how much product is held in the cooler and how much horsepower is drawn by the drive. In general, bottom discharge coolers and coolers with closed-end discharge buckets will have a fairly constant holdup (set by the height of the dam or buckets and this holdup) will be fairly independent of the granular material throughput. The situation will be similar to a granulator where the height of the dam basically determines the volume held. On the other hand, in coolers with ordinary flights discharging into a collecting hopper, the fillage of the flights and overall holdup will be a strong function of the product throughput. Coolers with this type of discharge may operate close to empty at low throughputs, and may actually "spill" over the dam at high product flows.

Since product cooling is seldom limited by the retention time in a cooler, calculating retention times in coolers may seem at times more of an academic exercise than a meaningful activity. However, for those who feel compelled to do so the following suggestions are offered:

1. For bottom discharge coolers, calculate the percent of total volume occupied by the granular material based on the height of the dam and the "roll over" angle of the product, plus an allowance for material held on the flights. Since most dams and flights heights are set about 11 to 13% of the diameter, not surprisingly the result of this calculation will fall in a similar range, 10 to 12%.

2. For top discharge flight - hopper arrangement, calculate the hold-up based on the fraction of the flight height which must be filled for the discharge into the hopper to equal the throughput. This is a slightly more complicated operation. However, because flight heights are usually set 1/10 to 1/8 of cooler diameter the results will be similar to a bottom discharge cooler when the unit is fully loaded.

Air Flow and Hold-Up

Some of the equations proposed for hold-up predict infinite retention times at air velocities in the 7 to 10 ft/sec range. For example, in the equation of Saeman and Mitchell the hold-up increases to infinity when the product of the air velocity times a constant exceeds the slope of the cooler.

In reality, a cooler can seldom be "choked" by the flow of counterflow air. Typically, as the air flow is increased, the <u>internal slope</u> of the material inside the cooler becomes steeper to support the requirement for a higher slope. This allows for higher air flows which may at first seem impossible for the usual cooler shell design slopes.

Theoretically the point could be reached, however, where material chokes or spills at the front end of the cooler. In practice, this seldom happens, since fan capacities are seldom high enough to support the pressure drop created by this phenomena.

In practice, a flow of 11 ft/sec is usually the maximum practical with the typical fans available in fertilizer plants. This velocity based on the total cross sectional area of the cooler can result in pressure drops of 9-10 inches (23 - 25.4 cm) of water, (or pressure drops which are more typical of tray coolers as discussed below than of rotary coolers).

The above figures for pressure drop/air velocity also depend on the type of discharge, a bottom discharge allows for flow across the full cross section of the cooler (minus the dam). A top discharge hopper, deflecting baffles and louvers obstruct air flows and can contribute another 1 to 1.5 inches of pressure drop at high air flows.

Thermal Performance of Rotary Coolers

As a heat transfer device, the thermal performance of coolers is expressed in terms of a "volumetric" heat transfer coefficient i.e. BTU/hr°Fft^3.

In practice, this volumetric heat transfer coefficient seems to vary for commercial coolers between 10 to 35 BTU/hr °Fft^3. In practice also, for any given cooler, published data (Figure 7) and data collected by this writer (Figure 8) seem to indicate that the volumetric heat transfer coefficient is also a function of the air flow rate. The data of Figure 8 are quite interesting. It involved five coolers with very different products and solids loadings, from 20 tons to 80 tons per hour.

TRAY COOLERS

General

Tray coolers usually consist of rectangular boxes internally fitted with trays. The trays are normally three in number, placed horizontally and perforated with openings. The vertical separation of these trays is usually 3 to 4 feet (0.9 to 1.2 meters). Openings in the trays are usually 1.5 to 3 inches (3.8 to 7.6 cm), oval shaped and formed by sliding two plates parallel to each other (Figure 9). The open area across each tray varies with location on the tray from 25% to 40%, with the overall area usually about 30%.

Granular material is fed at the top of the unit and flows throught the openings from tray to tray into a bottom hopper. The flow of air is counter-current through the openings. Typical maximum loadings for tray coolers are 0.75 Short tons per hour per square foot (7.3 MT/M^2-HR) and about 650 ACFM of cooling air per square foot based on the total cross section of the cooler (123 m/sec). Through the openings, where the fertilizer material flows counter-current to the air, the air flow can reach velocities as high as 30.95 ft/sec and very good heat transfer is obtained.

Tray coolers are sometimes called "fluidized". This is really a misnomer because at no time is the material sitting on top of each tray "fluidized". The tray cooler operates more on a "cascade" mode than a "fluidized" condition.

Thermal Performance

The thermal performance of tray coolers can vary between 350 and 500 BTU/hr°Fft^3. The thermal performance seems to correlate with the pressure drop through the unit more directly than with the quantity of solids or simply air flow. In some typical units 300 BTU/hr°Fft^3 correspond to 6"WG pressure drop and 500 BTU/hr°ft^3 corresponding to 9.5" of pressure drop.

Since the volumetric heat transfer coefficient is so much higher for tray coolers than for rotary coolers, for the same heat duty much more compact units can be utilized. Notice however that the more compact design comes at the price of higher air pressure drops and a larger product fall required to operate the unit.

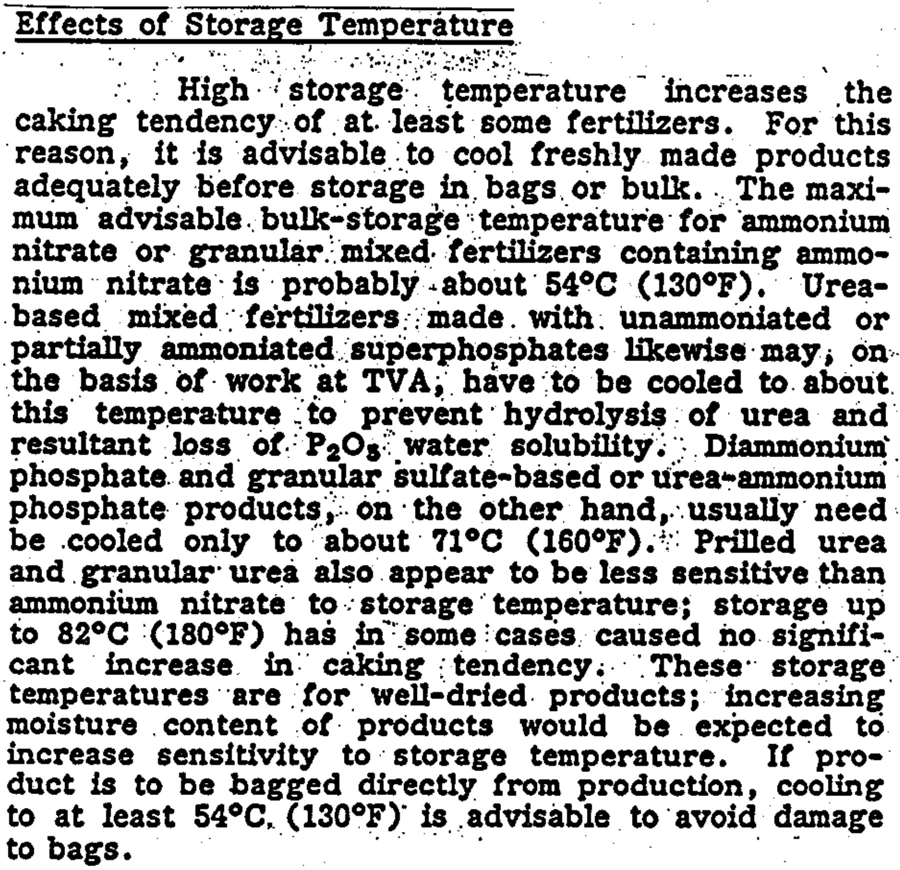
Some Common Problems

One typical but generally undesirable feature of most designs incorporating tray coolers is that they draw cooling air from inside the granulation building, instead of outside air. Since the air inside the building can be significantly warmer than outside air, the product would not cool as much as would be possible with outside air. (Obviously this problem could have been prevented in the original design, and in some cases may be corrected later)

Another problem is poor spreading of the incoming granules across the top tray. This can be frequently corrected with conical shape or fluted type distributors.

FLUIDIZED BED COOLERS

Fluidized bed coolers have been successfully utilized for powder DAP and MAP's, and for prilled urea. For granular materials of larger size (2 to 4 mm) a true fluidized regime cannot be obtained unless very high air velocities and the accompanying pressure drops can be tolerated. For this reason, although not impossible, truly fluidized bed coolers are not currently utilized for larger size, high density granules.



Effects of Storage Temperature

High storage temperature increases the caking tendency of at least some fertilizers. For this reason, it is advisable to cool freshly made products adequately before storage in bags or bulk. The maximum advisable bulk-storage temperature for ammonium nitrate or granular mixed fertilizers containing ammonium nitrate is probably about 54°C (130°F). Urea-based mixed fertilizers made with unammoniated or partially ammoniated superphosphates likewise may, on the basis of work at TVA, have to be cooled to about this temperature to prevent hydrolysis of urea and resultant loss of P_2O_5 water solubility. Diammonium phosphate and granular sulfate-based or urea-ammonium phosphate products, on the other hand, usually need be cooled only to about 71°C (160°F). Prilled urea and granular urea also appear to be less sensitive than ammonium nitrate to storage temperature; storage up to 82°C (180°F) has in some cases caused no significant increase in caking tendency. These storage temperatures are for well-dried products; increasing moisture content of products would be expected to increase sensitivity to storage temperature. If product is to be bagged directly from production, cooling to at least 54°C (130°F) is advisable to avoid damage to bags.

Figure 1. Recommendations on Product Cooling. From p. 21, TVA Bulletin Y-147, "Physical Properties of Fertilizers & Methods For Measuring Them."

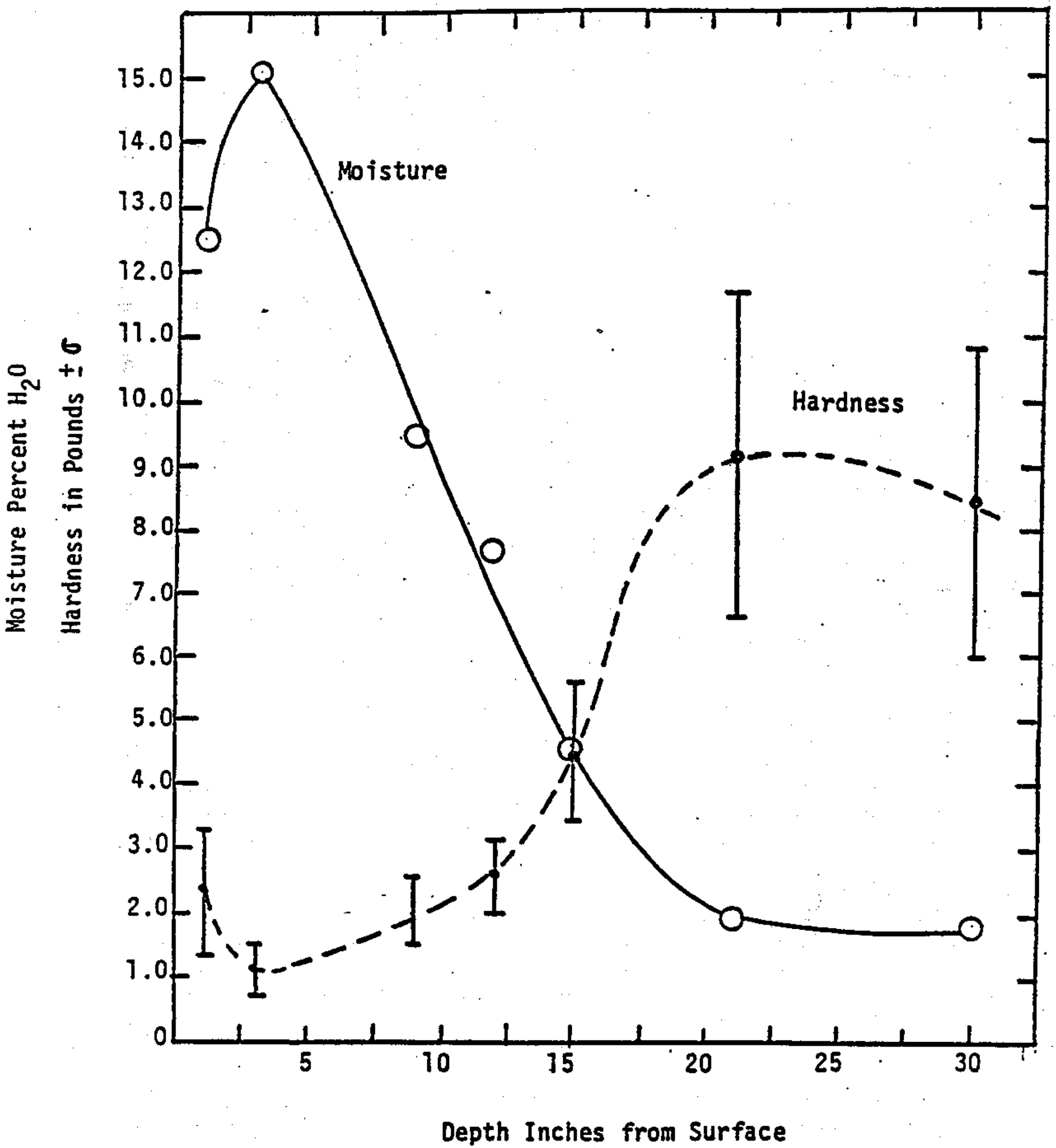


Figure 2. Moisture and Hardness Profile for a "Wet Cap" of a MAP Fertilizer Pile. (Pile was approximately 20 feet high and had been in storage for about five weeks.)

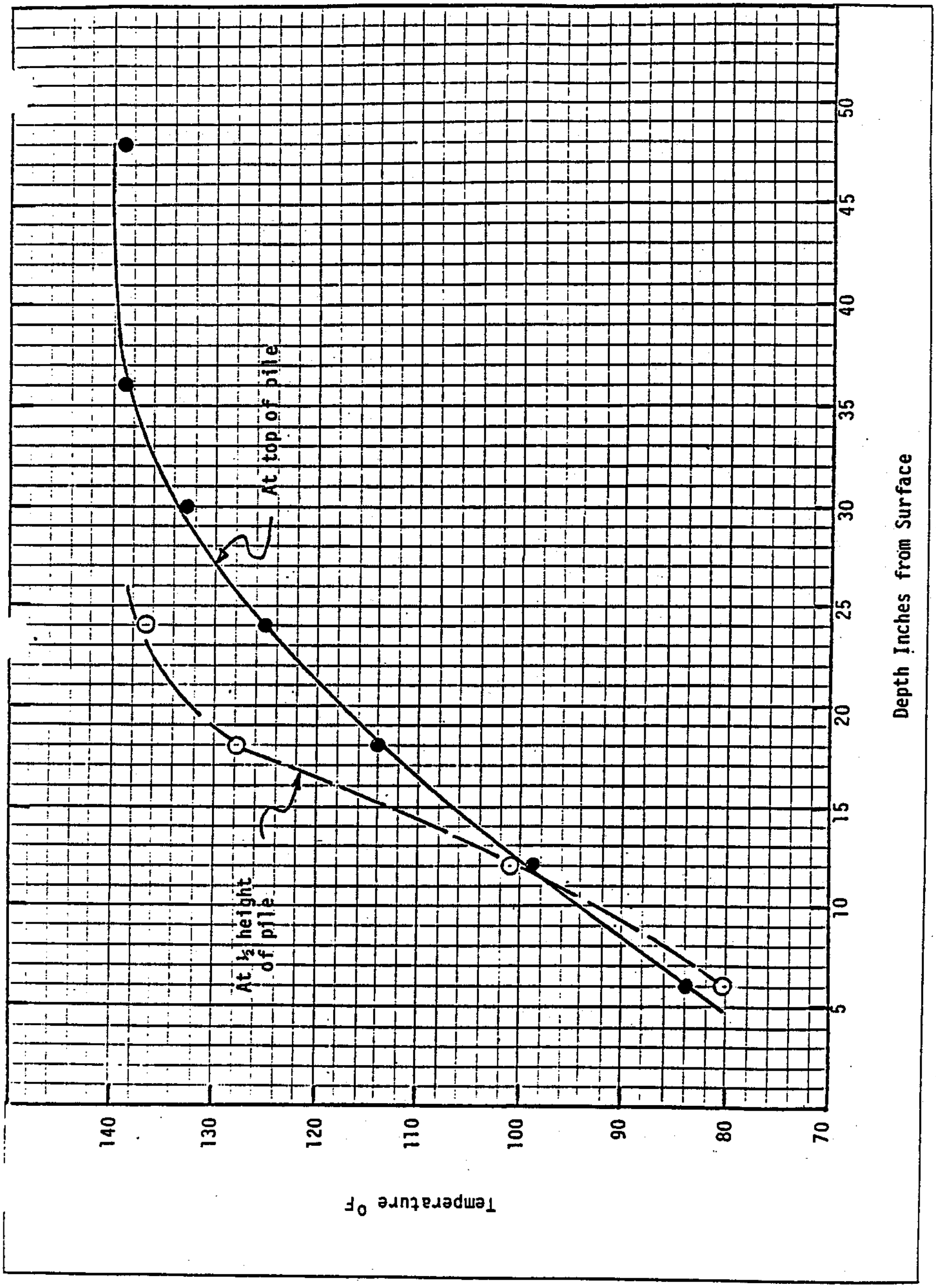


Figure 3. Temperature Profile for the MAP Pile of Figure 2.

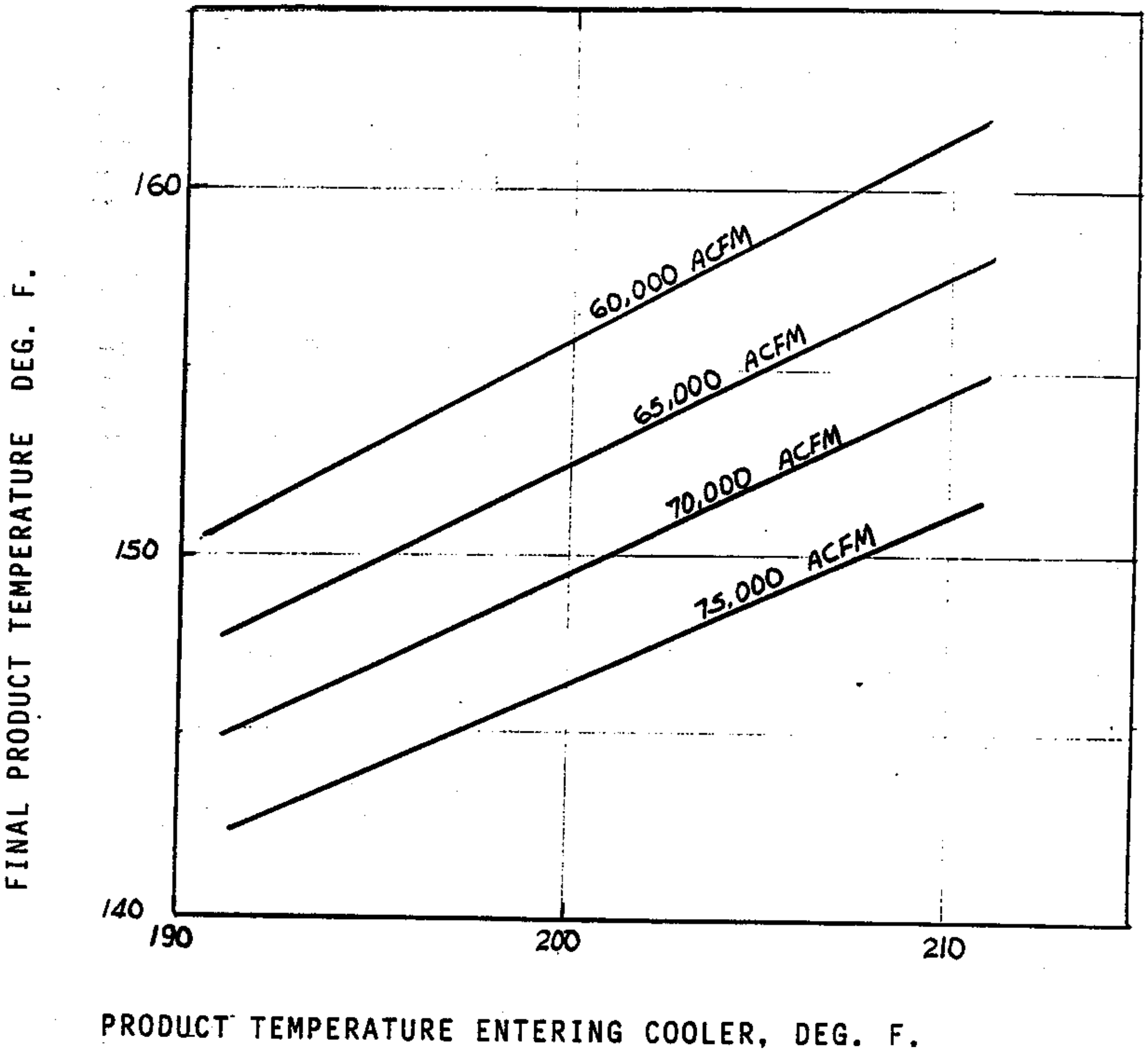
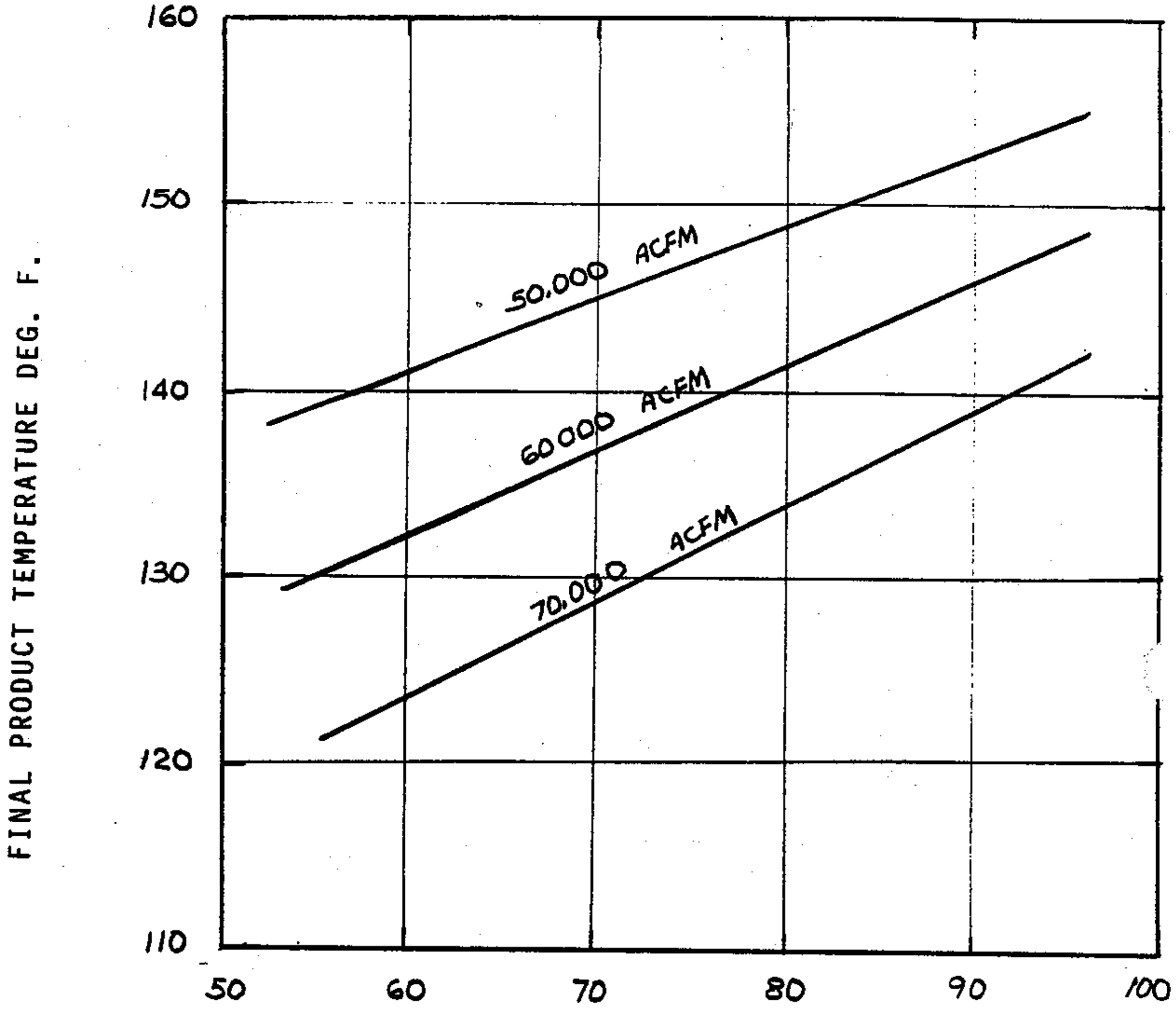


Figure 4. Effect of Product Temperature Entering the Cooler on Final Product Temperature.

Plot is for a 12.5 ft diameter, 40 feet long cooler, but shape of curves is typical of most coolers.



TEMPERATURE OF AIR ENTERING COOLER DEG.F.

Figure 5. Effect of Air Temperature Entering the Cooler on Final Product Temperature.

Plot is for a 12.5 ft diameter, 40 feet long cooler, but shape of curves is typical of most coolers.

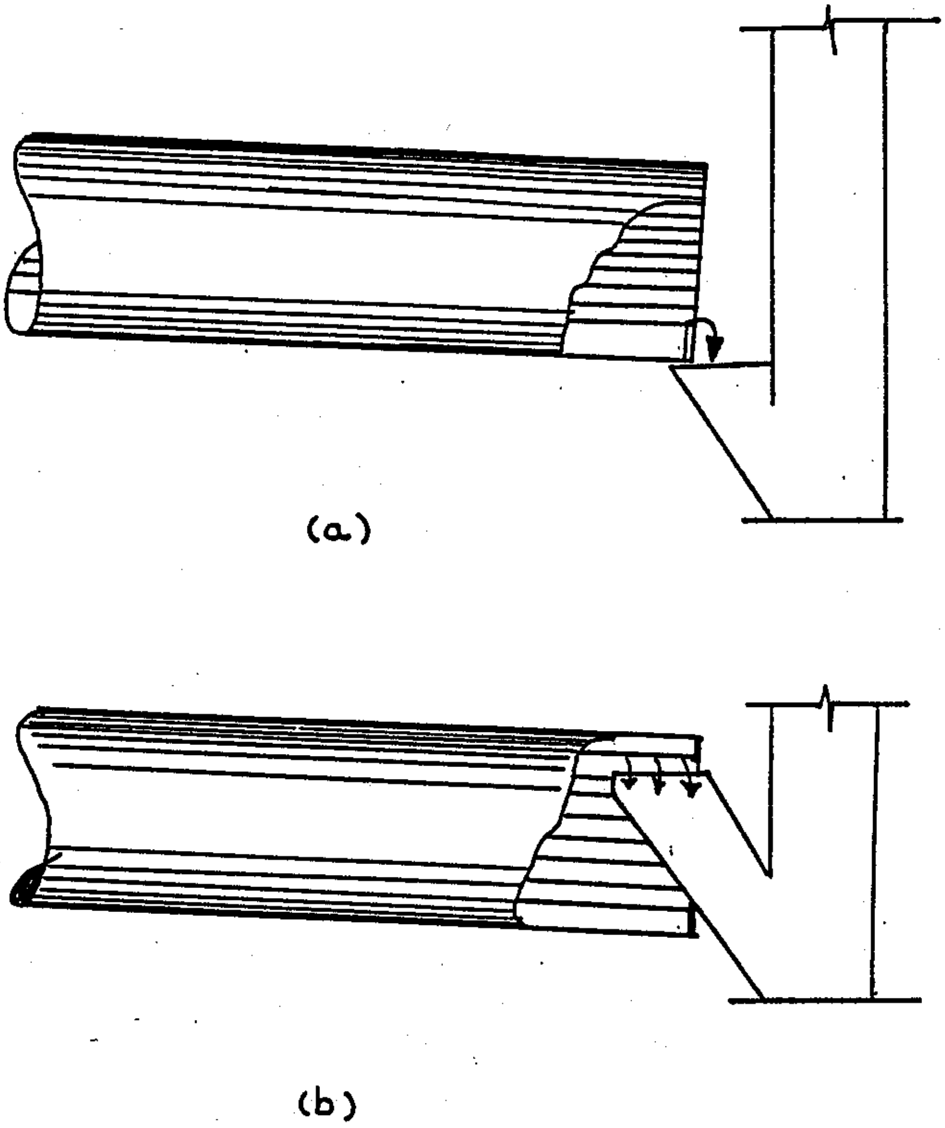


Figure 6. Cooler Discharge Arrangements. (a) Bottom Discharge, (b) Top Discharge.

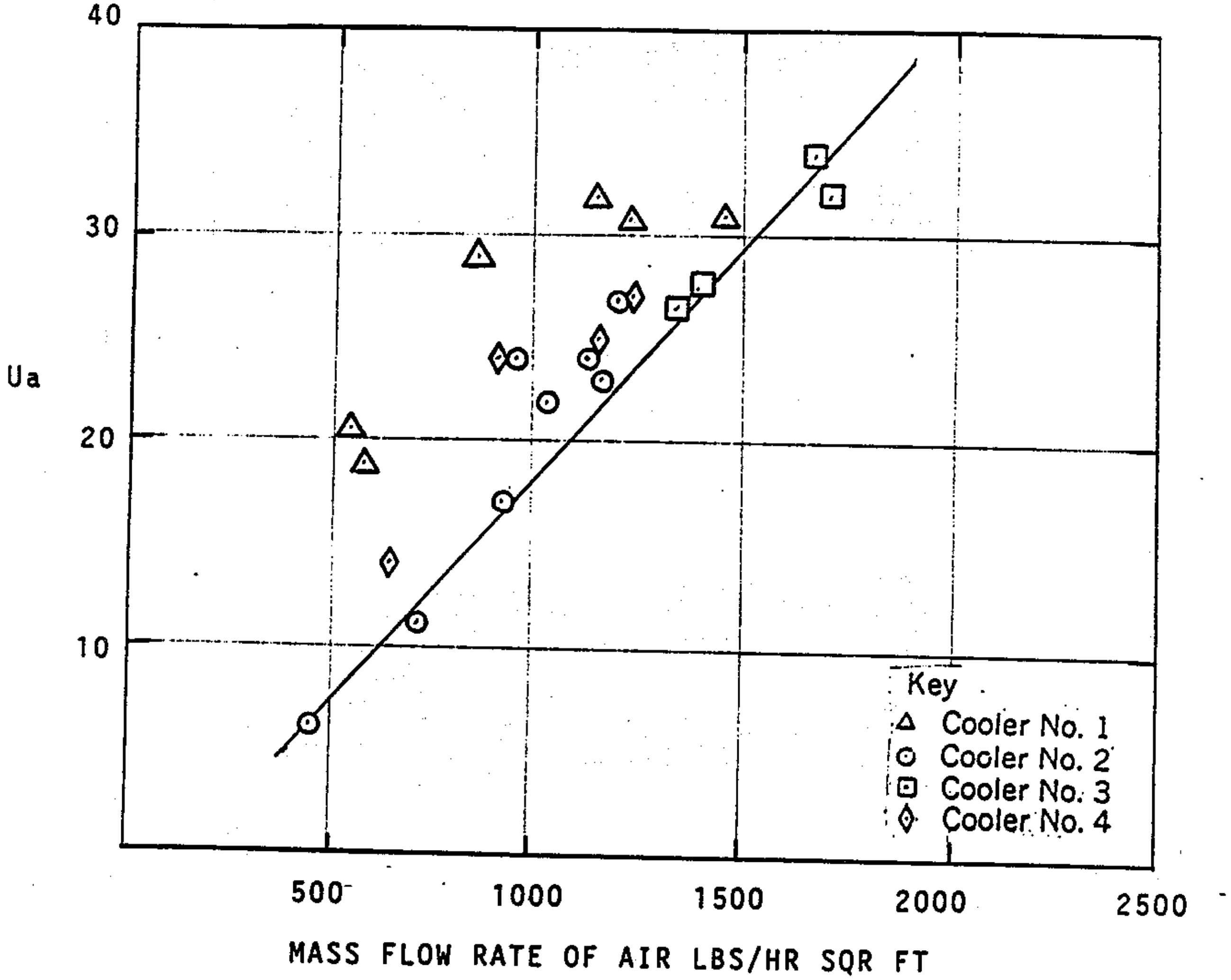


Figure 7. Volumetric Heat Transfer Coefficient Ua, CHU/Hr-Deg.C -Cubic Foot, Versus Air Mass Flow Rate.

(Data originally from Porter and Mason as recalculated by Saeman)

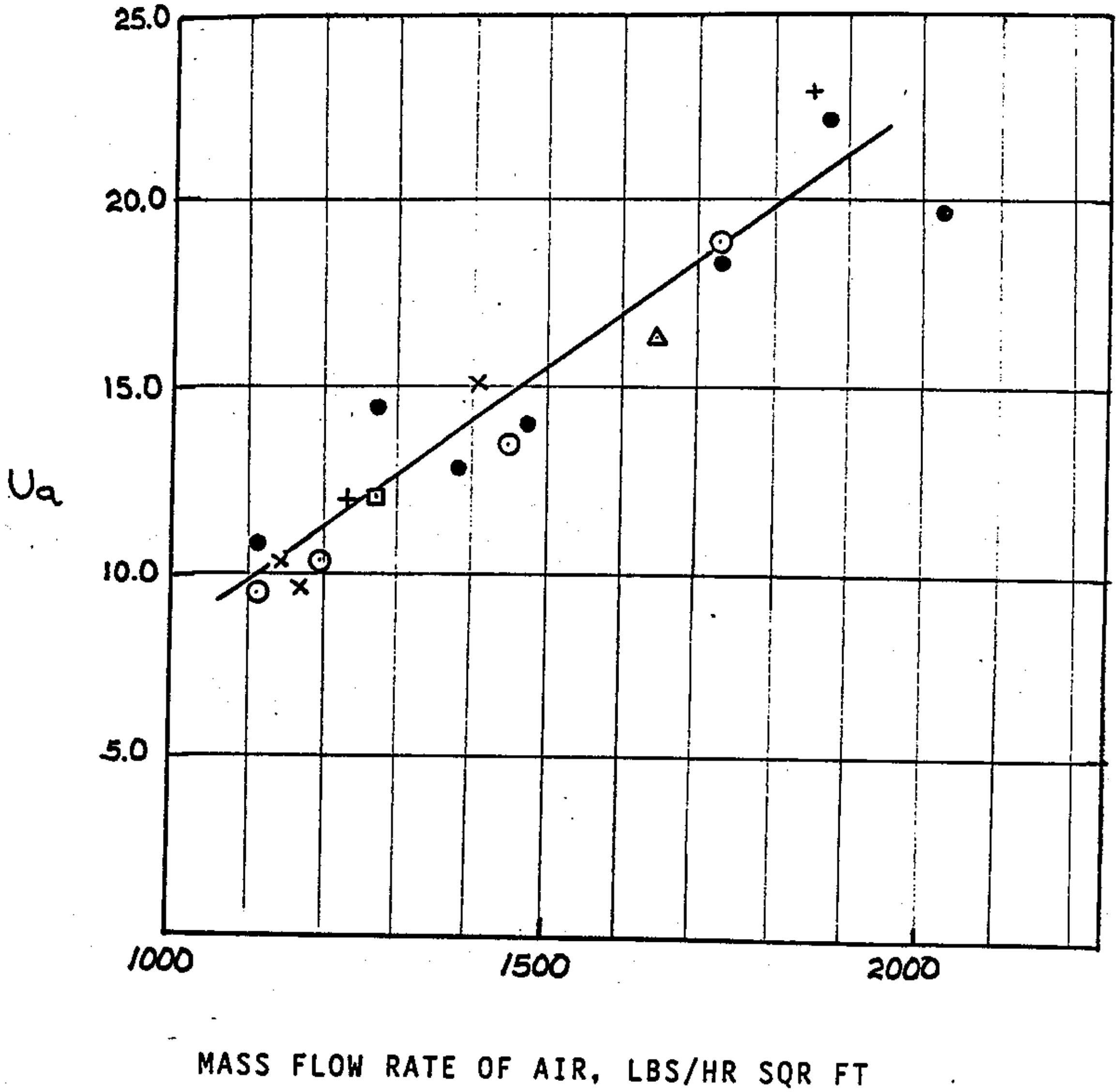


Figure 8. Volumetric Heat Transfer Coefficient Ua, BTU/Hr-Deg F-Cubic Ft, Versus Air Mass Flow Rate.

Dimensions, Ft:

Cooler:	Diameter	Length		
A	10	45	9-25-25 ●	
B	10	45	DAP +	
C	10	50	DAP ×	MAP ○
D	12.5	40	DAP △	
E	14	45	DAP □	

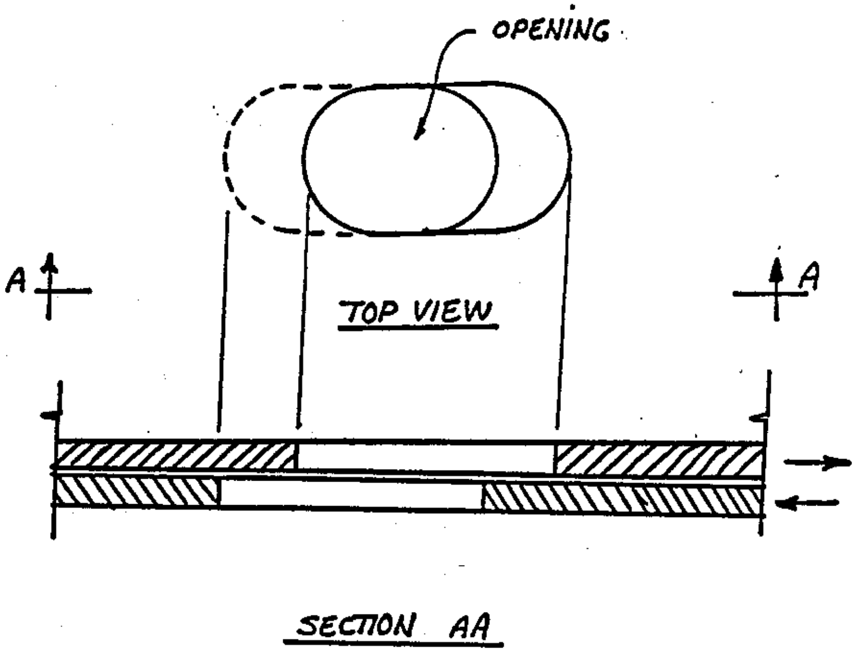


Figure 9. Detail of Openings on Tray Coolers. The opening size can normally be adjusted by sliding the two parallel plates which form each tray.