Sugar Cooler—Tubular, Water Cooled

A. L. Cooper[1]

Development of apparatus for cooling granulated sugar to improve its storage, transport, and packaging qualities has received much attention from the industry in recent years. It has long been recognized that relatively cool sugar is responsible for better weights and uniformity of packages. Hot sugar, when stored in large bulk bins, seems to have a thermal driving force which causes the residual moisture to migrate to cooler zones, resulting in hard cores particularly in the lower one-third of the bins, and excessive moisture content adjacent to the walls and floor. Some of the earlier bulk storage bins, such as those at the Sidney, Montana plant, have hollow walls through which warm air is circulated to offset this condition. This practice results in a slight increase in sugar color over a period of time if an excessive amount of heat is used.

The bulk bins at Carlton, California were built with solid walls with the thought that climatic conditions in the Imperial Valley would not require any special preventive measures, other than the dehumidification of the scavenging air introduced above the sugar. Such is not the case and observations indicate that difficulties with bulk sugar stored at Carlton would be reduced to a satisfactory minimum if the sugar could be sent to the bins at a temperature approximately equal to the mean ambient. This reasoning is well substantiated by experience with sacked sugar in the warehouse where it quickly cools to the temperature of the surrounding air. No means are used for controlling relative humidity or temperature in the warehouse.

It was this need that prompted the development of a continuous sugar cooler. After investigating several types, it was decided to start experimental work on a tubular, water cooled design.

Experimental Units

The first experimental tube-unit consisted of a 3-inch O.D., 16-gauge, brass tube 20-feet long mounted vertically in a 4-inch pipe water jacket. Water at 15°C. was pumped through the jacket at 10.5 g.p.m. with a ½-inch Jabsco pump. The lower end of the brass tube was closed and hot sugar introduced at the top until full, after which it was allowed to flow continuously as a column through the tube at a rate of approximately 10 lbs./min. This flow rate was governed by an .8-inch diameter orifice at the bottom. Results were unsatisfactory as the laminar flow resulted in a hot core. To prove this point, a dumy 1¼-inch O.D. brass tube was installed concentrically within the 3-inch tube and, although the sugar retention time was decreased, there was a greater temperature drop for the same flow rate. Smaller and lager orifices were tried and corresponding flow rates obtained, but it was found that the original size, i.e., .8-inch diameter gave the best overall results. The average sugar temperature drop was 8.7°C.

The final arrangement was to mount a 1½-inch O.D. brass tube concentrically within the 3-inch tube and circulate water through it, as well as around the 3-inch tube. This resulted in an annular sugar space between the two water cooled surfaces, whose inside diameter was 1½-inch and outside the diameter 2⅞-inch, or a ring thickness of 11/16 inch.

---

[1] General Engineer, Holly Sugar Corporation, Colorado Springs, Colorado.

The following are data obtained in nine tests:

Sugar temperature in	55.2° C.
Sugar temperature out	35.5° C.
Water temperature in	14.6° C.
Water temperature out	15.3° C.
Cooling water	10.5 g.p.m.
Sugar flow	9.72 lbs./min.
Sugar retention time in tube	3.7 min.
Cooling surface	22.6 sq. ft.
Heat transfer rate	6260 Btu/hr.
Coefficient of heat transfer	5.23 Btu/sq. ft./° F./hr.

Design and Operation of Full-Scale Cooler

The complete assembly of a full-scale unit consists essentially of the cooler and a bucket elevator, each having a maximum capacity of 50,000 lbs. granulated sugar per hour. The cooler has an over-all diameter of approximately 4.5 feet. The cooler and the elevator require a relatively small amount of floor space, and 45-50 feet vertical distance. This arrangement lends itself very well to adaptation in our existing plants (extending from the ground floor through the pan floor) and permits outage of the cooler-elevator unit without shut-down of other machinery.

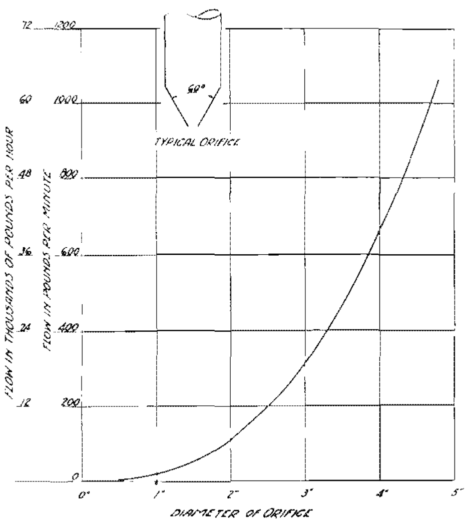

Figure 1.—Flow of sugar through orifice.

The graph in Figure 1 shows the relationship between orifice diameter and rate of discharge of dry granulated sugar. Actual flow rates of several sizes of orifices were obtained, from which was derived the formula:

$$F = KD^{2.6}$$

where K = 18.13 — a constant for fine granulated sugar.
D = Diameter of orifice in inches.
F = Flow — pounds of sugar/minute.

This formula applies only to an orifice having a 60° conical approach lcoated at the bottom of a tube, and has been found to be less than 3 percent in error for fine granulated sugar. It is an essential part of the cooler since a constant rate of through-put for each tube-unit is desirable. All tube-units that are in service are full of sugar and discharge at an average rate of 9.7 lbs./min./tube, except those on the fringe of the conical pile of sugar in the inlet chamber. Through-put of the cooler is accomplished automatically because the angle of repose of the sugar in the inlet chamber covers only a sufficient number of tubes to accommodate the quantity entering. In other words, if the cooler is operating at less than maximum capacity, some of the outer tubes remain empty. This results in a fairly uniform sugar discharge temperature regardless of through-put, other things being equal.

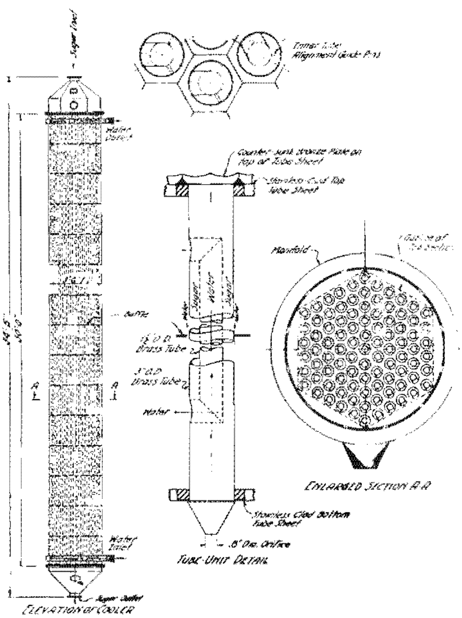

Figure 2.—Detail of sugar cooler.

As mentioned before, the reason for the "Tube within a tube" arrangement is that sugar is a very poor conductor of heat and has to pass between cooling surfaces in a relatively thin layer. (See Figure 2). Obviously, tube-units consisting of a single tube only, and of much smaller diameter, could be utilized and accomplish the same results but the discharge orifice would become so small that there would be plugging by very small lumps. The counter-sunk bronze plate resting on the top tube sheet makes the cooler self-cleaning.

Excessive clearance is provided where the tubes pass through the baffles and there are no "passes" as such. The function of these baffles is to cause a thorough mixture of the coolant as it passes upward and provide sufficient coolant pressure drop to induce flow through the 1½ inch tubes.

Salient Features of the Cooler are:

Maximum rated capacity 50,000 lb./hour.
Cooling surface—86 tube-units 2924 sq. ft.
Sugar contained in tubes at maximum capacity 4235 pounds.
Sugar retention time 5.0 minutes.
Coefficient of heat transfer 5.2 Btu/sq. ft./°F./hour.

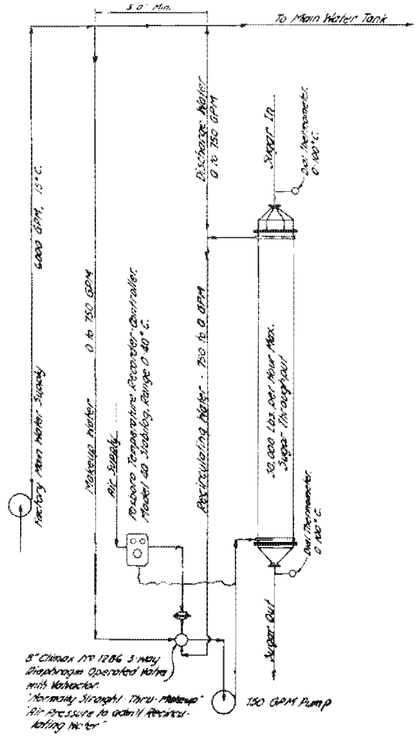

Figure 3.—Torrington sugar cooler.

Two coolers were built and installed, one at Torrington in 1951 and the second at Carlton in 1952. Main water supply temperature at Torrington, about 15°C., was colder than necessary for use as a coolant and, to prevent the tubes from sweating, it was necessary to install a temperature controller, connected as shown in Figure 3. When the 3-way valve is arranged to allow recirculation of the cooling water at any desired temperature and the controller is adjusted to 30°C., the resultant 15°C. over-all sugar temperature drop (from 55°C. to 40°C.) through the cooler, elevators, and packaging equipment is found to be sufficient. The cooling water is returned to the main supply header and no water is lost. There are no bulk bins at that plant.

The Carlton cooler requires refrigeration because the main water supply temperature ranges from 20 to 30°C. A 60 ton, closed circuit refrigeration system provides cooling water at 17°C. constant temperature. Because of the high humidity in the Imperial Valley, a size CHK Lectrodryer activated alumina dehumidifier, capable of supplying 250 c.f.m. air having a —14° C. Dew Point under normal atmospheric conditions, is used for purging the cooler. This air is introduced at the top of the cooler and carried down through three tubes, thence upward through the vacant tubes and out the sugar inlet pipe counterflow to the sugar stream to carry off the moisture released by the hot sugar. This is necessary to prevent the tubes from sweating, and functions quite well, except when atmospheric relative humidities of 50 to 65 percent, or higher, are encountered at dry bulb temperatures of 160° F and above. Under such conditions, the dehumidifier is overloaded and incapable of supplying sufficiently dry air, and it becomes difficult to maintain the cooler in operation. Air to the Lectrodryer passes through efficient filters and the Precipitron that provides the sugar dryer with cleaned outside air. For best bulk storage results the cooler should be capable of reducing the temperature of the sugar to 29 or 30° C. which would correspond closely to the 24-hour mean ambient temperature in the Imperial Valley. The system has ample capacity to reach such a temperature, but tube sweating occurs when attempting to operate at much below 35° C. Figure 4 is a typical 24-hour recording of temperatures of sugar to and from the cooler, and of the coolant.

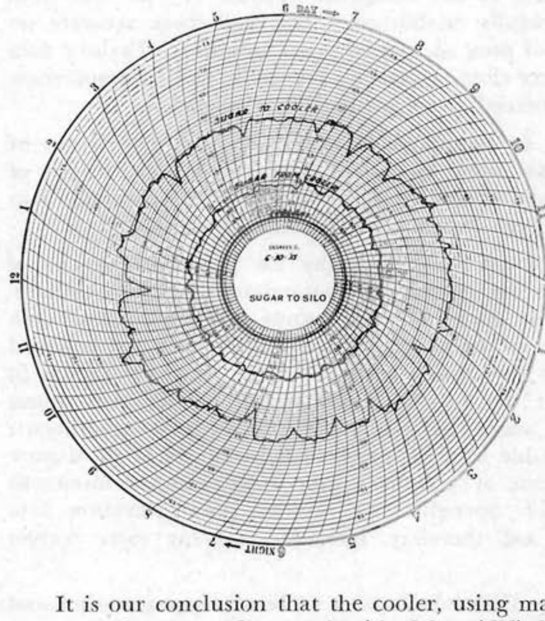

Figure 4.

It is our conclusion that the cooler, using main supply water controlled as at Torrington and purged with dehumidified air, would function satisfactorily under almost all atmospheric conditions except those that are encountered in the Imperial Valley the latter part of July and August.