

blast cooling. This method of cooling aggregates has been coming into greater use as time goes by, due to several assumed advantages over the other precooling systems. One of the advantages is that it does not require any particular changes to the materials handling set-up or additional tanks for inundation. The actual aggregate cooling is accomplished by blowing cold air through the aggregate in the batching bins. Also by introducing heating means, the air cycle used in cooling can be used in heating aggregates during the cold weather. Other apparent advantages are the fact that cooling effect is not limited by the quantity of mix-water specified. Cooling is applied at the final stage of handling aggregates and does not increase the moisture content of aggregates. However, the inundation method provides a positive means of keeping moisture content always relatively constant.

Cement and Sand Cooling

As specifications continued to require lower and lower pour temperatures, it became more apparent that direct methods for cooling sand and cement (which cannot be cooled by either the air blast or inundation and spray methods) would be of great help in obtaining the overall system heat removal required. On several recent installations, attempts have been made to accomplish this cooling by the use of hollow flight screw conveyors in which chilled water is used to cool the hollow flights. As yet, not enough experience has been obtained in this method of cooling to determine its effectiveness and economy. In any event, it does not seem likely that too much heat removal could be accomplished by this method, since cooling of either of these components below the wet-bulb temperature could result in condensation and serious handling problems. Condensation bringing excess moisture into the sand would undoubtedly cause it to clog in the screw conveyor; but condensation taking place in the dry cement before it was introduced into the mixer could be a very serious and dangerous problem, resulting possibly in the actual cementing up of the conveyor.

Vacuum Cooling

A fourth development in the technique of precooling aggregates is a proprietary system which uses a vacuum system to evaporate the surface moisture on the aggregate and thereby reduce the temperature of the aggregate.

DESIGN CRITERIA FOR REFRIGERATION SYSTEMS FOR CONCRETE PLACEMENT

As indicated above, there are a number of different systems from which a selection could be made in deciding upon the type of cooling which could be used on any particular installation. As a matter of fact, where the total yardage of concrete is relatively small and where mechanical installations cannot economically be set up in connection with the mixing plant, ice manufactured by existing commercial ice plants has been used satisfactorily on a number of occasions. For larger installations, plant selection is dependent on a number of factors, including the following:

- Normal pouring rate—cu yd per hr.
- Maximum pouring rate—cu yd per day.
- Total allowable mixing water in lb per cu yd.
- The required concrete placement temperature.
- Concrete temperature when coming from the mixer.

The difference between this and (d) is the estimated rate of gain of heat by radiation during transporting from mixer to final placement.

- Average ambient temperature during period of maxi-

mum placement. Generally speaking, the period of maximum rate of placement will be during the summer months of June, July, August and possibly September, because in most temperate zones this is when the best progress can be made on construction work. The average temperature of the aggregates will assume the mean ambient temperature of the air (this includes night and day), during the period of maximum placement and for an estimated period dependent on the amount of aggregate storage specified or available. It is customary on the larger dams for the agency writing the specifications to specify the minimum amount of storage capacity to be provided. Basically, the minimum requirement is stipulated to insure continuity of concrete placement should there be any interruption in the supply of the aggregates from whatever source it is being furnished.

However, if the minimum live storage specified is, for instance, 100,000 tons of aggregates; and the pouring rate is 2000 cu yd per day, this would mean the consumption of approximately 3800 tons of aggregates per day. If the job is working a 6 day week, this would provide 26 days of actual storage in place, or approximately one month's live storage. Under these conditions, we can assume that the temperature of the rock when delivered into the reclaiming tunnel will be equal to the average ambient temperature for the month preceding that particular day on which the aggregate is transferred from the storage piles to the reclaiming tunnel.

GENERAL CONSIDERATIONS FOR SELECTING A SYSTEM

In the light of recent developments in various types of installations, it is obvious that considerable analysis and study is necessary to determine the most satisfactory method for each particular condition and specification. Initial cost, satisfactory operation, and degree and flexibility of control must be considered in deciding whether to use the inundation system, plus the use of ice in the mix (such as was used on the Buggs Island Dam), or the use of the air blast cooling plus the use of chilled mix water, and the addition of ice when necessary in the mix.

Where the aggregate cooling range from initial to final temperature of the mix is relatively small (15 to 20 F deg at the most) or where the required pour temperature is relatively high (65 F or more), chilled water plus ice in the mix, or chilled water plus air blast on the larger aggregates, may be able to take care of the entire cooling load. When the overall temperature reduction is greater than this, or lower pour temperatures are specified, such as 50 F or less, it is almost certain that a combination of all three types of cooling will be required because only a limited amount of heat removal can be obtained by one of these methods alone. Cooling by ice and chilled water is limited by the amount of mix water specified. Cooling by air blast alone is limited by the entering air temperature, which must be maintained high enough to prevent coil frosting. Cooling by inundation, although it involves the necessity of relatively large inundation tanks does offer the most positive and sure method of cooling, plus a positive degree of control of surface water on the coarse aggregates. By the addition of ice into the mix to take the remainder of the heat balance, there is a very satisfactory degree of control of the aggregates insofar as blending in the mix is concerned and of the exact amount of water introduced by the inundation and the ice.

DESIGN CONDITIONS

In order to illustrate the principles involved in the selection of a refrigeration plant and the mathematics involved in working out its application, the following is based on an

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arbitrary set of conditions which were set up as a typical medium sized installation. The assumed conditions set forth below involve a system with a high enough cooling range and a low enough pour temperature to require a combination of at least three basic systems, such as inundation, or air blast and chilled water, plus ice. The source of these design conditions is a combination of ambient conditions (Weather Bureau), rate of pour (Contractor) and ultimate result specified (Using Agency):

Assumed Typical Conditions

- Normal pour rate, based on three 4 cu yd mixers with 3 min to the batch giving a rate of 240 cu yd per hr.
- Maximum pour rates (in cu yd per day); 4800 cu yd per day (20 work hr per day).
- Total mix water allowing 8 gal per sack, three sacks to the cu yd; 24 gal or 200 lb of water per cu yd.
- Concrete placement temperature, 55 F.
- Concrete temperature from mixer, 50 F. An arbitrary allowance of 5 F deg was made for rise in temperature after the concrete leaves the mixer until its time of final placement. This temperature difference will vary somewhat dependent upon the time of emptying of the mixer and placement of the concrete in the forms. The actual amount of radiation can be accurately computed but a rise of 5 F deg is an adequately safe allowance under normal conditions. Under ideal conditions it will probably be somewhat less than 3 F deg rise.
- Average ambient temperature and aggregate temperature during period of maximum rate of placement, 80 F.
- Additional cooling load, if any (such as cooling pipes in monolith, etc.).

For purposes of illustration, it is assumed here that the engineers may want 500 gpm cooled from 65 F (assumed river temperature) to 40 F and pumped through the thin wall tubing in the monoliths, giving:

$$500 \times 8.33 (65 - 40) = 520 \text{ tons}$$

The first step in computing the loads for which to design the refrigeration plant is to draw up a table listing the various ingredients in the mix and calculating the total heat to be removed.

The next step in planning the refrigeration plant is determination of the size and type of bins in which the aggregate is to be cooled.

Inundation Tanks

With the inundation system for precooling aggregates, generally the three largest sizes of aggregates are placed in large cylindrical tanks. It has been felt practicable to have two complete sets for each of the three sizes, making six tanks in all. The proposed cooling tanks, loaders, unloaders, chutes, screens and conveyor systems from the tanks into the concrete plant should be enclosed and cooled to 40 or 45 F by air-conditioning units with blowers placed at appropriate points in the housing around the tanks and conveyors. The Bull Shoals job, being the first to use the inundation method for precooling aggregates, posed a new problem which (although it had been theoretically solved before) had never actually been solved in practical experience. V. L. Peugh, together with Ivan Tyler, at Morris Dam wrote a paper entitled *Mathematical Theory of Cooling Concrete Aggregates*. The original studies were made in 1934, and mathematically determined by spherical calculus the problem length of time necessary to cool various sizes of rock to the core of the rock from one temperature to another. The calculations were borne out to a remarkable degree of accuracy in pilot tests conducted for the Bull Shoals Dam. The calculations by Peugh indicated that the time required to cool the various sizes of

aggregate from 90 F, using 35 F water, to the temperatures indicated was as tabulated below.

TIME (MINUTES)	AGGREGATE SIZE, IN.				
	6	3	1½	¾	¾
1	83 F	69 F	49 F	39 F	38 F
2	77	59	41	38	
5	66	46	38		
10	56	40			
15	50	38			
20	46				
25	44				
30	42				
40	40				
50	39				

This study indicates that an immersion period of 25 min will bring even the cobbles down to an average temperature of 45 F. Theoretically, the smaller sizes can be brought to a much lower temperature in less time. Practical considerations, such as the rate at which cooling water can be pumped, make it unlikely that a cooling period less than 30 min should be considered. Any excess cooling will provide a needed factor of safety.

Pilot tests conducted by Royal McShea for the Bull Shoals Contractors brought out the graphical corroboration of Mr. Peugh's computations (Fig. 1).

However, the limiting factor on the overall cycle, as there had to be a very definite proportion between the various sizes at all times, was the cooling time for the largest size aggregate, which implied a cooling period of nearly 45 min, plus about 15 min for loading and unloading.

Tabulated actual pilot test results compared with V. L. Peugh's theoretical computations for cooling times of cobbles indicate the following (using 35 F cooling water):

TIME (MINUTES)	MEASURED TEMP, F	THEORETICAL TEMP, F	
		$\alpha^2 = 0.07$	$\alpha^2 = 0.08$
0	103	102	102
5	101	101	101
10	91	96	94
20	64	76	73
30	51	56	51
40	44	45	41
50	40	39	36
60	37	36	34

Note that α^2 is the diffusivity constant of the material under consideration, and is equal to conductivity/(specific heat) (density). To determine the value of this constant for a typical piece of aggregate, a cobble of 8.8 in. diameter, as nearly spherical as could be found, was selected and a small resistance thermometer placed in the center by drilling a small hole in from one side, filling the hole with mortar after the thermometer was in place. The cobble was brought to a uniform temperature by immersion in warm water, and was then placed in an ice bath in a home-made calorimeter. During its cooling period the temperature was read at five minute intervals.

BIN SELECTION AND CRITERIA FOR AIR BLAST COOLING

The size of the compartmented bins (octagonal bins) above the concrete mixers is usually determined by having an ample factor of safety from a materials handling standpoint so that if there were any supply breakdowns, the concrete mixing plant would not be shut down before a particular pour could