There are also self-contained coolant units using low temperature cooling mixtures such as 20 F glycol for circulation through the jacket.

Mixer manufacturers usually specify the condensing unit for use with their various mixers.

Dough Capacity, Lb	*Refrigerant 12 Condensing Unit Hp*
800	5
1000	7½–10
1300	10 –15
1600	15 –20
2000	20

Formulas, batch sizes, mixing times and almost every other part of the mixing process vary considerably from bakery to bakery and must be determined for each application. These variations usually fall within the following limits:

Final dough weights	1000–2000 lb
Ratio of sponge to final dough weight	50–75%
Ratio of flour to final dough weight	50–65%
Ratio of water to flour	50–65%
Sponge mixing time	6–10 min
Final dough mixing time	8–12 min
Number of mixes per hr	2–5

To calculate refrigeration requirements for the mixing process, the following factors are used:

1. Specific heat of flour = 0.42 Btu per (lb) (F deg).
2. Specific heat of dough = 0.60 Btu per (lb) (F deg).
3. Average specific heat of other ingredients = 0.40 Btu per (lb) (F deg).
4. Average heat of hydration = 6.5 Btu per lb.
5. Heat generated by mixer motor = 42.4 Btu per (min) (hp).

In larger operations the sponge and final dough are mixed in different mixers, and the refrigeration requirements have to be determined separately for each process.

In smaller operations a single mixer is used for both the sponge and final dough.

The cooling load for the final dough mix is greater than that for the sponge mix, and is used to establish the refrigeration requirements.

The cooling load for a final dough mix may be calculated from Equations 1 to 7.

$$Q_s = 0.60 w_s (t_s - t_d) \quad (1)$$

$$Q_f = 0.42 w_f (t_f - t_d) \quad (2)$$

$$Q_h = 6.5\ w_f \quad (3)$$

$$Q_i = 0.40 w_i (t_i - t_d) \quad (4)$$

$$Q_m = 42.4\ P \quad (5)$$

$$Q_w = w_w (t_w - t_d) \quad (6)$$

$$Q_n = Q_s + Q_f + Q_i + Q_m - Q_w \quad (7)$$

$$Q_T = N Q_n \quad (8)$$

where

Q_s = sensible heat gain from sponge, Btu per mix.
w_s = weight of sponge after fermentation, pounds per mix.
t_s = temperature of sponge after fermentation, Fahrenheit.
t_d = temperature of final dough, Fahrenheit.
Q_f = sensible heat gain from flour, Btu per mix.
w_f = weight of flour in final dough mix, pounds per mix.
t_f = temperature of flour, Fahrenheit.
Q_h = heat of hydration, Btu per mix.
Q_i = sensible heat gain from other ingredients, Btu per mix.
w_i = weight of ingredients other than flour and water, pounds per mix.
t_i = temperature of other ingredients, Fahrenheit.
Q_m = heat of friction from motor, Btu per mix.
P = motor horsepower.
θ = mixing time minutes.
Q_w = heat absorbed by ingredient water, Btu per mix.
w_w = weight of water used in final dough mix, pounds per mix.
t_w = temperature of water used in final mix, Fahrenheit.
Q_n = net heat gain per dough mix, Btu per mix.
Q_T = total theoretical cooling requirements, Btu per hour.
N = number of dough mixes per hour.

FERMENTATION

After completion of the sponge mix, the sponge is placed in large troughs which are rolled into an enclosed conditioned space for a period of fermentation. This period lasts for three and one half to five hours, depending on the dough formula.

The sponge comes out of the mixer at a temperature of 76–78 F and during the fermentation period, the sponge temperature will rise from 8–10 F deg as a result of the heat producing yeast action.

In order that the temperature may be substantially equalized throughout the dough mass, the room temperature is maintained at the approximate mean sponge temperature of 80 F. Even temperatures throughout the batch produce even fermentation action and a uniform product.

Water makes up a large part of the sponge and uncontrolled evaporation causes significant variations in the quality and weight of the bread. A certain amount of evaporation is required to remove excess alcohols and esters which produce too strong a flavor. The rate of evaporation from the surface of the sponge varies with the relative humidity of the ambient air and also with the rate of air flow over the surface. The rate of movement of moisture from the inside of the sponge to the surface does not react similarly to the same external conditions, and the net result is the drying out of the surface and formation of a crust. The formation of the crust produces an inactive area which causes undeveloped portions, which when later folded into the dough mass produces the hard, dark streaks that show up in the finished bread.

To control the rate of evaporation from the surface of the sponge, the air is maintained at a relative humidity of 75 percent and air movement over the surface is restricted. Control of air movement requires an efficient means of introducing conditioned air into the process room and the use of a multiplicity of return air openings spaced around the entire periphery of the room. With the use of perforated ceiling panels at an 8 ft level, an air quantity of as much as 18 changes of the room volume per hour has been successfully used. Less efficient methods of air introduction make it necessary to reduce the air volume substantially.

In older installations, cooling of the air in the process room is accomplished with pipe coils suspended from the ceiling together with open humidifiers within the room which provide the humidity control. The high relative humidity requirement causes a large amount of condensation on the pipe coils which is very hard to collect without some detrimental dripping on the products.

Modern installations use an air-conditioning unit with air temperature control and humidification handled within the unit, allowing conditioned air without free moisture to be circulated through the room to pick up the heat load.

In calculating the cooling load, the product is not considered, as the air temperature is being maintained at approximately the mean of the temperatures of the various doughs in the room. Transmission heat loss through walls, ceiling and floor is the principal load source. Infiltration is estimated as 1¼ times the room volume per hour. Usually the light requirements for a fermentation room are approximately 75 watts per 400 sq ft of floor area. The conditioning units are often placed within the conditioned space, and the full motor heat load must be considered.

The only possible source of latent heat would be about 0.5 percent weight loss in the sponge. Under full operating load this could account for a 1.5 F deg increase dew-point temperature. For conditions of 80 F db and 75 percent rh, the dew-point temperature would be 71.5 F, and the supply air would be introduced into the conditioned space at 72 F dry-bulb and 70 F dew point.

In large rooms sufficient air volume can be introduced to pick up the sensible heat load with an 8 F deg rise in air temperature. In smaller rooms it is often necessary to introduce a latent heat load by spraying water directly in the room by means of compressed air atomizing nozzles. The introduction of free moisture into the open air always presents a condensation problem and consequently is only employed when absolutely necessary. Water sprays have been most successfully used when a relatively large number of small nozzles have been spaced around the periphery of the room.

Due to the importance of the relative humidity control, the cooling is usually controlled by a wet-bulb thermostat. This can cause serious short cycling if the refrigeration condensing unit is oversized. To maintain a high removal ratio of sensible heat to latent heat, the condensing unit is usually specified for operation as close to 60 F evaporator temperature as is practicable with the temperature and quantity of condensing water available.

BREAD COOLING

The baked loaves come out of the oven with an internal temperature equalized at 212 F due to the evaporative cooling effect of the moisture being driven off during baking. The crust temperature is closer to 450 F.

To cool the loaves for handling and slicing, they are removed from the pans and allowed to cool to an internal temperature of 90–95 F. The cooling of a hygroscopic material takes place in two stages or phases, which are not distinct periods. When the bread first comes out of the oven, the vapor pressure of the moisture in the loaf is high in comparison to the vapor pressure of the moisture in the surrounding air. A rapid displacement of moisture takes place with a resultant evaporative cooling effect, which, combined with heat transmission at a relatively high temperature differential from bread to air, causes rapid cooling as indicated by the steepness of a time-temperature reduction curve (Fig. 1) in the early stage of cooling. As the vapor pressure begins to approach equilibrium, the heat transfer is mainly by transmission and the cooling curve flattens out rapidly.

Many bakeries carry out the cooling on racks standing on the open floor and cooling times vary from 1½–3 hr, depending on seasonal air conditions in the bakery. Where time control becomes an important factor, due mainly to present day delivery schedules, tunnel-type cooling enclosures are used with controlled temperature counterflow air cooling being employed.

The cooling tunnel may be a prefabricated insulated room similar in design to the proofing room with doors at both ends of a series of aisles. The racks of baked bread are moved through the room in one direction while the conditioned air flows in the opposite direction.

Other types of cooling arrangements employ travelling trays carrying the bread back and forth in descending tiers, or a descending spiral conveyor. These coolers are usually automatically loaded and unloaded for handling large steady productions. Conditioned air in these arrangements is usually introduced into the bottom of the enclosures and exhausted from the top to approach as close as possible the counterflow cooling action.

Bread can most satisfactorily be sliced and wrapped without

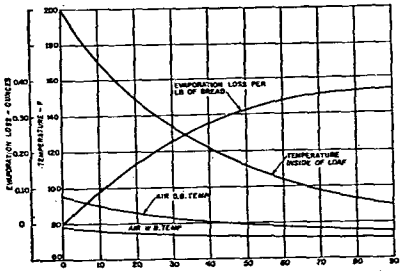

Fig. 1 .... Moisture Loss and Air Temperature Rise in Counterflow Bread Cooling Tunnel

successive condensation on the inside of the wrapper at 90–95 F. Excessive condensation can encourage mold spore development.

Approximately 90 min of cooling time is required to bring the internal loaf temperature to 90 F because of the more or less fixed time factor for cellular movement of heat and moisture from the center of the loaf to the surface (Fig. 1).

In counterflow cooling the optimum temperature for the air introduced into the cooling tunnel is about 75 F. A relative humidity for the entering air of 80–85 percent will control the moisture loss from the bread during the latter stage of cooling and will improve the keeping quality of the bread.

Attempting to shorten the cooling time by forced cooling with air temperatures below 75 F is not satisfactory because the rate of heat and moisture loss from the surface, and the movement of the heat and moisture from the interior to the surface as a replacement, becomes so unequal that shrivelling and cracking of the crust results.

Cooling time, however, is often shortened when mold inhibitors are used, by taking the bread to the slicers at 105–110 F.

The cooling load is calculated on the basis of a sensible heat transfer based on a specific heat of 0.74 Btu per (lb) (F deg) for bread, and a temperature reduction from 180 F to 90 F. The evaporation of moisture from the bread may be considered as being responsible for reducing the bread temperature to 180 F for calculating purposes. The heat transmission