heated wires are used, while in another there is a gridwork of small diameter tubes through which warm refrigerant flows.

A different type of cube machine uses vertical refrigerated plates spaced ¼ in. apart, with water flowing down the inside of each plate. Freezing tubes contact the outside of the plates in spots directly opposite each other, thereby causing ice *lenses* to form on the inner surface of each plate. If permitted to grow large enough, these ice lenses freeze together, two by two, to form large, solid, pulley-shaped pieces of ice. They slide off and tumble into a bin when loosened by hot refrigerant gas.

In one rod-type machine, a series of short, refrigerated rods, about ⅜ in. in diameter, are immersed in a tank of agitated water. Clear, bulb-like pieces of ice are formed and at a pre-determined time the rods, with ice attached, are raised from the water. Subsequent thawing loosens the ice bodies which then tumble down a chute into a storage bin. One design utilizes refrigerated rods of ⅜ in. diameter projecting from the bottom of a water-filled tank. Cylindrical, bulb-like pieces of clear ice form on the rods to the desired size. Here they are melted loose to float to the top of the tank. Slowly revolving paddles agitate the water for ice clarity, and also serve to nudge the floating ice over a spillway into a storage bin.

A *channel-type* machine flows water down slightly inclined, refrigerated channels to form long sticks of clear ice. At the proper time, automatic controls shut off the water flow, rotate the channels to an upside down position and thaw the sticks of ice loose. They fall onto electrically heated cutting wires which sever them into cubes of the proper length.

ICE CUBE MACHINES FOR WHITE ICE

Some of the early automatic ice cube makers were white-ice machines. Water was frozen in cells without agitation, and the resulting white cubes were melted loose and harvested. One unit went so far as to introduce carbon dioxide into the water to produce a more completely white cube for which the inventor claimed carbonating advantages.

One early type of cubemaker utilized cylindrical, upright cups from which the cubes were harvested by flooding the chamber with water. Upon receding, the water left the cups full for the next freezing cycle. Since no agitation of the water took place during freezing, the cubes were predominantly white.

FLAKED-ICE MACHINES FOR WHITE ICE

An automatic machine for producing white flakes of ice appeared on the market in the late 20's and is still being manufactured. The apparatus utilizes a horizontal, flexible, refrigerated cylinder which rotates partially submerged in water. The ice that is formed on the outer surface is peeled away as the cylinder flexes in passing over a small diameter roller. This continuous ribbon of ice breaks into small pieces as it falls.

A later type flaked-ice machine produces ribbons of white ice which break into small fragments when handled. The principle of operation is as follows: A metal belt turning over two pulleys slides upwards across a slightly curved, inclined, refrigerated surface. Flowing water strikes the belt near the upper end of its length and flows downward, forming ice as it flows. Subcooling of the band of ice beyond the water injection point occurs and, as the belt curves around the upper pulley, the ice pulls away from the surface and is discharged in fragments into the storage bin.

Another version of the horizontal-drum, flaked-ice machine freezes a thin film of ice on the *outside* of a slowly revolving, refrigerated cylinder. This ice layer is wedged free by means of a series of curved blades which simulate the cutter in a reel-type lawn mower.

Table 1 .... Typical Operating Performance of a ¾ HP Clear-Cube Machine Using Water for Condensing[a]

Water Temp F	Pounds of Ice per 24 Hours			
	50 F Air	70 F Air	90 F Air	100 F Air
50	471	467	465	460
70	419	419	410	398
90	368	370	356	336

[a] Power Consumption: Approximately 940 watts at ASHRAE Standard conditions.

A different type of machine utilizes a stationary, vertical, refrigerated cylinder on which ice is formed on the *outer surface*. Fixed blades or a rotating spiral cutter held in a slowly revolving out-rigger, free the ice from the surface.

A fourth type of machine makes ice on the inside of a stationary, vertical, refrigerated cylinder. Ice-removal teeth, bolted to a slowly revolving shaft, sweep to within a few thousandths of an inch of the cylinder wall to push the ice free.

A recent entry into this field is a machine which makes ice on the outside of a refrigerated cylinder submerged in water. A close-fitting, steel helix slowly revolves in a chamber around the cylinder forcing flakes of ice off the surface and out the top of the chamber.

FLAKE OR CHIP MACHINES FOR CLEAR ICE

One version of this design is exemplified by a machine in which ice is formed on the outside surface of a slowly revolving vertical cylinder. The ice is broken into semiclear, curved fragments by means of a revolving cutter having helical edges.

Clear flat chips are produced by a machine in which thin sheets of ice are made on inclined flat plates then thawed loose, after which the sheets are directed to a crusher for sizing to chip form. Clear-chip machines go through periodic hot gas defrosting for ice removal, rather than through a drying and sub-cooling period with mechanical removal as in the cylinder-type machines.

Still another type of icemaker produces clear curved chips by freezing water on the outside surface of vertical, refrigerated, cylindrical tubes, then melting the shells loose and breaking them into odd-sized pieces.

COMPRESSED ICE MACHINES FOR WHITE ICE

A development of the last decade is a flaker which makes ice inside of a vertical, brass cylinder which is kept partially filled with water. A close fitting auger, slowly turning inside the cylinder, scrapes ice from the walls, and compresses it upward against an inclined breaker, whence the pieces of ice fall into a storage bin.

Table 2 .... Typical Operating Performance of 1½ HP White-Flake Machine Using Water for Condensing[a]

Water Temp F	Pounds of Ice Per 24 Hours			
	50 F Air	70 F Air	90 F Air	100 F Air
50	1200	1165	1145	1125
70	1055	1020	1000	970
90	920	885	855	830

[a] Power Consumption: Approximately 1200 watts at ASHRAE Standard conditions.

Table 3 .... Typical Operating Performance of a ¾ HP Clear-Chip Machine Using Water for Condensing[a]

Water Temp F	Pounds of Ice Per 24 Hours			
	50 F Air	70 F Air	90 F Air	100 F Air
50	636	620	600	588
70	564	546	526	514
90	478	460	440	429

[a] Power Consumption: Approximately 900 watts at ASHRAE Standard conditions.

PERFORMANCE CHARACTERISTICS

Tables 1, 2, and 3 give performance data for various icemakers.

Clear-cube machines make a batch of ice in 15 minutes to 2 hr and may take up to 5 minutes for harvesting.

White-flake machines operate on continuous freezing cycle, building up ice to a thickness of $\frac{1}{16}$ to ¼ in. and removing it mechanically at a steady rate. Because of the rapid freezing that takes place, the ice is white from trapped air. The original hardness of the supply water is retained in the flakes.

Clear-chip or flake machines usually operate on an intermittent freezing and thawing cycle. Ice is frozen to a thickness of ¼ in. to ½ in. in the small, plate-type machines and up to ¾ in. in the big, tube-type machines. After approximately 10 min of freezing, the ice is harvested in a matter of seconds. Made in this manner, it is transparent and nearly free of any dissolved salts. Ice made on a brine-filled flexible cylinder operating on a continuous freezing cycle may be made clear by controlling the rate of freezing at various parts of the cylinder by means of brine flow distribution and by air agitation through the water being frozen. The clear-flake machine described earlier freezes continuously.

A summary of automatic iceflake makers is given in Table 4, and a summary of automatic icecube makers is given in Table 5.

DESIGN REQUIREMENTS

Clear-chip machines and clear-cube machines should have sufficient water flow to help keep the ice clear as it forms. The proper freezing rate is also important for ice clarity. For example, too rapid freezing will trap air and minerals in the ice and cause cloudiness. Extremely low freezing temperatures will cause the ice to crack and lose its clarity. These machines need suitable automatic controls to terminate the freezing and harvesting cycles, to shut off the unit when the storage bin is full, and to turn it on when the ice is removed. They should operate satisfactorily on fresh water, at water temperatures between 50 F and 100 F and in ambient air temperatures between 50 F and 110 F.

All of these ice-making machines should use non-corrosive and non-toxic materials in the water-handling circuit. Designs should also conform to health standards regarding cleanability. Safety standards and good design practice required by the Underwriters' Laboratories must be met.

Flake-ice machines require that the ice be readily removable from the freezing surface without excessive power consumption and be delivered to the storage bin dry, or at least relatively free of water. They should operate satisfactorily on fresh water, at water temperatures between 50 F and 110 F. Self-contained machines should be completely automatic so that no operator is needed to start and stop the machine.

SYSTEM DESIGN

All automatic icemakers utilize: (1) a refrigeration system, (2) a water system for icemaking, (3) a water system or an air system for condensing, and (4) an electrical system. Some designs have utilized air as a water agitation means for ice clarity and as an ejection means for ice removal.

Refrigeration System

The system is conventional in that it comprises a compressor, condenser, high side liquid receiver or low side accumulator, drier-strainer, expansion means, evaporator, hot gas solenoid-valve and refrigerant such as Refrigerants 12, 22, or 500.

Compressor: The compressor is usually a conventional *medium back-pressure* type of hermetic or bolted-hermetic design operating at 1725 rpm or 3450 rpm.

Condenser: The condenser may be water-cooled, air-cooled or a combination of both. The water-cooled type usually consists of a 3-in. diameter copper or steel shell in which a tight coil of finned copper tubing is inserted. Water flows through the coil, and refrigerant is condensed in the shell. The air-cooled condenser is normally a plate-fin type on ⅜ in. or ½ in. diameter tubes.

Receiver: Where a thermostatic expansion valve is used in an air-cooled machine, a liquid receiver is usually inserted between condenser and valve. It is common practice in the water-cooled models to utilize the condenser for a receiver as well. The principal reasons for liquid storage of this sort are to make the charge less critical, provide a good liquid seal ahead of the valve, supply storage for pump-down, and, in the case of the air-cooled condenser, to keep the liquid in the condenser to a minimum.

Drier-Strainer: The drier-strainer is placed in the high pressure liquid line to strain out particles of metal, sand, scale, etc., that may be carried along by the refrigerant, and to trap moisture that might turn to ice at the expansion device. This could cause blockage of refrigerant flow, or combine with other products to form acid or cause copper plating of compressor parts. However, in hermetic systems where excellent production techniques are used, it should be possible to operate without a drier-strainer.

Expansion Means: The high pressure liquid refrigerant is allowed to expand to evaporator pressure through either a thermostatic valve, constant pressure expansion valve or capillary restrictor tubes. Constant pressure expansion valves are not used in cycling type icemakers because they do not permit rapid and complete flooding of the evaporator so essential to uniform ice formation.

Evaporator: This portion where ice is formed is the most distinctive part of the machine. Here the designers and fabricators exercise their ingenuity to devise something different from other designs, something that will offer advantages over other icemaking units, and can be made on a practical basis. The evaporator must be of such a shape that the ice can be easily removed. Another requirement is that the pressure drop through the evaporator be kept to a minimum to assure rapid feed-through of refrigerant for uniform ice formation. Non-rusting metals should be used for the freezing surfaces. Smoothness, cleanability, and accessibility for cleaning are essential from a health standpoint.

Hot-Gas Solenoid Valve: Most of the self-contained cube machines on the market, and some of the clear chip machines, melt the ice free of the evaporator in harvesting. A solenoid valve in the discharge gas line allows hot gas to bypass the condenser and expansion device at the proper time and flow directly into the evaporator inlet. As a consequence, the temperature of the evaporator is raised above the melting point of the ice for easy harvesting. This is the easiest way to loosen the bond between ice and freezing surface. However, at low ambient air temperatures and low water temperatures (50 F and below) there may not be enough heat available to do a proper melting job. The evaporator design may require that additional thawing means, such as hot water or auxiliary electric heat, be used. Even a reversing valve for heat pump operation might be necessary. In machines that remove ice by mechanical means such as scraping, wedging or flexing, a hot-gas solenoid valve is not required.

Water System for Icemaking

Drinking water is used for icemaking except for certain types of machines which produce salt-ice *ribbons* from sea water. Water enters through a float-valve or solenoid-