The Centennial Series

The General Electric Monitor Top Refrigerator

The author provides a personal history of this pioneering, hermetically-sealed household refrigerator

By William L. Holladay
Presidential Member and Fellow ASHRAE

From 1925 to 1936, the General Electric Company manufactured a unique, truly hermetically-sealed household refrigerating machine that was mounted on top of its cabinet. The motor and compressor operated in a refrigerant atmosphere, the condenser was a helical coil of tubing (or a double cylinder of corrugated steel) around the outside, and the evaporator was inside the cabinet. The entire assembly, a single unit, was sometimes sneeringly referred to as "that thing on top," or more commonly as the Monitor Top.

The genesis of the Monitor Top was the Audiffren Dumbbell (see *Figure 1*), which was invented by Abbe Marcel Audiffren of France about 1894. The following quotation, from the *Air Conditioning & Refrigeration Museum* magazine, describes the Audiffren machine:

"Originally developed in France, the machine was manufactured by the Audiffren Refrigerating Machine Co. of New York City from about 1911 to 1928 (sic). It used sulphur dioxide as the refrigerant and since both highside and lowside were sealed within this so-called "Dumbell" it was probably the first true hermetic unit. The right hand bell, rotating in a tank of cooling water, acted as the condenser and contained the compressor and highside float. The compressor hung on the shaft and rotation was prevented by a heavy lead weight. Excessive pressures caused the entire compressor to revolve with the shaft, thereby eliminating the amount of overload.

"Liquid and suction lines ran through the hollow shaft to the left hand bell, or evaporator. This bell rotated in a tank of brine which was then cooled and circulated through refrigerators or ice makers."

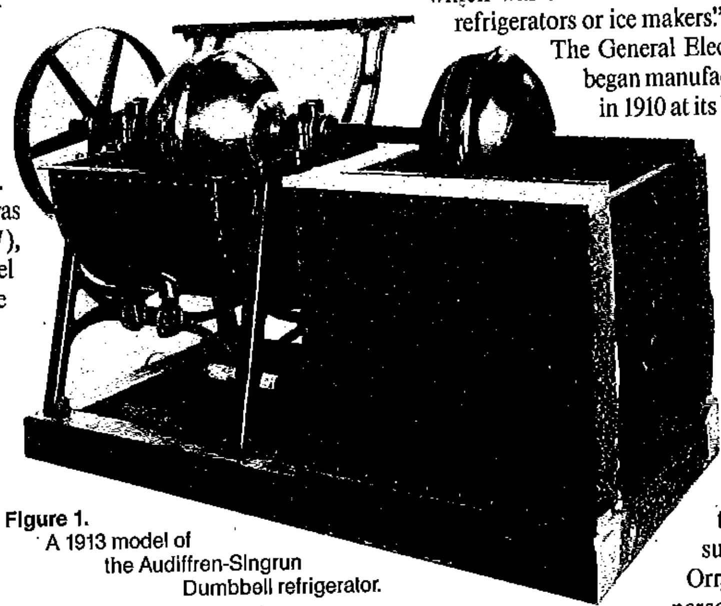

Figure 1. A 1913 model of the Audiffren-Singrun Dumbbell refrigerator.

The General Electric Company (GE) began manufacturing the Dumbbell in 1910 at its Fort Wayne Works in Indiana under contract with Johns Manville. The machines were used principally for cooling milk in dairies.

Because the GE center for innovation was in Schenectady, New York, little attention was paid to a manufacturing subcontract. But Clark Orr, a GE senior engineer, personally developed the first hermetically-sealed household refrigerating unit, the OC-2. Orr was encouraged in his endeavor by Walter Goll and P.C. Morganthaler, the Fort Wayne Works manager and assistant manager, respectively.

About the author

William L. (Bill) Holladay received a BSEE from the California Institute of Technology in 1924. He joined ASRE in 1930 and ASHVE in 1934, and is a Life Member and Distinguished 50-year Member of ASHRAE. He received the ASRE Wolverine Award in 1950 for Best Paper of the Year. He and his wife are donors of the Louise and Bill Holladay Distinguished Fellow Award, which is annually awarded to an ASHRAE Fellow for exceptional research or technical work. Holladay is the author of papers on weather data, low temperature refrigeration, heat transfer and fluid flow, and of a pocket handbook, *Numbers*. As the first sales representative hired in the Electric Refrigerator Division of the General Electric Company, he is uniquely qualified to write a history of the legendary Monitor Top.

The OC-2 refrigerating unit

The OC-2 used the oscillating cylinder compressor from the Audiffren, with sulfur dioxide as the refrigerant. The compressor cylinder wiggled back and forth on trunnions as the piston, driven by an eccentric, moved in and out. The shaft was driven by a four-pole, 1,750 rpm motor that operated in a sulfur dioxide atmosphere. This was a giant step from the Audiffren, whose pendulum-like compressor was driven by an external motor that rotated the dumbbell.

The oscillating cylinder design eliminated the connecting rod and wrist pin. The latter would have needed to be so small (inside a 5/8-in. or 16 mm diameter piston) that its life was problematical. The use of an eccentric instead of a crank allowed a much larger bearing surface with a longer probable life.

The boiling point of sulfur dioxide (R-764) at one atmosphere is 14°F (−10°C), as compared to −28°F (−33°C) for ammonia. Because it was taken for granted that the condenser of a household machine would be air cooled and that the condensing temperature might reach 125°F (52°C), the expected head pressure of 110 psig (758 kPa) meant lighter and safer construction than that of ammonia (293 psig; 2020 kPa). In fact, air cooling for ammonia was considered impractical. (Some still hold that belief.)

Thus, sulfur dioxide was the refrigerant of choice, not only for General Electric, but also for Frigidaire, Kelvinator and others. It is a highly stable compound with a sharp, penetrating odor which, once inhaled, is never forgotten. It is the odor of burning sulfur, not that of rotten eggs, which is due to hydrogen sulfide.

Sulfur dioxide not only smells terrible, it causes watering of the eyes, severe coughing and, with exposure to higher concentrations, vomiting. It is also toxic, although this was not generally known at the time. In fact, General Electric for a brief period operated a room in Schenectady with a low concentration of sulfur dioxide, where employees could sit for a time in the mistaken belief that exposure to sulfur dioxide would alleviate or cure the common cold.

An advantage of sulfur dioxide was the ease of leak detection; spraying the leak with ammonia forms a dense white cloud of ammonium hydrosulfide.

The OC-2 was an ugly brute; a vertical cylinder surrounded by a helix of finned tubing (possibly Aerofin), the whole painted a dull machine gray (see *Figure 2*). This assembly was set on top of a refrigerator that held a brine tank containing a copper coil evaporator and three slots for ice trays. The brine tank was 1 ft (305 mm) square and 2 ft (610 mm) high and held about 12 gallons (45 L) of sodium chloride brine.

The cabinet, manufactured by Seeger, was oak with a porcelain liner, and was insulated with 2 in. (51 mm) of corkboard. Two models were offered: 9 ft^3 (0.25 m^3) with four doors, and 14 ft^3 (0.4 m^3) with six doors. (An early, wise decision ruled against mounting an OC-2 on an existing ice box.)

Problems developed with the brine tank. Frost would form heavily on the upper half, while the lower half containing the ice trays would merely condense moisture, which continually dripped into the defrost tray. It was my good fortune to discover the reason.

The unit's instructions called for 24 lb (11 kg) of salt and 12 gallons (45 L) of water. The usual way to mix this was in a washtub in the backyard. Because a washtub would not hold all 12 gallons (45 L) without sloshing out during mixing, the installation man put in about 6 gallons (23 L) to start with, then added salt as he stirred.

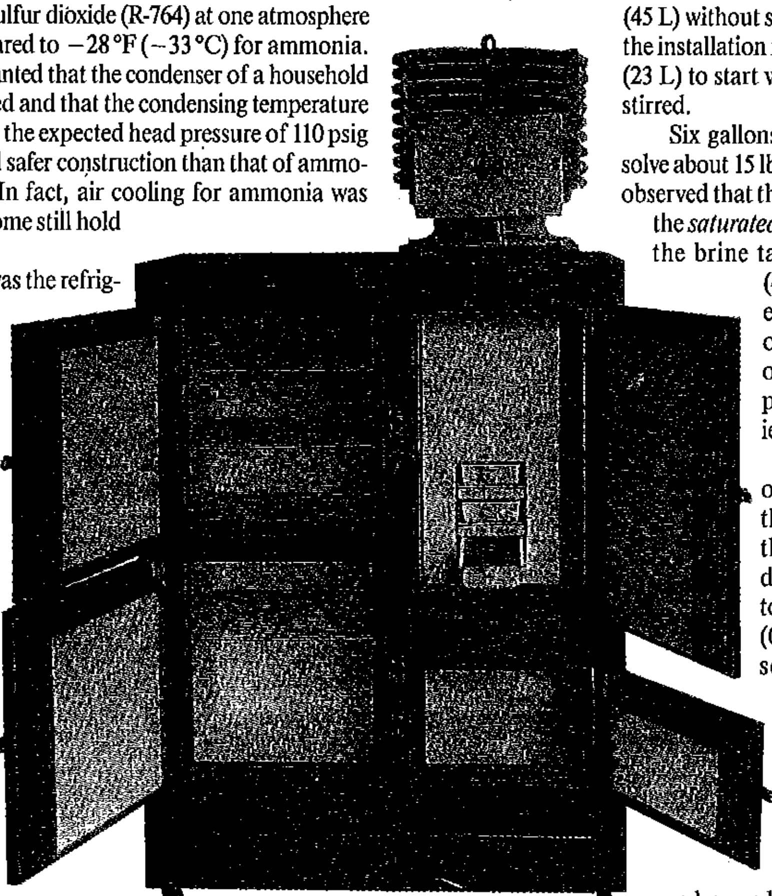

Figure 2. A 1924 OC-2 unit and brine tank installed in a Seeger refrigerator.

Six gallons (23 L) of water will dissolve about 15 lb (7 kg) of salt. When it was observed that the salt no longer dissolved, the *saturated* solution was poured into the brine tank. The remaining 9 lb (4 kg) of salt then dissolved easily in 6 gallons (23 L) of water, creating a solution of lower density. This was poured on top of the heavier solution, where it stayed.

The evaporator, which occupied the upper part of the brine tank, cooled only the upper half, while the denser solution in the bottom never got below 32°F (0°C). The problem was solved by adding salt in the same proportion to each batch of water; this was promptly added to the instructions. I then became known as the Brine Expert, and never was a title more richly undeserved.

Another problem developed between the OC-2 and the wood cabinet. The barrier between the condensing unit above the box and the evaporator inside was of insulated wood, edged with a copper breaker strip. (Both the unit and the cabinet had such a strip.) During humid summers, pools of water formed around the joint and, in one case, the unit actually fell into the cabinet. Sixty-nine years later, it is hard to remember such ignorance of heat conduction; no material worse than copper has ever been chosen for a breaker strip.

Another serious situation developed within the unit itself. Clark Orr, foreseeing the possibility of warm brine surrounding the evaporator and overloading the motor during pull-down, devised an ingenious valve in the suction line, which was opened and closed by a bimetallic strip. At higher temperatures, the opening was very small, and after pull-down, the valve opened to full suction line size.

Unfortunately, sulfur dioxide and moisture make corrosive sulfurous acid, and the complete removal of moisture during charging proved to be very difficult. The result was that the valve froze in the closed position, with excessive suction line pressure drop and greatly reduced unit capacity. Many units were changed for this reason.

The OC-2 was marketed by the newly created Electric Refrigerator Division. As the first of the sales representatives, I was assigned to the Dallas office. At that time, sales were to be made entirely through electric utilities, which had close relations with General Electric.

A.R. Stevenson Jr.

At this point, I must give proper credit to A.R. Stevenson Jr. (1893-1946), who was especially involved in the early history of the OC-2. Stevenson was also the 1934 president of the American Society of Refrigerating Engineers, a predecessor society of ASHRAE.

Stevenson was assigned to research the refrigeration industry as it existed in the 1920s, and to prepare a recommendation as to whether or not General Electric should enter the household refrigerator market. His recommendation (which was published in the July 1926 *General Electric Review*) was an unqualified yes, and it was accepted by GE vice-president F.C. Pratt and president Gerard Swope. Thus began the complex chain of circumstances that resulted in the Monitor Top and, eventually, an entire line of major household appliances.

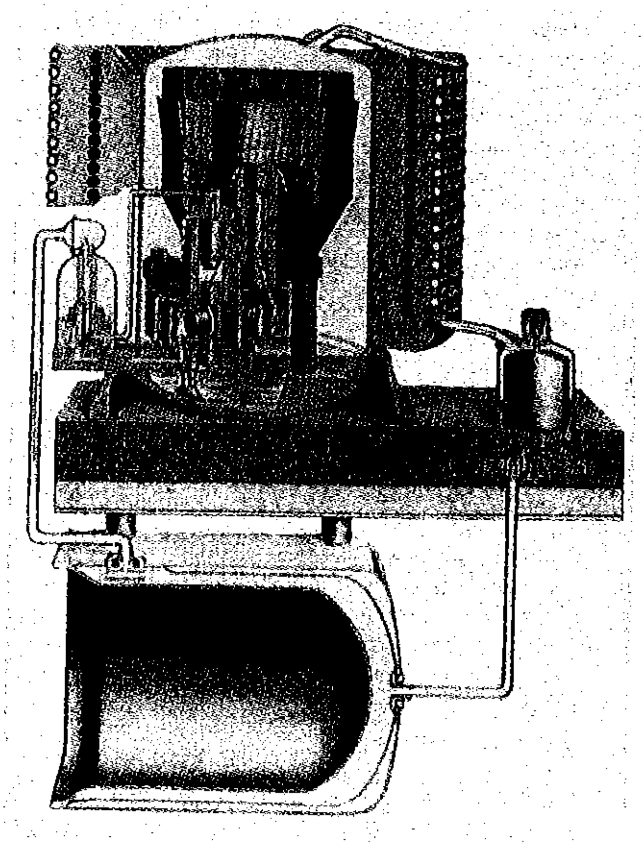

Figure 3. A DR-2 unit, circa 1927-29.

DR units

During the OC-2 experience, Christian Steenstrup (1873-1955), assisted by Walter Timmerman (later general manager of the Electric Refrigeration Department) developed the DR (Domestic Refrigerator) machine, the first unit to be called a Monitor Top. The name is attributed to advertising manager Walter J. Daily, although it may have originated with a member of his staff.

Gleaming white instead of dull gray, the finned condenser replaced with 3/8 in. (9.5 mm) OD tubing, it used the original oscillating cylinder compressor and sulfur dioxide. The 350 Btu/h (103 W) DR-2 had a single evaporator, a 1/8 hp motor and was manufactured in Schenectady. The Fort Wayne 600 Btu/h (176 W) DR-3 had two side-by-side evaporators and a 1/6 hp motor.

Originally, cabinets of 5 to 7 ft^3 (0.14 to 0.20 m^3) were cooled by the DR-2 and larger sizes by the DR-3. Later, it was seen that the 7 ft^3 (0.20 m^3) model required excessive running time from the DR-2. Thus, a hybrid called the DRB-3, with the larger compressor but a single evaporator, was manufactured for this size only.

Also, the DRA-2 (a DR-2 with a smaller box top for the 4 ft^3 or 0.11 m^3 cabinet) was manufactured for the apartment market. At that time, this market was dominated by multiple units; 30 or more small refrigerators would be connected to a single compressor in the basement through refrigerant liquid and suction lines. The refrigerant was usually methyl chloride (R-40).

The original DR evaporator was not a very good ice maker. The design engineers were concerned that excessive lowside pressure might cause deformation of the evaporators, so the ice tray space was a horizontal circular cylinder of white porcelain. A piece of cast iron (called the freezer block, flat on top and convex on the bottom) was supposed to be frozen into the evaporator by pouring water over it after the unit got down to temperature. Many owners never learned the trick, and complaints of slow cube freezing were common.

The block had to be frozen into place each time the unit was defrosted. Later, the cast iron block was replaced with a neater aluminum block with short vertical sides, which made it easier to freeze to the evaporator. I recall hearing a dealer comment during a sales meeting that the freezer block "was poor but necessary."

The designers were also concerned that a sensitive thermostat would cause short-cycling, which might burn the motor. So the evaporator had two concentric sections, the inner one for the boiling sulfur dioxide, and the outer one for a freezing solution. This was a "secret brine" that alternately froze and melted, thereby increasing the length of the on and off cycles (see *Figure 3*).

As we look at it today, the evaporator probably was not very efficient. Liquid sulfur dioxide was introduced from a highside float valve, and pool boiling with a relatively low heat transfer rate was the result. However, it did not short-cycle.

The Schenectady-based Electric Refrigerator Division was reorganized in 1927 into the Electric Refrigeration Department, with offices in the Hanna Building in Cleveland, Ohio. Sales by electric utilities were deemphasized, and a group of about 50 distributor-dealers was established. They were to sell at retail in their metropolitan districts, and through dealers in smaller cities. The plan worked well for nearly 15 years, until Pearl Harbor and World War II brought a temporary end to the manufacture of civilian products.

I was transferred at my own request to my home territory of Southern California. After the appointment of distributors in Los Angeles and San Diego, I joined the George Belsey Company, to handle what George Belsey referred to as "this product thing." My title was product manager, and I was put in charge of warehousing, deliveries, service and shop repairs.

Regarding repairs, the early DR units had a few problems, such as the accumulation of oil in the evaporators. Fleeta Hoke, our home economist, suggested a method of defrosting that accidentally solved this problem. Instead of merely turning off the unit and waiting (maybe all day) for the frost to melt, she repeatedly filled the ice trays with hot water until the evaporators were free of ice.

This method increased the temperature difference so much that the violent boiling drove the oil out of the evaporator when the unit was restarted. It could also be done in an hour or less. Hoke was rewarded by GE for having made the best suggestion of the year.

Another problem was that some early DR units were noisy. This occurred mostly in cold weather, and with backporch installations. Most kitchens in those days had no room for a refrigerator, and the icebox was on the backporch. So that is

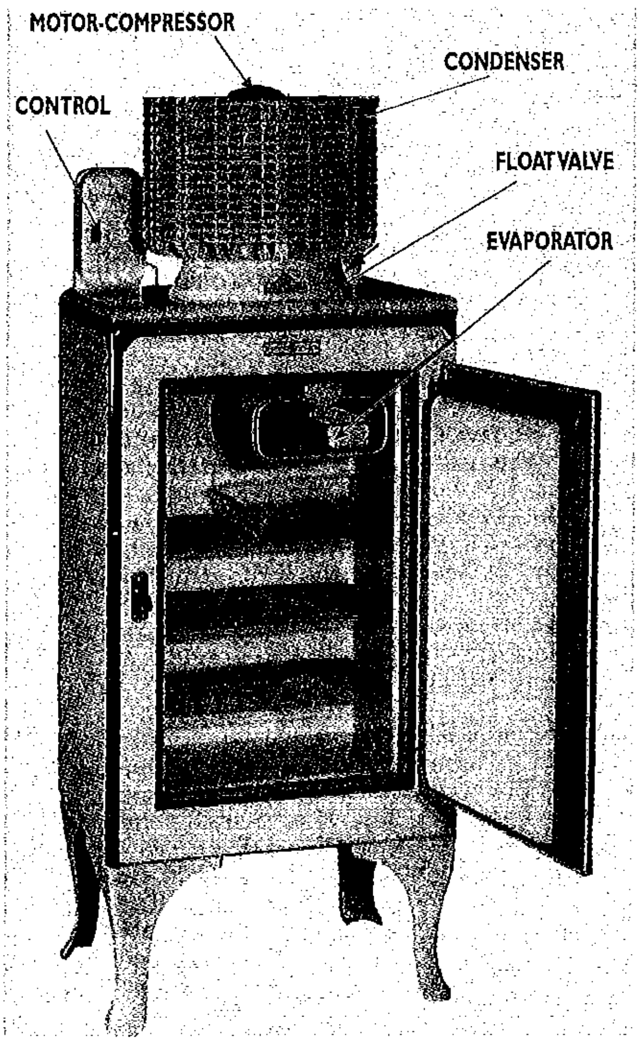

Figure 4. A 1930 DR-1 unit on a P-4 (porcelain exterior) cabinet.

where the new electric refrigerator was installed, with power coming from a double plug in the lamp cord hanging from the ceiling.

Today's serviceman would know that the noise was that of liquid refrigerant in the oil entering the compressor. But, in 1927, it took some testing to discover this. The solution was to install an 8-watt heater in the oil, possibly the world's first crankcase heater.

Another problem was freeze-ups. When the refrigerator was opened in the morning, frozen cream and milk were found projecting out of the top of the glass milk bottle, and other foods were equally stiff and solid. The serviceman, noting that the unit was still running, would remove the control box cover, and as he did so, the unit would shudder to a stop (there was a vibration point at around 1,000 rpm).

If he examined the switch contacts carefully, he would see evidence of an electric arc, which had weakly welded the contacts together. This condition was largely limited to Southern California, where the electric power delivered to two-thirds of Los Angeles and nearly all the rest of Southern California had a frequency of 50 cycles per second (50 Hz).

The reason for the arcing lay in the design of the control contacts, one of which was very solidly mounted. The movable contact, when closed by a temperature rise, would bounce off the fixed contact, causing a small arc. This arc was bigger with 50 Hz power, and more likely to weld the two contacts together. A control redesign solved the problem.

DR units had three principal causes of failure: burned motor, refrigerant leak or stuck float valve. Burned motors were nearly always due to lack of ventilation. Many architects considered the Monitor Top a terrible monstrosity and used any means to conceal it. A common method enclosed the unit in cabinetwork with a louvered front, to let the air in. However, the necessity to let the air out was never considered, and the obvious result was high condensing pressure and a burned motor.

The lacquer on top of the unit turned brown and the unit was exchanged. When such installations were made known to me, I demanded ventilation, saving the lives of Monitor Tops but estranging the architect.

A sulfur dioxide leak is a fearsome thing. The owner would be alerted by the highly unpleasant, penetrating odor, and trace it to the refrigerator. On opening the door, the intensity of the odor would be increased by at least one order of magnitude. Any food not in sealed containers would be rendered inedible.

My company gave a reported gas leak the highest priority, and a replacement unit was generally in place within an hour, day or night. We usually paid for the spoiled food, and sometimes for drapery cleaning. The leak nearly always occurred at the weld between the float valve and the porcelain evaporator. Improvement in welding technique eventually brought an end to this catastrophic failure.

Stuck float valves were due to the old bugaboo of moisture. The point and seat of the valve were subject to moisture in hot liquid sulfur dioxide, an ideal combination for a chemical reaction to occur. When the valve froze in the closed position, refrigeration stopped and the motor continued to run. The serviceman would phone in for a replacement unit.

When the old unit arrived at the shop, it sometimes operated perfectly; the truck ride back had separated the valve and seat.

However, if that failed, turning the unit over and bouncing it up and down sometimes worked. Soon, the factory developed a float valve lifter (an electromagnet drawing about 10 amperes at 110 volts) which, in all cases except those with severe corrosion, corrected the problem without changing the unit. Strangely, the condition almost never repeated itself on the same unit.

Our shop foreman devised an ingenious but chancy repair. With the unit running and the evaporator at a slight vacuum, he would bore a 3/32 in. (2 mm) hole in the curved portion of the liquid line under the float valve. He would then insert a piece of stiff piano wire and work it up and down against the needle. (This worked sometimes, but when it did, the sudden rush of liquid sulfur dioxide dissuaded anyone else from trying it. Also, it was never tried on units under warranty.) Afterward, he soldered the hole closed, a feat demanding both speed and skill.

The DR-1 was an improved model for the 4 ft^3 (0.11 m^3) market, replacing the DRA-2. It had a new flat-bottom evaporator with neither a freezer block nor a freezing solution. It was greeted with enthusiasm in the field, and the improved design was later applied to the larger units (see *Figure 4*).

The D-2 unit was an improved DR with a flat-bottom white porcelain evaporator. Its cabinet (termed the S-67) was frameless, with the all-corrugated insulation construction described below.

It is unlikely that any DR units survive. I know of at least two D-2/S-67 combinations, one in a historical museum in Creede, Colorado, and the other in an appliance store in Southern California. There must be many more in various museums.

Refrigerator cabinets

Originally, cabinets were produced by outside manufacturers, including Seeger, Bohn, Heintz and possibly others. Jewett made a few magnificent 18 ft^3 (0.5 m^3) cabinets for the DR-3, with a thick cast-porcelain liner. The thermal mass of this was so great that temperature recordings showed a perfect circle, with no indication of on-off cycles.

Cabinet design slowly changed from a multi-door box with uninsulated mullions to a single door on most models. The final design (manufactured by GE at Erie, New York) was frameless, with a porcelain liner supported by the insulation, and with a bakelite door jamb and breaker strips. The insulation was corrugated cardboard; the size of the corrugations was determined by a differential calculus equation familiar to every freshman math student. The cabinets were very efficient, and contributed to the low energy consumption discussed later.

CA units

The DR design, with additions, modifications and improved cabinets, lasted six years. Efforts to find a better refrigerant than the terrible-smelling sulfur dioxide resulted in the introduction of methyl formate ($HOOCH_3$, R-611), which was usually referred to as "H-Cooch."

With a boiling point of 89.2°F (32°C) at 1 atmosphere, its use required a completely new compressor, and a rotary design was chosen. The low operating pressure (1.6 in. Hg at 86°F; 5.3 kPa at 30°C) allowed a new condenser design: a flat plate welded to a corrugated plate, the whole formed into a circular cylinder surrounding the motor-compressor assembly. (This design proved to be stronger than expected, and was later applied to the CK units.)

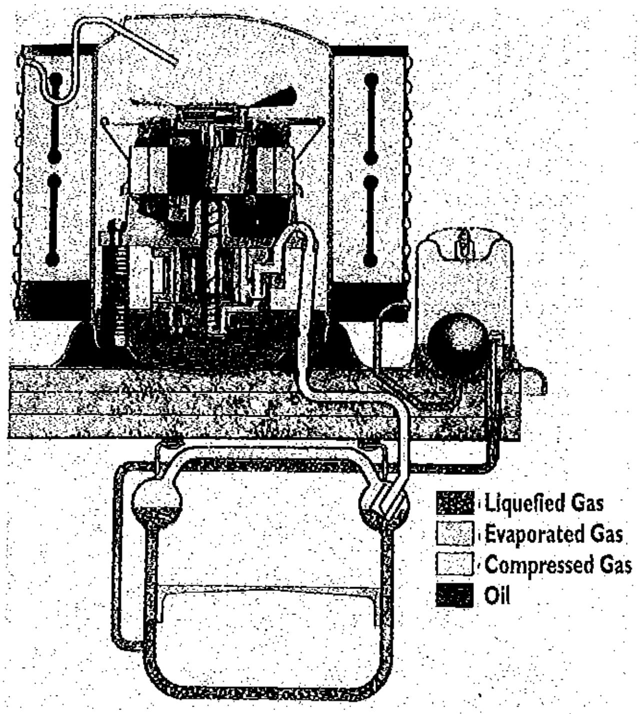

Figure 5. A 1933 CA-2 unit, which used methyl formate as the refrigerant.

The CA-2 evaporator had two headers, a flat bottom, and a dead shelf of cast aluminum. It normally operated at a vacuum of about 26 in.Hg (88 kPa) (see *Figure 5*).

The CA units lasted only two years. The virtues of methyl formate did not include chemical stability; within a few months, normal operation caused an accumulation of non-condensible hydrogen gas. This gas could be purged at the float valve, but it was highly undesirable. For the second year of production, a band-aid fix consisting of a pipe riser above the float valve just inside the condenser allowed the non-condensible gas to collect for a longer time between purges.

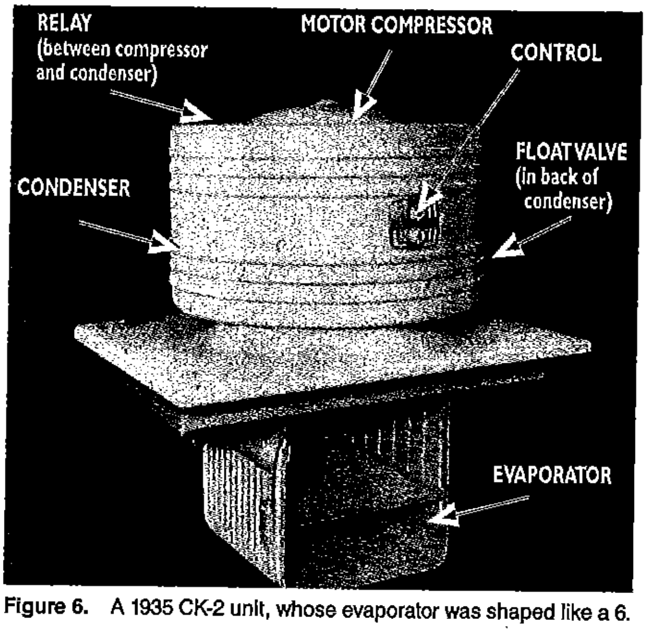

Figure 6. A 1935 CK-2 unit, whose evaporator was shaped like a 6.

Table 1. Monitor Top Unit Specifications

Model	Capacity (Btu/h)	Motor (hp)	Cabinet (ft^3)	Evaporator
D Units[1]				
DR-1	250-330	1/10	3,4	1 Flat bottom
DR-2	300-385	1/8	5,6,7	1 Round
DR-3	600	1/6	9,13,17	2 Round
DR-4	1100	1/3	27	Vert. plates
DR-5	1800	1/2	40	Vert. plates
DR-35	620	1/6	9,13,17	2 Flat
DRA-2	320-360	1/8	41	Round
DRA-4	1100	1/3	27	Ice maker
DRB-3	500	1/6	71	Round
DRB-31	590	1/6	71	Flat
DRE-3	610	1/6	9,13,17	2 Flat
DRE-4	1100	1/3	27	Ice maker
D-2	440	1/8	5,6,7	1 Flat
D-15	370	1/10	4	1 Flat
D-30	590	1/6	9,14,18	2 Flat
D-31	590	1/6	9,14,18	2 Flat
D-35	620	1/6	9,14,18	2 Flat
D-40	1100	1/3	27	Ice maker
CA Units[2]				
CA-1	430	1/8	4,5	Flat
CA-2	480	1/8	7	Flat, dead shelf
CK Units[3]				
CK-1	480	1/8	5	Flat, 6-shape
CK-2	530	1/8	6,7	Flat, 6-shape
CK-15	480	1/8	6	Flat, 6-shape
CK-26	530	1/8	6	Flat, 6-shape
CK-28	530	1/8	8	Flat, 6-shape
CK-30	730	1/6	9	Flat, 6-shape
CK-35	780	1/6	14,18	Flat, 6-shape

1. All D units used sulfur dioxide refrigerant. All condensers are helical coil, gravity circulation.
2. CA units used methyl formate refrigerant, and had a cylindrical plate condenser.
3. CK units first used sulfur dioxide, later CFC-12 refrigerant. CK units had a cylindrical plate condenser.
To convert Btu/h to W, multiply Btu/h by 0.2931. To convert hp to kW, multiply hp by 0.746. To convert ft^3 to m^3, multiply ft^3 by 0.02832.

The CK units

The CK was the greatest Monitor Top of them all (see *Figure 6*). It had no problems. It was the most efficient, with an average energy consumption of 20 kWh per month; this compared to 50 kWh for the DR-2 and even higher for the DR-3. The refrigerant was good old smelly sulfur dioxide, although R-12 was used on the last production runs.

The compressor was a Scotch Yoke, on which parts were selectively fitted to a few ten-thousands of an inch. The Scotch Yoke has a fixed cylinder. The piston projects at a right angle from the center of a slotted bar, making a T-shaped part. As the crank from the motor shaft moves back and forth in the slot, the piston moves in and out of the cylinder. It is a simple mechanism and, like the oscillating cylinder, eliminates the connecting rod and wrist pin. Such a design should result in low service costs, and it did; the failure rate of these units was an incredible 0.2% a year.

The CK evaporator was also very efficient. It was made of stainless steel and had a single header, with a live flat bottom and shelf. Each corrugation had a nozzle through which liquid refrigerant was sprayed at high velocity, increasing the rate of heat transfer. It was a superb ice maker; 1 quart (0.9 L) of water would freeze in two hours.

For a period of 12 months in 1935-36, my staff and I at Belsey Company ran a series of energy consumption tests on 114 Monitor Top and Flatop refrigerators, using souped-up kWh meters accurate to 0.1 kWh. (The Flatop unit used the same mechanism as the CK, mounted under the box.) The results, reported in the February 1937 issue of *Refrigerating Engineering* magazine, were:

- Average energy: 20.3 kWh per month
- Ambient effect: 0.637 kWh per deg-mo.

The results of these tests were used in an advertising campaign, and at that time, showed the Monitor Top and its brother Flatop to use much less energy than any competitive refrigerator. Because this time was near the end of the Great Depression, differences in energy and its cost were very important. Present day refrigerators, with large freezers, run from 60 to 100 kWh per month.

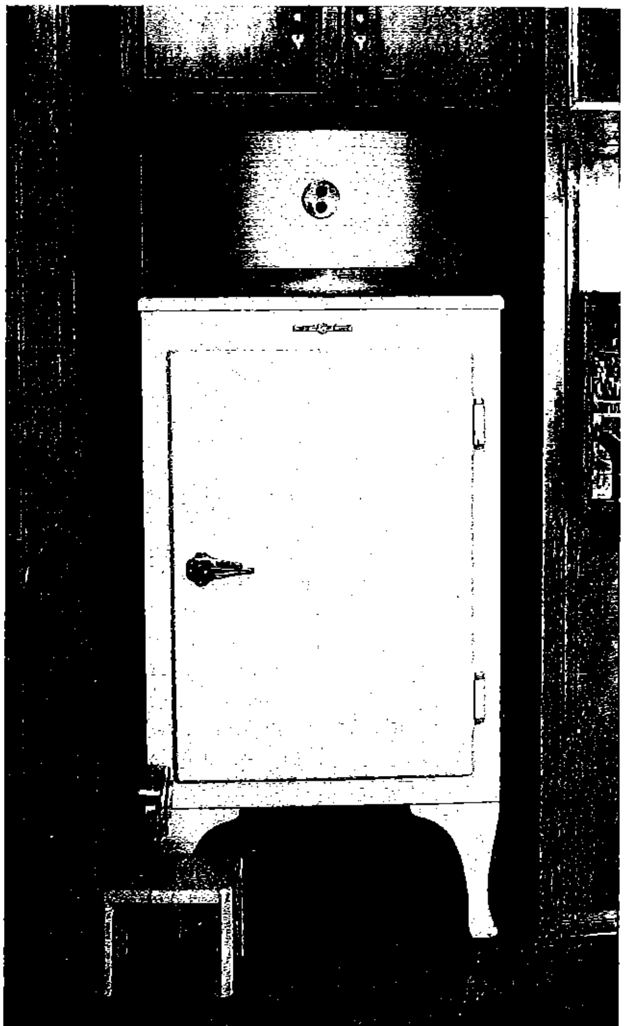

Figure 7. A CK-2 unit on an X-7 cabinet was the last and best Monitor Top.

Conclusion

A proud possession of my family is a CK-2 unit on an X-7 cabinet, now more than 60 years old, still faithfully preserving food and making ice cubes at our second home in the mountains (see *Figure 7*). We figure its actual running time at about 80,000 hours. If an automobile engine had run that long, the car at 30 mph would have circled the earth 96 times. We have replaced the starting relay once, and the door gasket several times.

Eventually, aesthetic objections to the Monitor Top (together with the equally good and more popular Flatop CF unit) doomed the Monitor Top, and the last units came off the line in 1937. It was the DC-3 airplane of household refrigeration: simple, efficient and long lived. It was the pioneer household hermetically-sealed machine, the granddaddy of them all. We will not see its equal again.

Acknowledgments

Appreciation is extended to my good friend W.K. (Dick) White, who succeeded me as product manager in southern California, who corrected errors in the manuscript and who reminded me of long-forgotten points of interest; and to Bernard Nagengast, volunteer industry historian, who shared with me many documents from his personal collection, and who nagged me into writing this article.

I welcome correspondence with anyone who was a part of the Monitor Top project in any way, or who owns an operating Monitor Top refrigerator. ■

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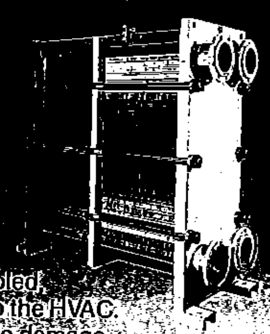
water within a Paraflow plate heat exchanger. It's a simple closed loop concept whereby clean, warmed HVAC water surrenders heat to tower water as both pass through the Paraflow. The newly cooled, clean water then recycles to the HVAC. No fouling. No corrosion. No damage.



As a bonus, the same Paraflow can save thousands of hours of refrigeration. Using free cooling available in outside air under optimum wet bulb conditions, the efficient unit delivers tower water at a temperature low enough to reduce chiller use.

All details are in our new HVAC plate heat exchanger bulletin. Ask for a copy.

APV

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(Circle No. 46 on Reader Service Card)