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ARTIFICIAL REFRIGERATION THROUGH STREET PIPE LINES FROM CENTRAL STATIONS.

BY DAVID PRANSON.

[*Read at the stated meeting of the Institute, November 15, 1893*]

The methods of distribution from central stations through street pipe lines, or wires, of water, light, power, heat and speech, have all been made somewhat familiar to the public by years of common usage. That of distributing power to produce cold is known to comparatively few, and in its latest development, made during the past four years, is, as yet, almost unknown.

A popular idea prevails that we furnish cold air. As a matter of fact, we do not send out cold air, or anything cold, through our pipes. All such methods have been, and must be, financial failures, in spite of the most costly insu-

lation, because of the percentage of loss of cooling power through absorption of heat from the earth or air through which the pipes pass.

Correctly speaking, our business is not to furnish anything; but to remove from the premises of our customers two things of which they wish to be rid—heat and humidity.

The most suitable material, as well as by far the cheapest, which can safely be used as a heat extractor, is ammonia. It conveys heat to the central station, where the heat is disposed of through an application of cold water; and the water, after being thus loaded with heat, is ordinarily discharged into the sewer.

To make the illustration more clear to those having no knowledge of ice-making or refrigerating machines, it might be well to explain by saying that expanding ammonia absorbs heat and that water absorbs ammonia, just as a sponge absorbs water. One might say that water is a sponge for ammonia, and ammonia is a sponge to sop up heat.

Since the first practical development of artificial refrigeration and its application to the cooling of breweries and packing-houses, and to ice-making, it has been the dream of many inventors, and also the aim of industrial promoters, to achieve a practical, safe and economical method of distributing refrigeration. Some twenty or more costly efforts to accomplish this result had been made in a dozen different cities, including Paris, London, New York, Boston, Louisville and Nashville. These resulted either in failure or in only partial success, but there was a great gain of valuable knowledge of the difficulties to be overcome, with little knowledge of how to overcome them, until five years ago, when Messrs. Starr, Thornburgh and Branson, the inventors of the system which we are to discuss this evening, undertook to study the causes of the failures of their predecessors.

Fortifying themselves with all the data that could be obtained, they experimented extensively, and visited many of the wrecks of other experiments.

The result has been a series of inventions which have been put into practical operation on a commercial scale in the cities of Denver and St. Louis. The plant in Denver

was started on the eighth of August, four years ago, and has not been obliged to stop a single day since, though it has been twice enlarged and the street line extended. The street line in St. Louis has also been operated for more than three years. Both plants give such satisfaction to their patrons that many would not return to the use of natural ice could they procure it for nothing.

Let me quote from an able article by John E. Starr, which appeared in the *Engineering Magazine* for April, 1893:

"Up to the introduction of the pipe-line system, only those who required large amounts of heat to be transferred could afford the appliances necessary to effect such transfer without using ice as an intermediary. To such large consumers of cooling power the introduction of ice machinery has been of incalculable value. In the brewing, meat-packing, dairy and cold-storage warehouse industries, the refrigerating machine saves annually millions of dollars, and renders possible operations on an enormous scale. To secure to the smaller consumer the benefits, and to the vendor the profits, of mechanical refrigeration was the problem of the pipe line engineer. The general economical advantages required to be preserved may be stated as follows:

(1) "The realization of enormous economy by operating in such a way as to transfer the heat directly from the customer to the central station without using ice as an intermediary.

(2) "The great economic advantages in distribution.

(3) "The general advantage of producing power on a large instead of on a small scale.

(4) "The commercial advantage of being able to offer to the smallest consumer of refrigeration all the benefits and economies of artificial refrigeration now obtained only by large consumers.

"To explain more specifically the first of the above considerations, it may be said that all refrigerating machines have two ratings, one known as their 'refrigerating capacity,' expressed by stating how much ice must be melted to produce an equal cooling effect; and the other as their 'ice making capacity.' The latter is usually placed, at the out-

side, at only sixty per cent. of the former ; that is to say, if we have a refrigerating machine that will produce as much cooling power as could be obtained from 100 tons of ice if placed directly at work on the space to be cooled, this machine would manufacture only sixty tons of ice. This may be more readily understood when it is remembered that in ice making the water which is to be frozen has first to be cooled by the machine from a temperature of 80° or 90° F. to the freezing point, before the process of congelation begins. This loss, together with the absorption of heat in and around the ice-making tank, makes up the forty per cent. difference ; and this is why all refrigerating machines are catalogued commercially with the two ratings mentioned.

“In the pipe-line process the refrigerating machine is put directly at work on the spaces to be cooled. When a central plant has the equivalent of 100 tons of ice to deliver to its customers, the artificial ice plant has, with the same machine and the same expenditure in coal and engineer's wages, but sixty tons to deliver. This leads to the second consideration. The sixty tons of artificial ice, with the expense mentioned, are delivered only at the factory door. The 100 tons at the station have been delivered to the customers.

“The delivery of ice, even to large customers, is one of the principal factors of cost, while to smaller consumers, say of from fifty to 500 pounds per day, the delivery is by far the greater portion of the cost. The service of ice requires usually a team of horses, a wagon, and two men for delivery in a comparatively limited district, and the cost of delivery by this method usually ranges from fifty cents per ton for the larger consumers up to \$2.50 per ton for the users of small pieces of from ten to 200 pounds per day. This large ‘operating cost’ of delivery, which, to the ice dealer, is an item of expense, becomes to the pipe-line company an item of profit. The upkeep, or repair, account, is little, if any more, by the pipe-line method than by the horse and wagon system of delivery.”

At the outset of our attempt to construct and operate

our street pipe-line system, we found that the principal obstacles were:

(1) The loss of power by absorption of heat from the earth.

(2) The difficulty of handling the constantly changing refrigerating load.

(3) The occasional stoppage of service of an entire district by reason of fire or breaks in the line, through accident, or the necessity of making new connections.

(4) The automatic regulation of temperature.

(5) The leakage of the volatile material used as a refrigerating agent.

The absorption of heat from the earth is avoided by what is known as a direct expansion system, in which the liquid anhydrous ammonia (usually at a pressure of 150 pounds to the square inch at summer temperature), flows from the machine through one pipe (the liquid line) to the point of use, and is there expanded by being allowed to flow through a small hole, in a carefully adjusted valve, capable of being regulated to suit the amount of refrigeration required. This expansion takes place in a coil of pipe, within the space required to be cooled, which pipe is known as the expansion coil; and from this coil the anhydrous ammonia, now changed to a vapor, returns through a larger pipe (the vapor line) to the central station. By this system, the entire cooling power of the machine is delivered and utilized in the refrigerators of the customers, none being lost on the way. The pipes, with the exception of the expansion coil, remain at the temperature of the ground or air through which they pass.

Our predecessors had managed fairly well to provide regular temperatures in large establishments under the changing conditions of the seasons, or of day and night, by increasing or lessening the number of machines in operation or the speed at which a single machine was operated. But this had its limitations both financial and mechanical.

In the street pipe-line business this difficulty is increased tenfold. Experience soon taught us that no possible calculation could enable us to predict when the demand upon the

machine would suddenly rise tenfold, without a moment's warning, or as quickly fall to practically nothing.

To provide against this difficulty, we introduced one reservoir (for liquid anhydrous ammonia) at the outgoing end of the machine, a second reservoir (for strong aqua ammonia) at the incoming side of the machine, and a third (for weak aqua ammonia), which is usually placed at a higher elevation.

When the strong aqua ammonia reservoir is full, both others are empty, as their contents are supplied by the separation of the ammonia or the greater part of it, from the water originally holding it in the strong aqua ammonia reservoir. The contents of this reservoir are pumped into the still at a uniform rate, and from the still the pure ammonia passes through the condensing coils to the reservoir for liquid anhydrous ammonia and the water or weak ammonia remaining flows to its reservoir above, each impelled by the pressure obtained from the heat of the distilling process.

The contents of the weak ammonia reservoir flow by gravity to the absorber automatically, as required, and absorb the returning anhydrous ammonia vapor from the street line.

As we use what is known as an absorption machine (because compression machines have been found impracticable for this purpose) the anhydrous ammonia vapor returning from the line is first discharged into a tank of peculiar construction, called an absorber, where it is reunited with the weak aqua ammonia from which it was originally driven by distillation. When this aqua ammonia has absorbed all of the anhydrous ammonia vapor that it is capable of holding, it is automatically discharged into the reservoir for strong aqua ammonia, from which it is again pumped into what is known as the still or separator.

By this reservoir system several objects are accomplished; first, a machine of half the size that would otherwise be needed will answer for any required amount of service; as it will readily be seen that without the reservoir, a machine would have to be of sufficient capacity to perform the ser-

vice called for during the hottest hour of the hottest day, while during other hours a machine of one-tenth the capacity would often be ample.

In the reservoir system, the machine operates steadily throughout the twenty-four hours, while the reservoirs vary in the amount of their contents alternately as the demand reaches a rate greater or less than the average of the machine.

This system also enables us to shut off the machine entirely for short periods to make repairs, and in cold weather, to dispense with a night force entirely, allowing the reservoir and the absorber to work automatically, without attention.

Of course, in very large cities, multiples of the largest sized machine would be used with reservoirs of sufficient size to give steadiness to the operation of either machine and to permit of short stoppages.

Our third great difficulty was overcome by providing a vacuum or safety line, which is a vital part of the system; for, without it, continuous operation could not be secured, nor could necessary repairs be made. This vacuum line is a third pipe connected with the liquid and vapor pipes, at or near their entrance to each refrigerating box supplied, and also in the man-holes at the street crossings.

In case of necessary repairs, alterations or additions to the pipes in any premises, the stop-cocks on the liquid and vapor pipes are closed, and the cock on the vacuum line (which has been habitually kept closed) is opened, the vacuum pump is then started at the station, and thus the ammonia contained in the expansion coil is drawn back to the central station and a ten or fifteen-inch vacuum is also usually produced. Then the piping in the refrigerating box may be opened without any smell of ammonia escaping.

By the same method, any section of the main line may be cut into for additional connections or repairs, by means of opening and closing cocks in the manholes at street crossings.

In our later work we have made the vacuum line of such size that it can be used as a temporary substitute for either

the liquid or vapor line, during alterations, thereby enabling us to avoid cessation of service to any customer even for an hour.

By keeping a constant vacuum, the contents of any expansion coil or any section of the line may, without previous notice to the engineer, be promptly switched into the vacuum line from any place where trouble has occurred, especially in case of fire or break in the street, and thus the material liable to be lost is quickly saved, as the engineer at the works will immediately start the vacuum pump, upon his attention being called thereto by an electric bell rung by the movement of the hand on the dial of the vacuum gauge.

The advantages of this vacuum line are also very apparent when it becomes necessary to shut off a customer, and pump home the contents of his expansion coil, and leave him out in the hot for non-payment of his bill.

In the matter of automatic control we had to solve the problem of supplying all degrees of temperature, not only on the same branch line or street, but often three or four in one building, or even in the different compartments of one refrigerating box; varying from ice-making and fish-freezing, up to the very easy task of keeping rooms for furs and woollen goods free from moths, or taking a few degrees of heat and humidity from a restaurant dining-room, a public hall, business office or hospital.

To do this, numerous devices were invented and tested—nearly all with brilliant success at the start; only to be followed by dismal failure when put to the test of time and innumerable changing conditions.

They choked up, froze up, gummed up and broke up in every imaginable way. But, one by one, the weak points were weeded out, the strong features combined; until, finally, two forms of regulators were constructed, both of which have stood the test of every possible condition we could think of through the changing requirements of spring, summer, autumn and winter.

These automatic valves are operated by electric power supplied from a dynamo through a storage battery at the

SECTIONAL VIEW OF MANHOLE, SHOWING ARRANGEMENT OF PIPE LINES.

INTERIOR VIEW—SHOWING ARRANGEMENT OF SERVICE SYSTEM.

central station; thence through an insulated copper wire circuit laid in the same conduit which contains the pipe line, and they are caused to open and close by the action of an ordinary thermostat placed in the cooling box and easily adjusted by thumb screws to any required temperature. We ordinarily set them to open the valves at 1° above and close them at 1° below the average temperature required; though, with careful manipulation, they can be adjusted so as to permit of much less variation. In the preservation of eggs, for instance, we do not permit a variation of more than one-half of 1° ; and, as a consequence, have had remarkable success in the preservation of this most perishable product.

In connection with the automatic valve the electric circuit can be used to signal from any refrigerator on the line to the engineer at the station; and one form of valve is so constructed that, if it should get out of order, an electric bell would ring in the engine room until the valve is attended to.

The most obstinate difficulty in mechanical refrigeration was the leakage of ammonia or other volatile gas used as a refrigerating agent; but constant experiment finally evolved a series of fittings and packings for joints which have been found practically perfect under continuous use for more than two years; both under and above ground, in wet places and in dry, in heat and in cold; and after being subjected purposely to all kinds of abuse.

Provision is made in their construction for contraction and expansion of long and straight lines of piping; even when, through carelessness, there might be a sudden change of temperature of over 100° .

The absorption machine which we use does not radically differ in construction from some others, aside from the reservoir feature, and the automatic regulation of the discharge from the absorber. But we have made in it, during our four years of commercial operation, several minor changes, each adding to its efficiency, reliability and economy, and lessening the amount of intelligence required to operate it safely.

The question of measurement of the amount of service rendered has been solved in two ways :

First, by a meter, measuring the quantity of liquid ammonia passing into each expansion coil. Knowing as we do the heat-extracting power of a pound of ammonia expanded under any given condition, it is a simple matter to calculate the equivalent, in ice melting, of the service rendered.

Up to the present time, no cheap meter has been made for the measurement of ammonia, which is even as satisfactory as the ordinary illuminating gas meter; and we hope for something less costly for this purpose before undertaking general household service.

The second method of estimating the amount used is the measurement of the square feet of the interior surface of the refrigerating box or room, and the figuring out of the amount of heat removed therefrom, by the aid of a set of tables carefully prepared by means of a long series of experiments with every known form of insulation now in general use for refrigerating boxes.

By these experiments we have ascertained, as to each material and thickness, how many units of heat will pass through a square foot of service in twenty-four hours for each degree of difference between the average inside and average outside temperature. To this we add a small percentage (based on experiments) for the amount admitted by the opening of doors, and the placing of hot materials in the refrigerator.

The entire cost of street-line construction varies from \$9,000 to \$22,000 per mile, depending upon the character of the street-paving, which has to be removed and replaced, the kind of soil to be excavated, the crowded or free condition of the ground under the streets from other piping, etc., the correctness of the city records as to old work in the same, and the amount of street traffic interfering with operations. The highest cost has been in narrow, crowded business streets in St. Louis, Mo., where the paving is very expensive, and where there was a net-work of both old and new pipes, of many of which no correct record existed in the city

archives. This frequently necessitated the changing of plans after the streets had been opened. In a city with pavements of average character, the cost, including branches to the sidewalk, ready for service connections to the num-

REFRIGERATING PIPE LINE, IN PROCESS OF CONSTRUCTION, SIXTH STREET, ST. LOUIS, MO., JUNE, 1891.

Showing the open trench in which is first laid the lower half of each section of vitrified clay pipe which forms the conduit in which the wrought-iron pipes conveying ammonia are laid upon suitable brackets. These brackets also support the insulated copper wire for the electric circuit.

ber of 100 to the mile, will be about \$18,000 in business neighborhoods, and about \$14,000 in residence districts where the lines can generally be run through back streets containing no other pipes.

A power house* with duplicate machines to operate two or three miles of street line in a business locality, should not exceed in cost \$90,000. In large cities it would be better to build a larger plant, say one costing \$200,000, with five or six cooling machines of daily capacity of 100 tons each. This should take care of five or six miles of street line. Should it be required to cover more ground than this, in very large cities, it would probably be better to build another plant at a distance not exceeding two miles from the first. The limit of practical working distance is about the same as with illuminating gas.

It is immaterial whether the plant be on low or on high ground, or whether the lines run down or up hill, or both, alternately. It can be operated on any floor of a building, from cellar to garret; and it is now supplying cold on the second floor of a large hotel some thirty feet above the street line and fifty feet above the central station. We have made no failure in any kind of cooling operations that we have attempted. These have covered nearly the entire range of cooling work (including ice making in the buildings of customers at long distances from the works).

We have, so far, charged prices varying from ten to twenty per cent. less than would be paid for ice sufficient to furnish an equivalent amount of cooling. In addition to that saving in their ice bills, customers have avoided slop, wear and tear, and have saved the cost of labor in handling ice. We also give them much more uniform service, and in many cases do work which it is impossible to do with ice; especially continuous and hard freezing and furnishing dry cold where damp cooling with ice would be ruinous.

While it is, of course, not only probable, but certain that numerous improvements will be made in the apparatus, from time to time, they will be mainly in the line of minor

* The frontispiece shows an interior view of the power house of the Colorado Automatic Refrigerating Company, in Denver, erected in 1889. Horizontal tank, strong aqua ammonia reservoir. Upright tanks near the stairway, liquid anhydrous ammonia reservoir. The largest upright cylinder is the absorber. Cylinders in the foreground on each side are stills and exchangers. The weak aqua ammonia reservoir is on top floor.

economy; the system itself, and general operation being substantially perfected. The repairs on the work constructed two years ago, after we had finished experimenting on the original trial lines, have been only nominal, and the loss by leakage small, and this due to the carelessness of employés. By the improved fittings, leakage has been made almost impossible.

We operated, at first, with machines of twenty to thirty tons daily capacity; and continued to do so until more than two years ago, when a ninety-ton machine was added in St. Louis. This has been working successfully ever since, and a duplicate has since been used in connection with it. Another of the same size was put in operation eighteen months ago in Denver, and is working satisfactorily. The old machines are being utilized in the business of ice making; and at the same time are in readiness to take care of the street-line work in case the new machines should by any chance get out of order; in which event, the ice-dealers only would have to fall back on their store of natural ice.

THE USE OF STEEL IN ELECTRIC MACHINES.

BY H. F. PARSHALL.

During the last few years steel has come to be used largely in the magnetic parts of electrical machines. In the magnet frames of some classes of machines the changes brought about have been most marked. In armature cores which require thin plates there has been no change, since the requirements are so rigid that the properties, either physical, or chemical, of steel, differ but little from wrought iron; in fact, the distinction between steel and iron in this case is made on account of the difference in the processes of steel and iron making.

By the use of steel in magnet frames street-car motors have been so completely changed that the motors of to-day, so far as form and appearance go, are hardly comparable with those of a few years ago. Before it was possible to