REPORT

MADE BY

CHIEF ENGINEER B. F. Isherwood,
U.S. NAVY,

TO THE

National Superheated Water Company

ON THE

PRALL SYSTEM

OF

SUPPLYING HEAT

FOR

COOKING, HEATING AND STEAM POWER.

JANUARY 10, 1887.
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NEW YORK CITY, January 10th, 1887.

NATIONAL SUPERHEATED WATER COMPANY,

THEO. N. VAIL, President.

Sir: In compliance with your request to carefully examine the Prall system of supplying heat for warming, cooking, and power purposes, in view that I was the President of the Board of United States Naval Engineers that investigated this subject by order of the Navy Department in 1881, and submitted a report thereon, and to give you my opinion as regards its practicability, efficiency and safety, based on that investigation and on the additional information obtained by a maturer study of the subject, I have to state:

That this system supplies heat to distant places from a central position by means of "superheated" water—a technical term denoting water heated to a higher temperature than 212 Fahrenheit degrees in a space which it completely fills; that is to say, no steam is generated, the entire heat imparted remaining as sensible heat in the liquid water. Under this condition, the water so heated exerts a pressure equal to that which would be exerted by saturated steam of the same temperature.

The Prall system is composed of a centrally located boiler and steam pumps, from which diverge in as many
directions as may be desired direct hot water pipes and return water pipes; a hot water pipe and a return water pipe being necessarily combined, the first for furnishing the heat at the point of use, the last for bringing back to the boiler the water whose temperature has been reduced below the standard by the abstraction of its heat due to use.

The boiler may be any one of the many varieties grouped under the general head of “pipe boilers,” free to use, and designed with the especial purpose of carrying extremely high pressures with absolute safety, due to the very small diameter of the pipes or tubes and to the relatively thick iron of which they are formed. In general, these boilers are composed of an assemblage of wrought iron tubes inclosed within walls of brick masonry, or within a double shell made of sheet iron and having the intervening space filled with mineral wool or other non-heat conducting substance. The water is within these tubes and is heated to the required temperature in the ordinary manner by means of fuel consumed in a furnace beneath them. A cylindrical steam drum with hemispherical ends is attached to the boiler and supplies steam to the engines operating the pumps. The pressure is contained wholly within the tubes and the steam drum.

The pumps are worked by steam taken from the steam drum of the boiler; one set of pumps draws the hot water from the boiler and forces it through the hot water pipes; another set of pumps draws the used water from the return water pipes and forces it into the boiler.
to be reheated. The peculiar nature of the service of the pumps is such that the power required to work them will cost only about one-twelfth of the fuel that is required for the best steam engines doing the same amount of work, or exerting the same power, as will hereinafter be explained. The pumps and the steam engines operating them differ in no respect from those in common use as regards details of construction.

Both the hot water pipe and the return water pipe consist each of two parallel branches forming an excessively elongated U. One end of the hot water pipe connects with its pumps and the other end connects with the boiler. The two ends of the return water pipe connect with a tank and from this tank the return or used water is forced by the return water pumps into the boiler.

The hot water pipe forms a closed circuit of superheated water whose temperature is not allowed to fall at any point below 400 degrees Fahrenheit, the water being kept in constant circulation by the pumps. The power required to produce this circulation is only what is needed to overcome inertia, the resistance of the wetted surface of the pipe, and the resistance due to change of direction at the bends, as the hot water is received from and delivered to the same pressure at the boiler.

For each line of buildings to be supplied with superheated water, there proceeds from and returns to the boiler a hot water pipe of suitable diameter for the quantity of water to be conveyed, and of the length
required for the locality, and from this pipe the super-
heated water is drawn for cooking, heating and power
purposes. The quantity of water supplied depends on
the demand, the same pipe furnishing a greater or less
supply according as the pumps are worked faster or
slower. The only loss of temperature in this pipe is
what is due to conduction and radiation, and this loss
becomes relatively less the greater the quantity of water
pumped through the pipe per hour. Under ordinary
circumstances the difference in the water temperature
at the two extremities of the pipe will not exceed a
very few degrees. The more rapidly the water is cir-
culated through the pipe, the less will be the difference
of its temperature at the two ends.

The pipe is covered with a considerable thickness of
asbestos wool and paper, or other non-heat conducting
material, and is inclosed in a strong water tight rectan-
gular box of wood; or, in a strongly hooped cylindrical
box of wood with raised edges or flutings on the inside
for supporting the pipe and at the same time leaving a
free space around it. With any arrangement of inclosing
box, the essentials are that it be water tight, that it have
a considerable free space between it and the contained
pipe, and that it be strong enough to withstand a modе-
rate internal pressure. The box is laid at a convenient
depth below the surface of the ground, but not in a
straight line, because provision is necessary for the ex-
pansion and contraction of the pipe due to the inevitable
and considerable changes of temperature to which, at
times, it must subjected. This provision can be made
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by bending out the pipe at proper intervals in the form of a horseshoe; or, by carrying the pipe after it has proceeded a certain distance along one side of a street, squarely across to the other side, and then, after it has proceeded a similar distance along that side of the street, returning it squarely to the first side, and so on alternately, the material of the pipe possessing sufficient elasticity to make the required adjustment. The center of each straight length of pipe is secured to its containing box, so that expansion and contraction of the metal will be equal on each side of the center.

The pipe is made in sections of about 30 feet length which are united by having their ends screwed into couplings or sleeves of suitable length and strength, a space being left between the ends of the sections. Into the center of these couplings, and at right angles to their axes, are screwed branch pipes of suitable diameter and length, which pass through water tight joints in the sides of the wooden box, and have connected to them outside of the box the small service pipes of from $\frac{3}{8}$ to $\frac{3}{4}$ inch internal diameter which carry the superheated water into the buildings where it is used.

The hot water pipe once satisfactorily laid is never to be disturbed; and if the consumption of water in any district supplied by it is greater than it can deliver, other duplicate pipes are to be laid by its side.

As water is practically incompressible, no difficulty can be experienced in commanding its circulation by pumps, which at each stroke of their pistons force through the pipe a definite quantity of water, thus keep-
ing it always completely filled with water of the standard temperature, notwithstanding any quantity that may be drawn off through the service pipes, the portion not used being returned to the boiler with nearly the same temperature at which it left, the only reduction being the small loss due to conduction and radiation, which loss, being regained in the boiler, the same water is again forced into the hot water pipe to repeat its circulation anew.

The water drawn from the hot water pipe through the service pipes is used for the purposes of cooking, heating and generating steam power, losing in these operations an equivalent portion of its heat. When its temperature is thus reduced below what is necessary for effecting the above results, it is discharged into a return water pipe of suitable diameter, and made preferably of rolled copper or brass. The return water pipe is parallel to the hot water pipe, and resembles it in arrangement, being composed of two parallel branches, made by bending one-half of the pipe upon the other half, so as to form a very elongated U. Both ends of the return water pipe open into a receiving tank, placed adjacent the boiler and pumps.

The construction details of the return water pipe are similar to those of the hot water pipe, but there will be no pressure within it owing to the fact that the temperature of the contained water will not exceed 212 degrees Fahrenheit under any circumstances; and when the principal use of the superheated water is for heating, the temperature of the water in the return water pipe will not exceed the standard temperature.
pipe will not exceed 160 degrees Fahrenheit. The used water delivered into the receiving tank by the return water pipe will be pumped at its temperature from the tank into the boiler, where it will be again heated to the temperature of 400 degrees.

Exactly the same water is thus constantly employed without normal loss; the water acting merely as a carrier of the heat. The greater the quantity of heat required in a given time, the greater must be the rapidity of the water circulation, obtained by either working the same pumps more rapidly, or by adding other pumps, if a constant speed of pump piston is desired. The quantity of heat per hour that can be thus supplied by a small hot water pipe is extremely great, but always of the constant temperature due to the constant pressure. The same mass of water will furnish quantities of heat in the exact ratio of the speed with which it traverses the pipe.

The loss of heat by conduction and radiation will be much less from the return water pipe than from the hot water pipe, because of the greatly lower temperature and less mass of water passing through it. Like the hot water pipe, the return water pipe will be protected against loss of heat from conduction and radiation by the same non-heat conducting materials, and it will be inclosed in a similar (or in the same) wooden box similarly laid beneath the surface of the ground.

The loss of heat by conduction and radiation from the surface of both the hot water and the return water pipes is extremely small, owing to the thick covering of
non-heat conducting material given to them, and to their confinement in a watertight wooden box, between which and them is a considerable space filled with stagnant air. This loss being constant for a constant temperature, will be relatively less the greater the quantity of hot water passing through the pipes per hour, and vice versa. With the rapid circulation that would be employed, the loss of heat by conduction and radiation would not exceed from one-eighth to one-quarter of one per centum of the heat conveyed by the water.

The highest temperature required for any of the practical purposes proposed, is what is needed for cooking, and it has experimentally been found to be 400 degrees Fahrenheit, the pressure corresponding to which is 235 pounds per square inch above the pressure of the atmosphere, an easily manageable pressure capable of being confined with entire safety in properly designed pipes of wrought iron or steel having diameters sufficiently large for all practical purposes. These pipes being subjected to only atmospheric temperatures on the outside, are under very different circumstances from boiler tubes, and are not limited as regards the thickness of their material. Any thickness may be given that is deemed judicious, and a corresponding strength obtained, so that any desired factor of safety can be had, and the possibility of rupture absolutely avoided. Further, if deemed advisable, protection valves can be placed in the hot water pipes at proper intervals, which in the event of a rupture from any cause, would close automatically and restrict the escape of hot water to the length of pipe not per pressure. Fill the closed pipes with water. The fore and study of the execution of the results to be slight required, an easy adopt is the employ to the practical.

The object with a temp heat, from cheaper thro by the present and at each pro gas fire and consum portable waste stand of each river. There comes to a dis pressure being whether produc ment of a pur
of pipe lying between them. This water would generate
20 per centum of its weight of steam of atmospheric
pressure that would have no effective force and would
fill the space in the wooden box between it and the in-
closed pipe without damage.

The foregoing is a brief description of the apparatus
and system in general; and is given to show the sim-
plicity of the method, and the equally simple means of
execution, while there can be no doubt of the efficiency
of the result. The practical application will, of course,
be slightly variable with the locality, water supply
required, and other variable conditions, all admitting of
easy adaptation. The principle is sound and only requires
the employment of known mechanical means to carry it
to a practical success.

The object to be achieved is the furnishing of heat
with a temperature of not less than 400 degrees Fahren-
heit, from a central source more conveniently and
cheaper through the medium of superheated water than
by the present system of generation by the combustion of
coal at each point of use. It is analogous to the illumi-
inating gas supply from the central gasworks instead of
each consumer manufacturing his own gas; or to a
portable water supply from a general waterworks, in-
stead of each household bringing its own water from the
river. There is no more difficulty in conveying hot
water to a distance through pipes than cold water,
pressure being the cause of the flow in both cases
whether produced by a head of water or by the move-
ment of a pump piston, except what arises from the
greater strength needed to retain the greater pressure of
the hot water, a purely mechanical problem involving
simply thicker iron, or less diameter for the pipes, and
better joints. The practical details of the apparatus pro-
posed are adequately designed, and no greater difficulty
will be experienced in supplying hot water over supply-
ing cold water than was involved in the superseding of
low pressure steam by high pressure steam in the case
of steam engines.

The cleanliness and the convenience of the hot water
supply over the present system of separate fires in
houses are manifest; by its use, time, labor, money and
space will be saved. Storage for coal with the attendant
dirt and discomfort of the dust of the coal and of its
ashes; the services of servants to make and attend fires,
to bring coal and to remove ashes, will be dispensed
with; there will be no burning of fuel to waste when
not needed, and there will be no loss of time in having
the heat whenever it is needed. In the latter respect
superheated water supply resembles illuminating gas
and potable water supply, always coming by the turn-
ning on of a cock and going by the turning off of the
same. By the use of superheated water as the source of
heat instead of fires in apartments, danger of accidental
burning of buildings will be greatly lessened, and rates of
fire insurance will be correspondingly decreased. In this
connection may be mentioned the value of a superheated
water supply in a house for rapidly extinguishing acci-
dental fires in rooms. With cold water, the stream
must be directed upon the burning mass, and much
water is needed for a small result. The superheated water, however, in addition to the far greater distance the stream can be thrown, owing to its much higher pressure or head, liberates 20 per centum of its weight as steam, forming at atmospheric pressure about 1650 times the bulk of the water from which it is generated. This steam almost instantaneously displaces the air in an apartment, forces its way into every aperture, and as instantaneously extinguishes fire which expires at once when the oxygen of the air fails to reach it. Superheated water may thus be made to have an important use as a fire extinguisher, and a corresponding insurance value.

With the system of ordinary fires in houses, only the best coal is used, and the principal portion (above five-sixths) of the heat is lost. A more wasteful method of employing heat cannot be imagined, and the cost is commensurably great.

With the hot water system, there is but one fire employed to heat the water for a district of large area. The grate surface of the boiler being of proper extent, and the fuel fired by automatic mechanism, the poorest and cheapest coal can be utilized with a minimum of labor in the handling, and the dirt and refuse attending the burning of coal will be localized on one spot instead of being found everywhere. The heat at the point of use can be promptly controlled, being turned on or off by the opening or closing of a cock, whereas, at present, there is a considerable length of time between the lighting of a fire and its state of steady combustion proper
for use; and there is also a considerable time before it burns out after its use is no longer required. During these useless periods of combustion the fuel is wholly wasted, and, in Summer, the building uncomfortably heated.

In the continuous heating of water on the large scale, according to the Prall system, in a properly proportioned boiler, exposing a very large extent of heat absorbing surface in proportion to the quantity of heat thrown on it by the weight of fuel consumed in a given time, in consequence of which the gases of combustion would leave the boiler with a temperature but little above that of its contained water, three-fourths of the heat of combustion will be utilized in water vaporization. In the matter alone of the proportion of the fuel utilized in the two cases, there is a difference of certainly four and a half times in favor of the Prall system. This, by itself, would be a source of great profit, to which must be added the difference of cost between the best house coal and that which would be equally good for use in a boiler furnace, besides the greatly less price per ton for which coal can be purchased in the enormous quantities required for the Prall system, compared with the small quantities required per house, and separately purchased on the present system. The difference between the cost of handling the coal and its refuse in the two cases, would be as great in favor of the Prall system, as the difference in the cost of the coal.

The quantity of heat used by any consumer can be easily ascertained with a sufficiently close approximation.
for commercial purposes by water meters of known construction.

The fuel cost of the power developed by the steam engines employed in the Prall system for circulating the superheated water in the hot water pipe, for pumping the used water from the return pipe into the boiler, for driving the blowers if a mechanical supply of air is needed for the combustion of the coal, and for hoisting coal and its refuse, will, owing to the peculiarity of the system, be not over one-twelfth of the similar cost per horsepower developed by the most economical steam engines employed in other work. In fact, the only coal required to work these circulating, pumping, blowing and hoisting steam engines, is what furnishes the heat actually transformed into work according to thermodynamical theory, and to supply the loss of heat by conduction and radiation from the external surfaces of these engines. The cooled water from the return pipe will be in such excessive quantity compared with the feed water required for generating the steam used in the engines, that it will be enormously more than sufficient to condense all the steam worked through the engines, the condensed steam and the water condensing it will be wholly pumped back into the boiler, and there will be no rejected heat as in the case of other steam engines, which rejected heat averages about eleven-twelfths of the total heat of the vaporization of water. If the cost of the indicated horsepower in the best engines be taken at about 2 pounds of ordinary coal per hour, that cost, with the engines of the Prall system,
will be only two-tenths of a pound of coal per hour. The steam taken from the boilers at the temperature of 400 degrees Fahrenheit (pressure 250 pounds per square inch above zero) for working the engines, will be condensed by the water of the return pipe at the temperature of, say, 160 degrees Fahrenheit, and both the water of condensation and the condensing water will be pumped into the boiler, so that the total quantity of water in the boiler and in the hot water pipe and in the return water pipe will always remain constant.

This wonderfully economical production of steam power can be only obtained when the water feeding the boiler is enormously greater in quantity than the water required to be vaporized for producing the steam used in the engine, and when it has a considerably less temperature than that of the steam exhausted from the engine. These conditions, very rare to be found in industrial operations, exist superabundantly in the Prall system, and diminish its fuel cost of supplying superheated water to an extraordinary degree.

The fuel cost of the hot water supply by the Prall system, would be the fuel required to raise the temperature of the used water brought back to the boiler by the return water pipe, from, say, 160 degrees Fahrenheit to 400 degrees; to replace the loss of temperature sustained from conduction and radiation by the water in the hot water pipe and in the return water pipe; and to furnish the steam power for circulating the water through the hot water pipe, and for pumping the water from the return water pipe into the boiler, and for hoisting coal.
The coal required for all these operations, compared with the quantity of heat supplied for use, would be very small. The cost in fuel of circulating and pumping the water, which, under ordinary circumstances, would be great, has been shown to be only one-twelfth of what would be required for the same expenditure of power doing work under ordinary circumstances; and this reduction in the weight of coal consumed means likewise a corresponding reduction in the boiler plant and in the personal attendance.

The cooking by the Prall system is done in properly designed stoves, and the experiments which I have witnessed with them prove that vegetables and meat can be as well cooked and in as many ways, and with as fine a flavor, as by any of the methods now practiced.

The heating of houses by the Prall system can be most conveniently effected by using in ordinary radiators or heaters the steam generated from the hot water when the pressure upon the latter is lowered. The pressure of such steam can be made whatever may be desired from the atmospheric pressure upwards within the limits of the boiler pressure. In reducing the pressure from 250 pounds per square inch above zero to the atmospheric pressure there will be converted into steam of the latter pressure 20 per centum of the weight of water used. In the case of houses that are heated through flues by hot air from a furnace in the cellar, there can be substituted for the furnace an assemblage of tubes filled with superheated water, or with steam from it of any desired pressure, and a current of
cold air being passed over them will become heated in the passage and delivered into the existing flues for warming the apartments in the same manner as at present.

For the production of power, 16 per centum of the hot water is available; that is to say, when water at the temperature of 400 degrees Fahrenheit, being under the pressure of 235 pounds per square inch above the atmosphere, is liberated into a space where that pressure is 20 pounds per square inch above the atmosphere, which is as low as would be required for power purposes, the temperature being 260 degrees, 16 per centum of the water so liberated will be vaporized by its contained heat into steam of 20 pounds pressure per square inch above the atmosphere, and will be available for the production of power. By inclosing the steam pipe containing steam of 20 pounds pressure in another as a jacket, in which the boiler pressure of 235 pounds per square inch above the atmosphere is maintained, all condensation of the steam of 20 pounds pressure is not only prevented but that steam can be largely superheated if sufficient jacket surface be provided, and the economy of the development of the power greatly increased over what would be obtained with saturated steam. Or the difference of temperature between the jacket and its enclosed pipe can be utilized for the vaporization of more water into steam. Further, the superheated water of 400 degrees Fahrenheit temperature can be used by passing it through a properly constructed boiler as a source of heat to generate steam of nearly as high a
temperature as itself. In this manner steam can be fur-
nished for power purposes at any point at as high a
pressure as 120 pounds per square inch above the
atmosphere.

For many of the industrial arts water of excessively
high temperature has the greatest utility, and would be
in constant demand.

One great superiority in the use of hot water over the
use of steam as a carrier of heat, consists in the very
much smaller diameter pipes required for the former than
for the latter, due to the greater quantity of heat in a
given bulk of water than in the same bulk of steam, both
being at the same temperature. The total quantity of
heat in one pound weight of saturated steam at the tem­
perature of 400 degrees Fahrenheit above the tempera­
ture of zero is 1,236 Fahrenheit units, a unit being the
quantity of heat required to raise the temperature of one
pound of water at 32 degrees one degree. A pound of sat­
urated steam at the temperature of 400 degrees occupies
1.825 cubic feet. The total quantity of heat in one pound
of water at the temperature of 400 degrees above the
temperature of zero, is 406 Fahrenheit units, and this
water occupies 0.0173 cubic foot. Hence the relative
quantities of heat that are contained in one cubic foot of
space by water and by steam at the temperature of 400 de­
grees are, are \( \frac{406}{1.825} = 220.68 \) for the water and \( \frac{1236}{1.825} = 677 \) for the steam, the quantity of heat in one cubic foot of
water being \( \frac{220.68}{1.825} = 346.07 \) times as great as in one cubic
foot of steam. And the areas of the pipes will be in this
proportion, making their diameters in the proportion of
1 for the water and \( \sqrt[3]{34.2} \approx 5.89 \) for the steam. The thickness of the material of the pipes for equal strength, would have to be about six times greater for the larger steam pipe than for the smaller water pipe, even if both were lap welded.

One steam pipe of the large dimensions required for any considerable supply of heat, would evidently be impracticable, and if a number of smaller ones were adopted having in the aggregate the area of the one large pipe, the quantity of materials required and the bulk occupied would be so great as to make their use equally impracticable. The very much greater bulk and enormously greater cost of the steam pipes over the water pipes for conveying equal quantities of heat of equal temperature in equal times, places commercial competition between the two systems out of the question.

The loss of heat by conduction and radiation from the surfaces of the steam pipes will be greater than from the surfaces of the water pipes, both conveying the same quantities of heat per hour, in the ratio of the greater surfaces of the former.

But ignoring the above objections to the larger steam pipes, a steam supply of heat compared with a hot water supply, could be made satisfactory for only short distances, and it would fail when applied to long distances, owing to the facts that the water is practically an incompressible liquid while the steam is a highly elastic vapor. The use of the incompressible liquid secures a uniform circulation and a uniform temperature within a very few degrees, at every point, which is not possible with the
elastic vapor when the distance becomes great, because the delivery of steam cannot be forced mechanically to any desired and predetermined extent through a long system of pipes. Steam must propel itself through such pipes by its own expansive force alone, whence inevitably results that its pressure and temperature will continuously and considerably decrease as the distance from the boiler or source of supply increases. The greater, therefore, the quantity of steam drawn from the pipes in a given time, the greater will be the differences of pressure and temperature within them. The condensation of steam in the pipes will be not only what is due to the loss of heat by conduction and radiation, but to the transformation of a portion of its heat into the mechanical work of propelling itself along the pipes. The withdrawal of the water of condensation from the pipes using steam, would be a very troublesome and expensive operation, which is not needed with the hot water supply. Besides the foregoing, all the practical details admit of easier and more certain management with the water than with the steam, simply because of the great difference in the size of the apparatus. The money cost of the plant in the two cases will be enormously less with the superheated water system than with the steam system.

The safety of the Prall system is so thoroughly assured that water of considerably higher temperature than what is intended, could be employed without risk. The "pipe" type of boiler allows pressures to be carried much greater than are needed for the purposes of the system, and the hot water pipes can be made of any
desired strength—as strong as cannon if required. As the pipes used for heating buildings will have but little over the atmospheric pressure in them, they are absolutely safe under all conditions. The service pipes conveying the superheated water for cooking, will be so small—from \( \frac{3}{8} \) to \( \frac{1}{4} \) inch internal diameter—that their strength with the ordinary thickness of metal given will be so great as to make rupture practically impossible, while the quantity of water in them is so little that no appreciable damage would be done by it if set free. The return water pipe having only the atmospheric pressure in it, is absolutely safe under all circumstances.

As regards economy, a given quantity of heat can be undoubtedly furnished by the Prall system to consumers at a much less cost than would be required for separate fires in each building, and leave a handsome profit to the furnishers.

The Prall system of supplying heat for cooking, warming buildings, and producing steam power, is, in my opinion, much superior to the use of steam for the same purpose, and especially so when the distance is great, and to an eminent degree for the first two cases. There is no difficulty of making it an engineering success with known engineering means, and it would certainly prove a commercial success under circumstances that would involve failure were other methods employed. Its safety, practicability and efficiency admit of no doubt.

Your obedient servant,

B. F. ISHERWOOD,

Chief Engineer United States Navy