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CONTINUOUS HEAT EXCHANGE BETWEEN A CONDENSING VAPOR AND A LIQUID

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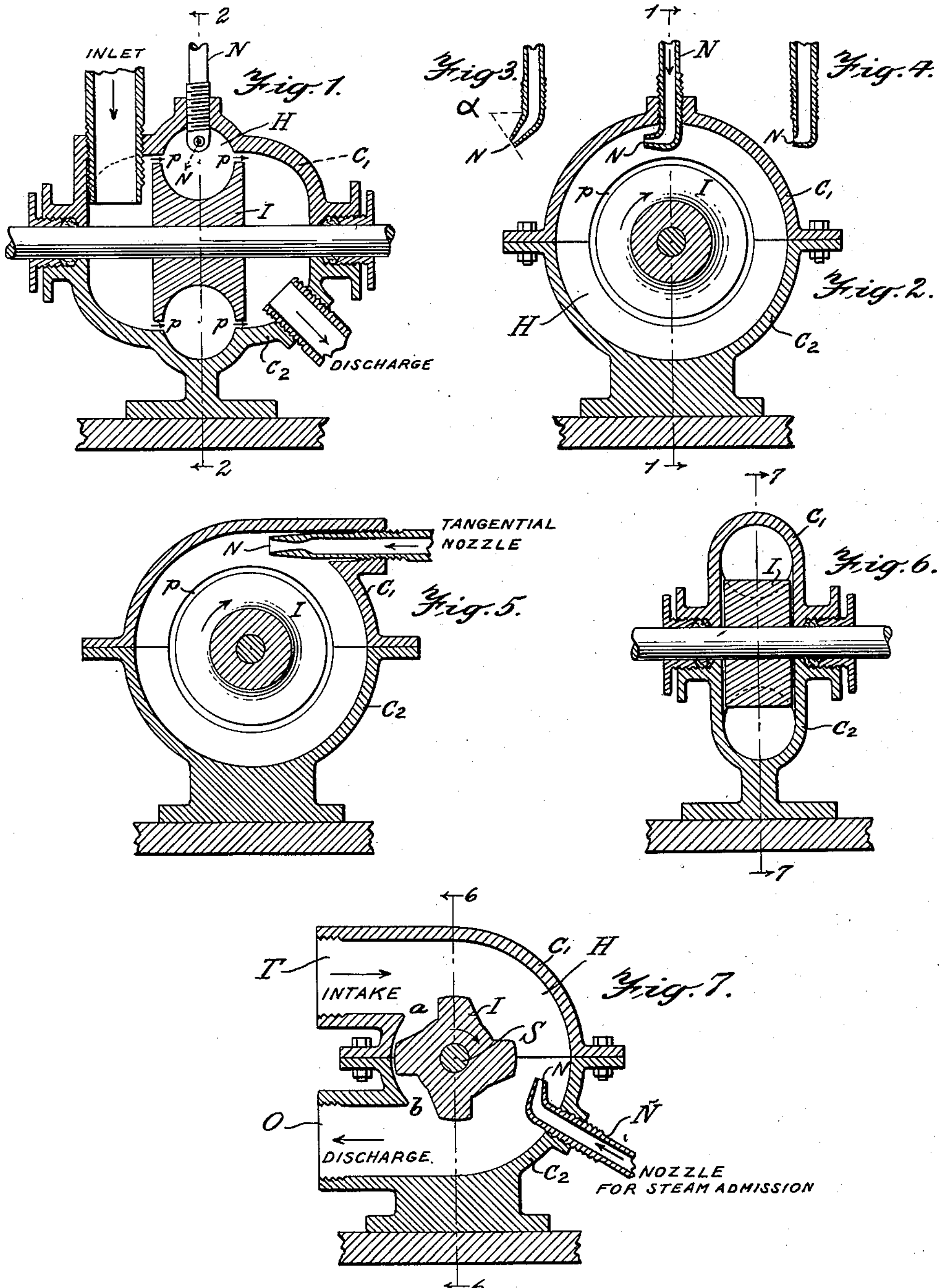

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CONTINUOUS HEAT EXCHANGE BETWEEN A CONDENSING VAPOR AND A LIQUID

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This invention relates to improvements in heat exchange and has for its general object an improved method of effecting continuous heat exchange by conduction between a condensing vapor and a liquid.

It is known that when injecting steam into a liquid, it is possible to raise the temperature of this latter by condensing the steam and consequently by imparting by conduction to the colder molecules of the liquid the latent heat of vaporization of the condensed molecules of water and as much of their sensible heat as is required to bring the complex—liquid plus water—, to a desired temperature. When the steam is superheated, it first releases, when condensing, whatever part of its sensible vapor heat may still be available.

Of these three sources of heat supplied by the steam, the latent heat of vaporization is by far the most important.

It is also well known that if steam is conveyed from an adequate supply of steam at a pressure p_1 and a temperature t_1, through a nozzle into a space wherein are prevailing a back pressure $p_2(p_2\ p_1)$, and a temperature $t_0(t_0\ t_1)$, the steam expands in the nozzle, in a very short time, from the pressure p_1 to a certain pressure which is equal to p_2 if p_2 is larger than the so-called critical pressure p_m (aproximately $p_m = .57\ p_1$), whereas if p_2 is smaller than the critical pressure, the expansion of the steam in the nozzle brings its pressure down to the said critical pressure and the steam after-expands more in said space.

In order to avoid any misunderstanding, attention is drawn to the fact that the term "critical pressure" used herein refers to a condition peculiar to the flow of gases or vapors; said critical pressure is entirely different from the saturation pressure corresponding to the critical temperature above which a gas cannot be liquefied by compression alone, said saturation pressure being also known as critical pressure.

It is also admitted that, due to the rapidity of this expansion in the nozzle, the steam, even if it were wet, i. e., already partly condensed, is in a certain state of supersaturation and consequently that it acts as if it expanded adiabatically and nearly according to the law of perfect gases. The result is that in the nozzle, the temperature of the steam drops much more than the drop which would correspond to a slow drop in pressure as given in the steam tables (for example: Mollier).

Thus if t_1, t_m, t_2 are the temperatures given by the steam tables as corresponding to the pressures p_1, p_m, p_2, respectively, the temperature of the steam t' after its adiabatic expansion in the nozzle is well below the largest of the two values: t_m or t_2. This temperature t' is practically a limit above which it is impossible to raise the temperature of the complex—liquid plus water—, as long as the initial conditions prevail, i. e., the back pressure is maintained at p_2.

Example A.—Saturated steam

Assuming that $p_1 = 50$ lb. sq. in. abs.
$t_1 = 281°$ F.
$p_2 = 20$ lb. sq. in. abs.
$t_0 = 70°$ F.
$t_2 = 228°$ F.
Then $p_m = 28.5$ lb. sq. in. abs.
$t_m = 247.4°$ F.

the adiabatic expansion in the nozzle reduces the pressure of the steam from 50 to 28.5 lb. sq. in. abs., and the temperature would drop, according to the law of perfect gases, to about $t' = 190°$ F., much below $t_m = 247.4°$ F. and, in the present case, also much below the temperature 228° F. corresponding to the back pressure p_2.

In this case, it is thus impossible to bring the complex—liquid plus steam— ,whatever the initial temperature of the liquid and the proportion of steam condensed, say to 228° F., unless, under favorable circumstances, by admitting such a very large excess of steam, the back pressure is built up far above its initial value of 20 lb. sq. in. abs.

Example B.—Saturated steam, same pressure p_1 and temperature t_1 as in Example A, and

$p_2 = 40$ lb. sq. in. abs.
$t_0 = 70°$ F.
$t_2 = 267.3°$ F.

then the back pressure is larger than the critical pressure; the adiabatic expansion in the nozzle reduces the pressure of the steam from 50 to 40 lb. sq. in. abs., and the temperature would drop, according to the law of perfect gases, to about 244° F., thus well above the temperature obtained in the previous example, but still below the temperature $t_2 = 267.3°$ F., which corresponds, for saturated steam, to the back pressure p_2.

In fact, the temperatures obtained are a little above those calculated from the law of perfect gases, due probably to the fact that the steam does not follow said law exactly; and it is to be understood that the above figures are only approximate. The examples, however, serve to illustrate that the smaller the difference between the pressure of the steam and the back pressure, the smaller, will be the drop of temperature due to the unavoidable expansion of the steam in the nozzle.

In order to raise the back pressure, it is customary to increase either the static pressure of the liquid or the pressure corresponding to its potential gravitational energy, while I increase the back pressure by utilizing an increase of the kinetic energy of the liquid by transforming it into pressure energy at the instant at which the steam is impinging upon the liquid, thereby checking the expansion of the steam.

By doing so, it is really possible to raise the back pressure, in the zone of contact between the impinging steam and the liquid, at least a part of the "velocity head" of the liquid being at each instant transformed into "pressure head", thus increasing the pressure without necessarily increasing either the "static pressure head" or the "gravity head".

The velocity head of a liquid may be shown experimentally as existing distinct from pressure head or from gravity head, by using a Pitot tube. If the said Pitot tube were utilized as a nozzle for injection of steam within the flowing liquid, it is easy to see that if the pressure of the steam were equal to the total of the static (gravity and pressure) heads of the liquid, it could not overcome the back pressure of the liquid facing the opening of the Pitot tube, because the back pressure in this zone is larger by at least a part of the velocity head transformed into pressure head.

Consequently, if steam is injected through a nozzle device laid out on the principle of the Pitot tube, into a liquid stream, the pressure of the steam must be larger than the total pressure, resulting from the static heads and the velocity head, for that part of the liquid which is impinging against the steam as the latter is blowing out of the nozzle.

Consequently also, it is possible to reduce the difference between the pressure of the steam and the static back pressure of the liquid (gravity plus static pressure) by utilizing its velocity head without having to increase either the gravity or the static pressure heads or both.

This latter condition is important in certain cases, and it may even be advantageous to reduce as much as possible either the gravity head or the static pressure head or both, when it is possible to increase the velocity head, for example by rotating the liquid stream at high speed in a special casing by the agency of a suitable impeller, and causing it to impinge against a steam nozzle shaped on the principle of the Pitot tube, as shown in the accompanying drawing.

In the drawing:—

Fig. 1 is a typical vertical sectional view of an apparatus adapted to carry the invention into effect, for example in treating liquid food products.

Fig. 2 is a similar vertical sectional view taken on the line 2—2 of Fig. 1.

Fig. 3 is a fragmentary, detail view in longitudinal section of a modified form of nozzle.

Fig. 4 is a similar view of another modification.

Fig. 5 is a sectional view, similar to Fig. 2, of a modified form of apparatus.

Figs. 6 and 7 are vertical sectional views of another modification of the apparatus, taken respectively at right angles from each other, Fig. 6 on the line 6—6 of Fig. 7, and Fig. 7 on the line 7—7 of Fig. 6.

Figs. 6 and 7 show a very simple device comprising, assembled on a base (which latter carries the bearings and may carry the motor) a casing whose two parts C_1 and C_2 form the "heating" chamber H in which rotates coaxially an impeller I assembled on a shaft S. The chamber is given any suitable form; in the figures it is shown shaped as the convex portion of a circular torus. A tangential inlet T admits the liquid to which is imparted a suitably high tangential velocity by the impeller. A tangential outlet O permits smoothly discharging the liquid, after its contact with the steam, which is injected through a nozzle N based on the principle of the Pitot tube. The portion of the casing between *a* and *b* is shaped so that the impeller clears it with a moderate clearance. The impeller I is shaped so as to have the maximum action on the liquid, and the inside of the casing is polished so as to avoid friction, with its consequent loss of energy, as much as possible.

Figs. 1 and 2 show another lay-out in which a liquid stream can be driven at a suitably high speed and be caused to impinge against steam injected through a nozzle, with this distinguishing characteristic that a lateral velocity is concomitantly imparted to the liquid by adequately utilizing its static energy, so that the liquid continuously circulates from the intake end to the discharge end as indicated on Fig. 1 by the arrows, penetrating into the "heating chamber" H and leaving this latter through the annular spaces *p*.

Steam is injected through a Pitot tube device N assembled on the casing so that the steam hits the rotating liquid whose velocity head at the instant of the contact with the steam is instantaneously transformed into a pressure head increasing the back pressure and thus preventing a too great drop in temperature of the condensing steam.

Of course, immediately after the impact, the liquid resumes its velocity, at least to a certain degree, (because it is impelled by the impeller) and only the static pressure will prevail, and it is conceivable that the temperature of the liquid may drop accordingly because some of its water content may evaporate again. The liquid, nevertheless, will have been at a certain desired temperature at a certain instant, and this may be entirely satisfactory as, for example, it is in the case of liquid food products. For such products, indeed, in order to sterilize them they must be brought to a certain minimum temperature; but any excess above said temperature, or the fact that the product is maintained too long at said temperature, will be injurious to the flavor and the taste.

As previously said, I show in Figs. 1 and 2 a machine incorporating these principles. The circulation of the liquid from the intake to the discharge through the "heating chamber" H can be regulated by the difference in static head between the intake and the discharge and by the areas of the annular passages *p* betwen the impeller and the casing. Depending upon this rate of flow and upon the dimensions of the "heating chamber", a unit quantity of liquid will remain in said chamber on the average a certain time and it will thus be dragged around by the impeller a certain number of times, at each revolution impinging against the steam injected through the orifice N of the nozzle, the rate of inflow of the steam being proportionate to the lateral rate of flow in the machine, in view of the temperature to be imparted to the liquid. So, at every instant, a certain quantity of liquid will be acted upon by a certain quantity of steam, increasing progressively the temperature of the liquid from the temperature prevailing at the intake, to the temperature prevailing at the discharge, having reached in-between a higher desired temperature for at least a small duration of time.

The orifice of the nozzle N may be shaped according to the usual art, as for example it may be divergent, as shown in Fig. 5. It is well-known that, in a nozzle, with a given throat-area, and with a given condition of pressure, a correspondingly definite weight rate of flow of steam will be obtained. Consequently, the throat-area must be determined, in each case by the weight rate of flow, the specific heat and the temperature chart of the liquid.

Moreover, the nozzle may be shaped as variously shown in the drawing. By slanting the orifice of the nozzle at a certain angle α, instead of having this orifice at right angles with the direction of the tangential velocity of the liquid, it is possible to obtain a different combination of the composition of the velocity of the steam with the velocity of the liquid, and consequently to transform only partially the kinetic energy of the liquid into pressure energy, whereby the back pressure will be reduced and the temperature of condensation of steam brought down. If the plane of the orifice were tangent to the velocity of the liquid, this reduction of temperature would be still more sensible, but there will nevertheless be a certain part of the velocity head of the liquid which will be transformed into pressure head because the steam will bulge slightly beyond the orifice of the nozzle, opposing a frictional resistance to the liquid. By assembling the nozzle backwards, so that the steam will blow in the direction of the flow, a still greater reduction of back pressure will be obtained.

So, all other factors being kept constant, it is possible by regulating the slant of the orifice, to regulate the temperature of the condensing steam.

The same effect can be obtained by rotating the nozzle and so regulating the orientation of said orifice, or by combining the regulation of the slant and that of the orientation.

It is obvious that the velocity of the liquid moving in the device shown in Fig. 1 is a combination of its tangential velocity and of its lateral velocity, but, in fact, this latter will always be so small compared to the former, that only the tangential velocity practically is to be considered. If, in a specific case, the lateral velocity were important enough, its influence could be dealt with by regulating the slant or the orientation, or both, of the orifice of the nozzle.

By the word liquid, I designate herein any liquid, whatever its viscosity or even plasticity or heterogeneity.

It is obvious that the nozzle will produce the same action on the liquid as a baffle, and cause a mixing effect to be produced within the liquid, thus providing also an equalization of temperature between the warmer parts of the liquid,—i. e., those parts having just been in contact with the condensing steam—; and the colder parts,—i. e., those parts having not yet come, or having previously come, in contact with the steam—, after which contact they may have lost some of their heat by conduction to other cooler parts.

It is obvious also that concomitantly with the raising of the temperature of the liquid, there is produced a dilution of it, by incorporation therewith of the condensed steam. It is moreover obvious that the same appliance can be used with any other suitable vapor, as for example, vapors of ethyl alcohol or of any other suitable solvent or extractor, as can be done when the liquid is treated in order to extract some of its constituents in the ulterior course of a process (if water were not suitable to this end).

For a machine of the type shown in Figs. 1, 2, and 5, as well as for the device shown in Figs. 6 and 7, the wall of the casing in the "heating chamber" should be as smoothly polished as possible in order to avoid frictional losses of energy, whereas the impeller should be made as effective as possible for imparting a high velocity to the liquid stream. To this end the impeller may be of a preferred form, such as the impeller of a centrifugal pump, or it may be supplied with peripheral notches or grooves or any other suitable means to increase the drag of the liquid and consequently to increase its tangential velocity.

From the foregoing it will be apparent that, by a novel adaptation and utilization of the natural laws inherent in the Pitot nozzle principle, I have provided for a continuous heat exchange of increased efficiency by conduction between a condensing vapor and a liquid, viz., by building up the temperature coefficient available in proportion to the increased regional pressure in or at the discharge orifice of the steam.

By so doing, I have made available the kinetic energy imparted to the liquid stream by the prime mover of the machine, so that without increasing the size of the machine or requiring bulky additions thereto, I have secured an effect comparable in efficiency with built-up pressures derived from a gravitational head of fluid in a relatively high and massive physical structure, or by increased fluid pressure on the introduced steam, and/or upon the fluid stream itself under treatment, these being the recognized conventional methods employed heretofore and involving a relatively higher cost than my method requires.

It is well known that there are many commercial steam injectors used for the purpose of raising the temperature of water in order to feed hot water to steam boilers, or to distribute it through buildings. Some of these injectors have two steps of injection. Said appliances promote the expansion of the injected steam beyond the nozzle and impart kinetic energy to the water, in some cases to raise it against gravity. It is also well recognized that conditions exist under which steam is injected into a liquid through two nozzles in opposite directions, one helping the liquid stream and the other checking said stream, and that in such instances the steam is caused to expand considerably. In all such cases the steam, as hereinbefore described, is in a state of supersaturation, and the temperature drops to a lower level, before condensation of the steam, than the one resulting from the equation of state as recorded in the steam tables.

By my herein disclosed process, the liquid stream, possessed of energy for promoting its flow, receives mechanically an additional amount of kinetic energy so as to be impelled against the orifice of the nozzle and the incoming vapor, whereby said additional kinetic energy is transformed to pressure energy at the instant of contact between liquid and vapor, and I am thus able to raise at said instant the back pressure opposed to the vapor, to about the pressure at which the vapor is delivered to the nozzle, thereby checking its expansion in the nozzle, also checking the change of its thermic and pressure energies to kinetic energy, and consequently checking the drop in temperature and causing condensation at higher temperature than would otherwise be possible.

While I have mentioned the use of my invention in sterilizing liquid food products, it is of course capable of utilization in any field for which it is adapted by the nature of the improvements herein disclosed, with such modifications as may fall within the spirit of the invention.

The following examples may further illustrate the process.

Example C

Supposing that the steam, injected through a nozzle of the Pitot tube type against an impinging stream of water, is saturated steam at a pressure $p_1=50$ lb. sq. in. abs., that the water is under a gravity head corresponding to 15.2 lb. sq. in. abs. and that it is moving against the nozzle at a velocity of 66.7 ft. p. s.; then this velocity head corresponds to a pressure of 29.8 lb. sq. in. and the total of the gravity head and of the velocity head corresponds to a pressure of 45 lb. sq. in. abs. which is above the critical pressure of the steam. The corresponding values of the temperature are respectively:

$$t_1=281° \text{ F.}$$
$$t'=263° \text{ F.}$$

In fact the temperature obtained is a little lower than this latter value.

Example D

Practically the same results as in the Example C would be obtained if the gravity head corresponded to a pressure of 20 lb. sq. in. abs. with a velocity of the water of 60 ft. p. s.

Example E

All the other conditions being identical to those of Example C, let us assume that the velocity of the liquid is 6.67 ft. p. s.; then the velocity head corresponds to a pressure of .298 lb. sq. in. abs. and the total of the gravity head and of the velocity head corresponds to a pressure of 15.498 lb. sq. in. abs., inferior to the critical pressure $p_m=28.5$ lb. sq. abs. of the steam; the corresponding value of the temperature t' is 190° F., the same as in Example A.

In fact, I have observed in several instances, under conditions very near those of Example E, that when the liquid is stationary or moving slowly, its temperature could not be raised above 190 to 195° F., even with a large excess of steam.

I claim:—

1. In the process of raising the temperature of a moving fluid material by injecting into it through a suitable nozzle a suitable stream of vapor, the step of checking the expansion of said vapor in said nozzle so as to maintain its pressure at least above the critical pressure, whereby a deep drop of the temperature at which it condenses in the fluid is prevented, said step being performed by temporarily increasing the kinetic energy of said fluid material by centrifugal impetus at the point where it contacts with the vapor, thereby increasing the back pressure opposed to said vapor at said point.

2. In the process of raising the temperature of a moving liquid material by injecting into it through a suitable nozzle a suitable stream of vapor, the step of raising the back pressure opposed by said liquid to said vapor above the critical pressure of the vapor in the nozzle by mechanically and temporarily increasing the kinetic energy of said liquid material at the point where it contacts with the vapor.

3. In the process of continuously raising the temperature of a continuously moving liquid material by continuously injecting into it through a suitable nozzle a suitable stream of vapor, the step of mechanically impelling said liquid material against the orifice of said nozzle in such manner as to raise the back pressure opposed by said liquid to said vapor above its critical pressure, at the instant of contact between liquid and vapor.

4. In the process of continuously raising the temperature of a continuously moving liquid material by continuously injecting into it through a suitable nozzle, of the type of a Pitot tube, a suitable stream of vapor, the step of mechanically impelling said liquid material against the orifice of said nozzle in such manner as to raise the back pressure opposed by said liquid to said vapor above its critical pressure at the instant of contact between liquid and vapor, thereby preventing a deep drop of the temperature at which the vapor condenses in the liquid.

5. In the process of sterilizing a continuously moving liquid food product, by injecting into it through a suitable nozzle a suitable stream of vapor, the step of mechanically imparting additional kinetic energy to said product and mechanically impelling the latter against said nozzle in such manner as to raise the back pressure opposed by said product to the said vapor at the instant of contact between product and vapor, thereby preventing a deep drop of the temperature at which the vapor condenses in the product.

6. The process of continuously sterilizing a moving liquid food product, and simultaneously diluting said product, by injecting into it through a suitable nozzle a suitable stream of steam, mechanically impelling the liquid against said incoming steam in such manner as to raise above the critical pressure of the steam in the nozzle the back pressure opposed to it by said liquid at the instant of contact between liquid and steam.

7. In the process of continuously raising the temperature of a continuously advancing liquid stream by injecting a suitable stream of suitable vapor into a space wherein an additional velocity head is imparted by centrifugal impetus to said liquid stream, the step of regulating the temperature of the condensing vapor by regulating the angle between the directions of the two streams.

8. In the process of raising the temperature of a moving liquid material by injecting into it a suitable stream of vapor, the steps comprising the imparting, by centrifugal impetus, of a temporary additional velocity head to the liquid at the vicinity of introduction of the vapor and discharging the vapor in opposition to the moving barrier formed by said liquid, in such manner as to raise the back pressure opposed to said vapor above its critical pressure, thereby checking its expansion prior to its condensation and causing its condensation in the liquid at high temperature.

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