

Sept. 21, 1965

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MEANS FOR INCREASING THE HEAT TRANSFER COEFFICIENT BETWEEN
A WALL AND BOILING LIQUID
Filed Dec. 28, 1962

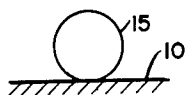


FIG. 1.



FIG. 2.

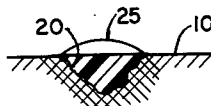


FIG. 3.

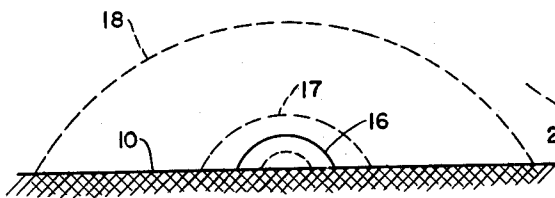


FIG. 2a.

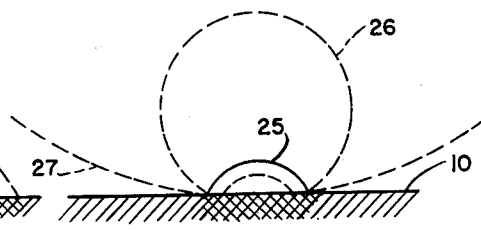


FIG. 2b.

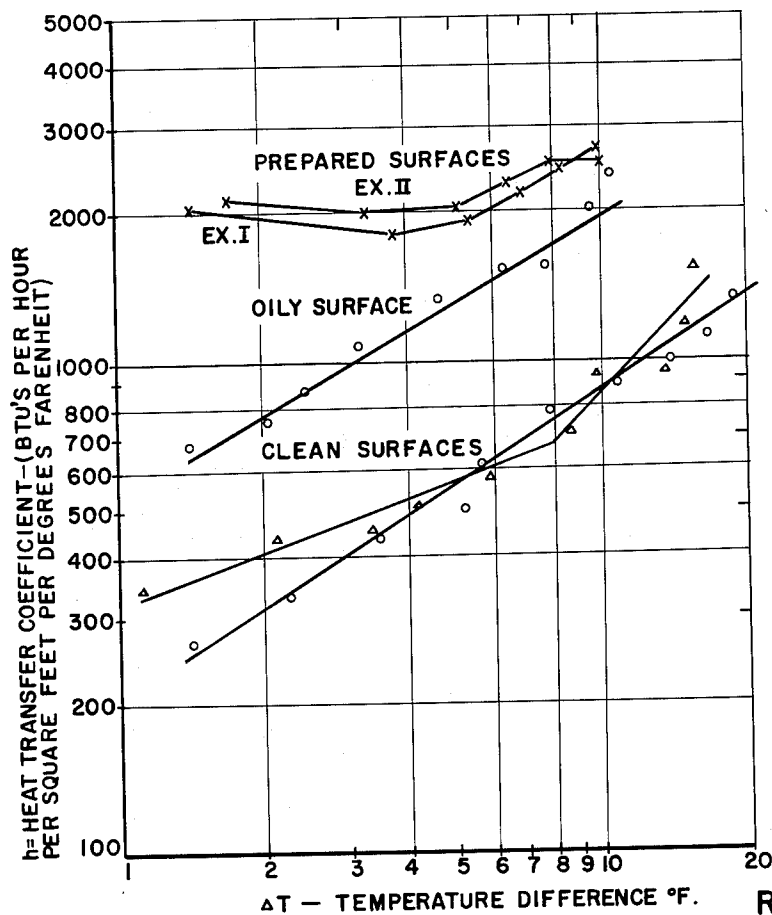


FIG. 4.

INVENTOR.

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BY

- EX. I—COMPARATIVE UNTREATED STRIP
- Δ EX. II—COMPARATIVE UNTREATED STRIP

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1

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MEANS FOR INCREASING THE HEAT TRANSFER COEFFICIENT BETWEEN A WALL AND BOILING LIQUID

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Filed Dec. 28, 1962, Ser. No. 247,975

5 Claims. (Cl. 165—1)

This invention relates to a process or method for the treatment of heat transfer surfaces in such manner that the boiling film heat transfer coefficient is relatively permanently increased in a very material respect so that, as will be well understood, the over-all efficiency of the involved surface is correspondingly substantially increased. More particularly, the invention relates to a method for the treatment of metal surfaces in particular wherein the surface, as ultimately prepared, represents one of relative heterogeneity. In other words, given a highly polished, clean, stainless steel surface, such may be considered as relatively homogeneous, i.e., smooth and non-pitted throughout its entirety. Also, such a surface represents what might be termed a "wetable" surface, i.e., a surface which is hydrophilic or having a relatively strong affinity for water (or other liquid under consideration) in contrast to a so-called hydrophobic surface, or a surface normally considered to lack affinity for water.

Experimentation has indicated that apparently the rate of boiling on a given hot surface is limited by the rate of vapor bubble nucleation, at least for reasonably low values of temperature difference between the given surface and the boiling liquid. In the instant case the particular temperature difference (ΔT) contemplated ranges from 1° to 20° F. At any rate it has been determined that the rate of boiling and in particular the related quantity—the boiling film heat transfer coefficient—can be increased by providing a relatively heterogeneous surface which consists, on the one hand, of a plurality of spots of hydrophobic substance or a plurality of pits or depressions rendered relatively non-wettable or hydrophobic by filling the same with a non-wettable substance; and on the other hand, a somewhat larger surface area of wettable or hydrophilic portions. Both types of areas of this heterogeneous surface represent a large number of extremely small, i.e., microscopic or near-microscopic portions. In the practice of the invention here under consideration these "wetable" areas represent the bare and clean surfaces of a relatively hydrophilic material—such as stainless steel; whereas the pits and depressions, representative of the non-wettable portions are filled with a hydrophobic material such as an epoxy plastic resin, which exhibits a lack of affinity for water. For other liquids such as petroleum or liquid oxygen the wettable area might be a thin coating of plastic on the original metal surface and the non-wettable spots might be holes in the plastic coating which expose the original metal.

Thus, here the term "non-wettable" is utilized in the sense that the material has a high interfacial tension with the liquid under consideration and thus tends to repel such liquid in comparison to the remaining relatively homogeneous portions of the surface. The latter is comparatively "wetable" which can be characterized as hydrophilic or having a relatively strong affinity for the boiling fluid. It is thus a basic concept of my invention that the referred to boiling film heat transfer coefficient can be increased by providing such hydrophobic spots or indentations at which either nucleation of the vapor bubble is energetically rendered easier, or such spots or indentations may be considered those areas which, being non-wettable, will maintain and hold extremely small bubbles of vapor as permanent nuclei. It is recognized also that in

2

the concept of this invention it would be undesirable for the entire surface to act in the same fashion as the wettable portions thereof; it is the combination of a non-wettable or hydrophobic surface together with numerous wettable or hydrophilic spots therein which affords the basis for the increase in heat transfer efficiency referred to in the foregoing.

Hence, as indicated, the prepared surface of this invention may be considered as a heterogeneous surface—one consisting in major part of a wettable area having interspersed throughout a large number of points which are hydrophobic, non-wettable or lacking affinity for, e.g., water.

The foregoing in part is expressive of what is considered to be the underlying theory on the invention, to wit, that unusually high surface film heat transfer coefficients can be obtained if such a heterogeneous surface is prepared as the surface for the boiling of a given fluid. However, the foregoing explanation of theory in this regard as well as any following explanation of the underlying theory of operation of the invention are not intended to limit the scope thereof. In other words, these expressions of the underlying theory of the invention do not detract from the fact that a surface prepared in accordance with the method advanced by this invention does demonstrate an appreciably higher and more effective surface film heat transfer coefficient than has been heretofore contemplated by the prior art.

It is accordingly a primary object of the invention to provide a method of surface preparation which appreciably increases the over-all efficiency of heat transfer of that surface or, expressed somewhat differently, which substantially increases the higher boiling film heat transfer coefficient.

It is a further objective of the invention to provide a method of the type generally outlined in the foregoing whereby such treated surface is permanent or at least sufficiently permanent to retain its inherent characteristic of higher efficiency over a relatively longer period of industrial use without substantial deterioration.

It is a further objective of the invention to provide a surface treatment of the type under consideration which results in what might be termed a heterogeneous surface or one having a multitude of unlike portions, certain of which are readily wettable or hydrophilic and other portions of which are non-wettable or hydrophobic, the latter being the starting point for bubble nuclei and the latter also materially contributing to the rapid formation of the bubble, which in turn is the primary requisite for rapid and efficient boiling.

It is another object of the invention to provide a method of this described type wherein various mechanical, chemical or electrical, or thermal operations may be employed to achieve the ultimate desiderata, that is, a surface in which the larger part is wettable but which in the lesser part is non-wettable, all to the end that bubble nucleation and ultimate bubble growth is materially increased in a sense of more rapid formation of the bubbles as the first step in the phenomena of a boiling of liquids. The method may or may not involve first the production of pits which provide both a means of locating the non-wettable spots and also provides protection for the non-wettable spots, from, for example, mechanical cleaning and descaling of the surface.

The following explanation of the invention is made in conjunction with certain diagrammatic or illustrative drawings with respect thereto, wherein:

FIGURE 1 illustrates diagrammatically a bubble formed upon a surface which is well wetted or hydrophilic in nature;

FIGURE 2 illustrates diagrammatically how the same bubble would be formed upon a comparatively non-wet-

3

table solid surface or one substantially hydrophobic, indicating, in comparison with FIGURE 1, that here the bubble is a segment of a sphere having an increased radius of curvature;

FIGURE 2a diagrammatically shows the growth of the bubble shown in FIGURE 2, on a surface which is poorly wet in its entirety, again demonstrating its retention of the semi-spherical shape;

FIGURE 2b diagrammatically indicates the growth of the bubble nuclei as shown in FIGURE 2 and is intended to graphically show the rapid development of this nuclei to a large bubble, spherical in shape where such poorly wet area as shown in FIGURE 2 is surrounded by a wettable surface;

FIGURE 3 diagrammatically illustrates the formation of bubble nuclei at the point where the surface has been pitted with a microscopic or near-microscopic indentation, and such indentation filled with a relatively hydrophobic material; and

FIGURE 4 is a comparative graph demonstrating the substantially increased surface film heat transfer coefficients obtained through practice of the instant invention, in comparison with the substantially lower heat transfer coefficients of surfaces not so prepared.

As indicated in the foregoing, the related objectives of the invention may be partially realized by merely rendering the surface more heterogeneous with regard to wettability. More exactly, such a prepared surface is considered to be heterogeneous having regard to the reaction of respective portions thereof to interfacial tension, the latter usually being indicated in computations involving the phenomena by the symbol γ . The variable factor γ may be considered as the arbitrary indicia of the comparative "wettability" or relative hydrophilic nature of a given surface. With respect to the instant invention, it is considered that larger effects or greater heat transfer coefficients can be obtained or influenced by the following factors:

Firstly, providing a surface where there are more extreme differences, or maximum amount of difference, in wettability as to different sections of that surface; i.e., some sections of the total area of the surface are definitely hydrophobic whereas other sections thereof are definitely hydrophilic; secondly, having these respective sections of area of very minute size—the wettable portions thereof as well as the non-wettable portions thereof being microscopic or near-microscopic in size and thoroughly inter-mixed throughout the total area; and thirdly, having in mind that such sections are not only extremely small as just described, but provide a surface where the total area of the hydrophilic sections exceeds the total area of the hydrophobic portions of the given surface. The optimum area for each individual hydrophobic spot or pit and possibly the optimum ratio of hydrophobic to hydrophilic area will depend on the design operating conditions of ΔT , pressure, and liquid.

With regard to the most ideal, prepared surface which will be obtained if these factors just recited are used as a guide, it must of course be acknowledged that all surfaces are heterogeneous to some extent, i.e., it is a practical impossibility to have a given metallic surface so clean or so unembellished that the same may be considered of perfect homogeneity. However, what is being dealt with here is heterogeneity as a relative term—the ideal surface being one which is hydrophilic throughout certain areas to the fullest practical extent and hydrophobic throughout other areas to the fullest practical extent, although in lesser total amount than the hydrophilic areas.

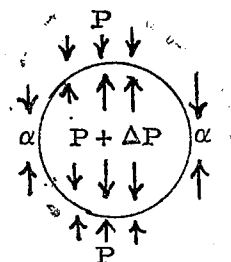
It is of course elemental that the boiling of a liquid on a metal surface requires that bubbles of vapor be formed in the liquid or between the liquid and metal surfaces. At times and locations where vapor is not being produced, boiling is not taking place and the heat transfer rates, or the heat transfer coefficients are low. Each

4

bubble of vapor necessarily germinates as a very small bubble, i.e., with dimensions of a magnitude not much greater than that of the molecular dimensions themselves. It is considered that there is an excess of energy required for bubble formation that becomes much greater with regard to the smaller bubbles; thus the formation of the small bubbles represents a major energy barrier to boiling. It follows that the frequency of bubble formation, and as a consequence the rate of heat transfer, during boiling, depends very greatly upon the magnitude of such energy barrier.

The required excess energy is consequent upon the involved surface tension which represents a uniform pull on the surface of a pure liquid which tries to reduce that surface to a minimum; surface tension has been defined as that property, due to molecular functions, which exists in the surface film of all liquids and tends to bring the contained volume into a form having the least superficial area.

Referring to FIGURE 1, a spherical bubble 15 is shown. The counterbalanced forces exerted upon this bubble include the following: firstly the pressure P of the liquid upon the projected areas of the upper and lower hemispheres of the bubble tending to push these two hemispheres together; secondly, the pressure $P + \Delta P$ of the vapor tending to push the two hemispheres apart; and thirdly, the surface tension, α , acting around the circumference of contact by the two hemispheres and tending to pull the two hemispheres together. Since the sum of forces in the vertical direction must be zero we may write the following equations:



$$\Delta P(\pi r^2) = \alpha(2\pi r)$$

$$\Delta P = 2\alpha/r$$

where r = the radius of the sphere. Similarly the excess work required for the production of a bubble of any size over that required to produce vapor is given by the following equations:

$$W = \int_0^V P dV$$

$$= 4\pi \int_0^r P r^2 dr$$

$$\Delta W = \int_0^V \Delta P dV$$

$$= 8\pi \alpha \int_0^r r dr$$

$$= 4\pi \alpha r^2$$

If this is divided by the volume to obtain the additional work per unit volume one obtains:

$$V = 4/3 \pi r^3$$

$$\Delta W/V = 3\alpha/r$$

For example, a bubble of 50A. radius has an additional work term several times as great as the heat of vaporization itself, thus making the formation of bubbles of 50A. or less energetically very unfavorable.

It has been determined that the excess energy required for small bubble formation or nucleation thereof at the interface of a liquid with the solid surface is greatly affected by the properties of the involved solid. If the solid surface, as that shown at 10, is well wetted (i.e., zero contact angle) any bubble formed will have a shape more nearly that depicted in FIGURE 1 at 15. If on the other hand, the surface of the solid 10 has not been well wetted by the liquid (i.e., a large contact angle) a bubble of the same volume will approximate the shape as shown in FIGURE 2, here designated at 16, and as a

result will exhibit a much larger radius of curvature and therefore also, a greatly reduced excess pressure and/or excess work of formation. The pattern of continuous increase in size of such a bubble 16 as it is formed upon a non-wettable or hydrophobic surface is diagrammatically indicated in FIGURE 2a where such bubble gradually increases to the dotted line dimension 17 and then further increases to the dotted line dimension 18, in both instances the bubble retaining this characteristic semi-hemispherical shape.

However, if the hydrophobic material is confined to a small spot on a hydrophilic surface, as is contemplated by this invention, then the bubble quickly reverts to spherical shape. This is diagrammatically illustrated in FIGURE 2b. Here the non-wettable spot 20 surrounded by wettable surface 10 is shown many times enlarged from the actual size. Such will reduce the radius of curvature to a substantial and significant degree and thus the excess pressure and work by an even greater extent.

Once such a bubble 25 as has been formed on this infinitesimally small area, it tends to grow very rapidly, absorbing heat from the surrounding liquid and solid as illustrated in FIGURE 2b. Here the initial semi-hemispherical shape of the bubble 25 quickly assumes the spherical shape indicated in dotted line at 26 and also quite quickly expands to a bubble formation 27 many times the diameter of the initial formation.

During this phase of bubble formation, it is undesirable to have the entire heat transfer surface, i.e., the metal surface, poorly wetted or hydrophobic throughout, for if it does exhibit hydrophobic qualities the vapor is likely to blanket the solid surface rather than to be disengaged from the surface when a bubble of sufficient size is obtained. Furthermore a blanketing of a surface with a vapor prevents effective transfer of heat to the liquid as would be necessary to continue the boiling.

Thus the unique concept of the instant invention which fully recognizes and takes into account the difficulty of bubble formation upon a relatively homogeneous surface which is substantially non-wettable throughout its entirety—that to attain high heat transfer rates or high heat transfer coefficients during the process of boiling it is essential that the bubble of vapor be first formed on a surface that is poorly wetted (hydrophobic), and equally significant, that such bubble be permitted to grow on a surface that is well wetted (hydrophilic) by the liquid being boiled. The answer to this problem propounded by this invention is, as indicated in the foregoing, to therefore provide a mixed or heterogeneous surface, part of which is poorly wetted or hydrophobic in nature, and part of which is well wetted or substantially hydrophilic and therefore suitable for heat transfer to the liquid as well as fully effective for bubble growth and disengagement, it being also considered that there be a greater proportion of the total wettable surface.

From the foregoing, it will thus be appreciated that the desired objectives of increased heat transfer are achieved by adding or developing small spots of hydrophobic material to a hydrophilic surface so that each spot is surrounded by a hydrophilic area which can be utilized in the heat transfer effect of the bubble, and preferably, in the practice of the invention, such spots or indentations are visualized, as in FIGURE 3, as providing an approximately rounded or concavo-convex shape.

Alternate methods may be used to obtain this surface effect, i.e., the creation or amplification of the existing heterogeneity of the surface, as by chemical, mechanical, electrical, acoustical, thermal, or other methods of modifying the surface which should be apparent to those skilled in the art with the understanding of this invention before them. The desired heterogeneity can be obtained by adding either the hydrophobic material to a hydrophilic surface, or vice versa, to create the spots. For example, a hydrophobic plastic could be dissolved in a solvent not wetting the heat transfer surface, and this solution dis-

solved in a much larger quantity of more volatile solvent which wets the metal surface; said final solution comprising a dip for the metal surface; resulting initially in a film of solution spread evenly over the surface, which on evaporation of the metal wetting solvent would collect into small droplets of non-wetting solution, and which on further evaporation would leave the desired minute areas of hydrophobic plastic. The reverse would be (for petroleum distillation), the deposition of a very thin layer of petroleum wettable plastic into which colloidal particles of wet salt had been mixed, which on treatment with water would dissolve, leaving holes in the plastic, to a non-wettable metal surface. For either type of surface, ultrasonics could be used to emulsify two liquids or a liquid and a solid and, for that matter, to place the suspended solid or liquid in a pattern determined by the nodes of standing waves. Heat treatment could be used to create non-wettable intrusions in the surface or to enhance the diffusion of such inorganic intrusions to the surface. An electrically charged mist of an appropriate solution could be caused to settle on the metal surface as small droplets which might either deposit a non-wettable residue or might, on the other hand, react chemically with the surface to produce a non-wettable material. These examples could be extended indefinitely.

A very important subclass of treatment would be to use chemical, mechanical, electrical, acoustical, thermal, or other methods of creating impressions in the surface followed by or accompanied by the intrusion of the non-wettable substance in the depression. As indicated, these depressions or pits may be obtained chemically through application of suitable chemical reagents. They may be created mechanically, as by light sand-blasting, surface to surface contact with appropriate rough surface, ultrasonic cavitation, etc. Electrical means may also be utilized wherein such methods as sparking, electro-chemical pitting, plating, etc., are appropriate. In short, any method of producing a pitted surface might serve as a first step in the production of the desired heterogeneous surface.

In initial experimentations, the surface of stainless steel strips were first treated to create this type of mixed wettable and non-wettable surfaces by chemical pitting. The surface was then coated with an epoxy plastic, and then polished to remove most of the plastic. Metal strips treated in this manner were then placed in an appropriate test apparatus, electrically heated to boil water, and then the boiling film heat transfer coefficient determined by usual and known computing methods. In one case, a value greater than 4000 B.t.u./hr./ft²/° F. at ΔT (the temperature differential) of 2° F. was obtained. With respect to this initial type of test, it was found that uncoated or untreated stainless steel strips, measured for a heat transfer coefficient in the same general manner as just outlined were termed to have a value of no greater than from about 200 to 500 at this same ΔT (2° F.).

Prior to reference to the specific examples which follow, it is to be understood that the general procedure utilized comprises the following: surfaces having both water wettable and water non-wettable regions as are necessary for the desired high boiling film coefficients are prepared by first pitting metal samples, coating the entire surface with water repellent plastic, and finally scraping the plastic from the surface. This procedure of necessity leaves some plastic remaining in the pits or depressions but no plastic over the majority of the surface.

The following specific examples of the practice of the invention are representative:

Example I

In this practice of the invention a stainless steel strip was treated in accordance with the method generally outlined in the foregoing. Here the pitting of the strip was accomplished chemically by the following treatment:

The strip was subjected to acid etching by immersion thereof in a body of hot sulphuric acid (H₂SO₄) maintained at a temperature of about 80° C. Although immer-

sion here continued for a period of about 7 minutes, other experimentations or runs indicate that the time of acid treatment would preferably fall within the range of from 5 to 10 minutes. The strip was then washed with water. Following this washing step the strip was transferred to a dilute solution of ferric chloride in water and permitted to remain in the latter solution for a period of about 10 minutes. Each of the reagents (sulphuric acid and ferric chloride) accomplished the required pitting by dissolving a part of the metal.

Approximate examination revealed that the surface of the strip, by reason of the foregoing treatment, had been pitted throughout its entirety with minute yet at least microscopically discernible depressions or indentations.

The strip was then subjected to a coating with a non-wettable substance, in this instance, a non-polar resin. Specifically, the latter comprised an epoxy resin sold on the market as "Epon 828," produced by the Shell Oil Company.

Such epoxy resin was mixed with diethylene triamine, as a hardener, in a ratio of ten parts of resin to one part of the hardener. The resultant solution was also thinned with a solvent, methyl ethyl ketone. This solution was then brushed onto the sample.

The resin was then allowed to cure for 24 hours at room temperature. After the resin had cured the surface of the strip was sanded lightly with a fine emery cloth to remove the resin adhering to the flat surface while leaving the resin in the pits or indentations created by the chemical pitting procedure described in the foregoing.

Whether or not such sanding procedure or other abrasive method was adequate for the purpose of removing the cured resin on the surface of the plate was determined by placing a drop of water on such surface, for if the latter were generally wettable the water droplet would spread over the surface, indicating adequate abrasive treatment; if too much plastic remained on the surface the droplet would not spread indicating that the non-wettable coating, in this instance the epoxy resin, had not been sufficiently removed from the surface.

In any event, in the instant practice of the invention such test indicated sufficient removal by spreading of the droplet on the wettable or sanded portion of the surface.

This sanding or abrasive treatment, as stated, removed the non-wettable coating from the surface of the plate but did not remove the same from the pits previously formed; hence these pits presented numerous wettable spots or indentations suitable for the creation of bubble nuclei, as described in the foregoing.

After sanding, the plate was well washed with soap and water before testing in an appropriate boiling apparatus.

By way of comparison, a similar stainless steel strip was sanded to the same extent as the treated plate and also well washed with soap and water before being submitted to the boiling procedure.

During the boiling step of each strip, one treated and one untreated, the heat transfer coefficient of each was determined by known measuring instrumentation and by appropriate methods of calculation known to those skilled in the art.

The resultant calculations are graphed in FIGURE 4. Here it is seen that the treated strip prepared in accordance with this example exhibited a heat transfer coefficient, at a temperature difference of about 1.5° F., somewhat in excess of 2000. In comparison the untreated strip at this same temperature differential (1.5° F.) exhibited a heat transfer coefficient of only about 270. In other words, at this ΔT the treated strip exhibited a heat transfer coefficient some 1700 units in excess of the untreated strip, or a most significant increase in heat transfer efficiency over the untreated strip of about 740%.

At higher ΔT 's it appeared that although the gap narrowed somewhat between the treated and untreated strip the increase in heat transfer efficiency of the former

still remained most significant. Referring again to FIGURE 4 it is seen that at a temperature difference of 10° the untreated strip exhibited only a heat transfer coefficient of about 900, whereas at this same differential the treated strip exhibited a boiling film heat transfer coefficient of about 2500, or a most substantial difference of about 1600 units.

Thus, as clearly demonstrated in FIGURE 4, the treated metallic surface of the instant invention exhibited a dramatic increase in efficiency of heat transfer over the same type of metal in its untreated state.

Example II

In this practice of the invention the main point of difference over the procedure utilized in Example I resided in the manner of pitting or forming the indentations in the metallic strip—here again a stainless steel surface. Here the pitting was accomplished mechanically.

A sandwich was made comprising a piece of sandpaper between two metal strips with the sample to be prepared in contact with the grit side of the sandpaper.

This composite lamination was then hammered upon one side to drive the grit into the sample at many various and random points. The result was to produce a great number of minute indentations or pits into the surface of the strip undergoing treatment.

The strip was then thoroughly washed in soap and water and after being dried the same solution as used in Example I was applied, i.e., the "Epon 828" epoxy resin, hardener (diethylene triamine) and an appropriate solvent, methyl ethyl ketone, in the proportions there stated.

After curing this resin coating for 24 hours at room temperature the strip was sanded lightly, as before, with fine emery cloth and then the plate was again well washed with soap and water before testing.

The strip was then immersed in a water solution, the water brought to boil and the heat transfer coefficient of the treated piece then determined.

As in Example I a comparable strip of stainless steel was also tested. This latter strip remained untreated except that its surface was thoroughly cleaned prior to immersion in the boiling chamber. The heat transfer coefficient of this untreated strip was then similarly calculated.

The result of the respective calculations of the boiling film heat transfer coefficients of the treated and untreated materials are also graphically recorded in FIGURE 4. Such results were similar to those obtained with respect to Example I.

As seen in this figure at a ΔT or temperature difference of about 1.5° F. the untreated sample exhibited a heat transfer coefficient of about 350. In sharp contrast to this, the treated sample at the same ΔT exhibited a heat transfer coefficient somewhat in excess of 2000.

The increase in heat transfer efficiency between treated and untreated products thus amounted to about 570%.

Although this percentage of increased efficiency diminished somewhat as the ΔT increased, the advantages of the instant invention are still readily apparent at such higher temperature differentials. For example at this temperature difference of 10° F. the untreated sample exhibited a heat transfer coefficient of about 825; whereas at the same ΔT the temperature coefficient of the treated sample was demonstrated to be about 2700 units or approximately 1875 units more than the untreated material.

FIGURE 4 also graphs the comparative results between the prepared surfaces of Examples I and II with results obtainable from a stainless steel surface to which has been applied an oily film. Any type of mineral or vegetable oil may be used as a coating for such surface, the result being to render such surface comparatively more "non-wettable" or more hydrophobic. The intermediate graph line represents the heat transfer coefficients obtained from test measurements made with respect to such an oil surface.

It will be noted that an oil surface shows a more rapid rise in heat transfer than a clean reference sample and that at the higher temperature differences, its coefficient approached that of the prepared surfaces of Examples I and II. It should be recognized, however, that such surface, if uniformly relatively non-wettable, will revert to film boiling and consequent very poor heat transfer coefficient at a ΔT not much greater than those measured, while the prepared samples would be expected to operate efficiently up to temperature differences of the order of 50°. If, on the other hand, the oil has collected into localized areas, then the surface comes under the scope of this invention. In this case, however, it should be recognized that such application of heat upon one side, the continued formation of bubbles during the boiling phase on the other side, will quickly dissipate the oil from the surface. Hence any increase in efficiency which might be developed as the result of an oily surface does not answer the involved problem—being temporary in nature such surfaces are impractical for any type of contemplated industrial usage. In comparison, the surfaces obtainable through practice of the instant invention are permanent and durable and do obtain a vast increase in the efficiency of heat transfer, particularly at the lower temperature differentials of below 10° F.

It should of course be apparent that there are many alternate methods which may be utilized to prepare the heat transfer surface herein described. These have been indicated. At any rate the important considerations of the invention revolve about the preparation of such surface in such manner that the respective areas, hydrophilic or hydrophobic, are extremely minute and of near-microscopic size. This is particularly true with respect to the hydrophobic areas which represent the starting point or nuclei forming areas for the initial small bubbles created during the boiling procedure. It is also important that the hydrophilic areas be at least as large as the non-wettable spots, and preferably that the total area of the wettable portion of the surface be in excess of the total area of nuclei formation. This is because the formation of the bubble itself begins with an extremely small, near-microscopic area, but the desire is to have adjacent to that nuclei forming point a somewhat larger area for growth of the bubble. If the growth area is wettable the bubble grows more rapidly, is completed more rapidly and disengages itself more quickly. The result is then an acceleration of the boiling process or stated differently, an achievement of an increase in the boiling film heat transfer coefficient of the material so treated.

Only one specific plastic coating substance has been referred to in the foregoing examples as suitable material for rendering the spots or indentations non-wettable or hydrophobic. It is obvious, however, that many other organic resins and inorganic compounds may be utilized for this purpose. Those skilled in the art will be able to choose such coating materials as are thus adaptable, once understanding that the coating in the procedure outlined in Examples I and II must, firstly, be hydrophobic or relatively non-wettable, must exhibit the quality of relative permanence during long periods of industrial usage, and must be effective despite an extreme thinness of application which may be, for example, in the order of from .00001 inch to .0005 inch.

The use of the treated material and particularly of a metal so treated, such as steel, iron, brass, copper, etc.,

should also be readily apparent. Increase in heat transfer efficiency has been a problem confronting many industries and hence any one of these metals treated in accordance with this invention would be most desirable for use in, for example, boiler tubes, heat exchangers, evaporators, or in any kindred industrial appliance where efficient boiling film heat transfer is always of great importance.

I claim:

1. A wall-like heat transfer element adapted for use between a heat source and a boiling fluid, one side of said element being adapted to face said fluid, said one side having a multitude of interspersed, minute and near-microscopic adjacent areas, the majority of said areas being of wettable characteristic, the minority of said areas being of non-wettable characteristic, whereby the boiling film heat transfer coefficient of said element is substantially increased.

2. A heat transfer material as defined in claim 1 wherein said areas of non-wettable characteristic comprise indentations in said wall filled with an epoxy resin of non-wettable characteristic, and said wettable areas and said element are of metal.

3. A heat transfer material as defined in claim 1 wherein said element is made of a metal taken from the group consisting of iron, steel, brass, copper and aluminum.

4. A method for treating a wall of a metallic heat transfer element to increase the boiling film heat transfer coefficient thereof when said surface is in contact with a boiling fluid, said method comprising forming a plurality of hydrophilic areas on the surface of said wall, forming a plurality of hydrophobic areas on said wall interspersed throughout said hydrophilic areas, said hydrophilic and hydrophobic areas being microscopic or near-microscopic in size, said hydrophobic areas providing bubble nuclei forming points for a boiling fluid, said hydrophilic areas providing bubble growth areas for said bubble nuclei.

5. A wall-like heat transfer element adapted for use between a heat source and a boiling fluid, one side of said element being adapted to face said fluid, said one side having a multitude of interspersed, minute and near-microscopic adjacent areas, the majority of said areas being of wettable characteristic, the minority of said areas being of non-wettable characteristic, said minority of said areas providing locations for bubble nuclei formation, said majority of said areas providing locations for rapid bubble growth and disengagement thereof, whereby the boiling film heat transfer coefficient of said element is substantially increased.

References Cited by the Examiner

UNITED STATES PATENTS

2,919,115	12/59	Vaaler	165—133
2,995,462	8/61	Mitchell	117—8
3,016,293	1/62	Cybsiwsky	117—8
3,053,511	9/62	Godfrey	165—133

OTHER REFERENCES

Sato: Science Reports, vol. XXI, No. 4, December 1932, Q77 S41 (pp. 564—576).

Jakob: Heat Transfer, vol. I, New York, John Wiley and Sons, 1949, QC 320 J3 V. 1 (p. 622).

CHARLES SUKALO, *Primary Examiner*.