

[54] **METHOD FOR PRODUCING A HEAT EXCHANGER ELEMENT**

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[58] Field of Search..... **204/16, 181, 23-27; 165/133**

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[57] **ABSTRACT**

Heat exchanger element having a porous layer electro-deposited thereon from an electrodeposition solution containing finely divided electroconductive particles and a source of the metal ions to be deposited, which element shows excellent performance characteristics and good workabilities.

9 Claims, 6 Drawing Figures

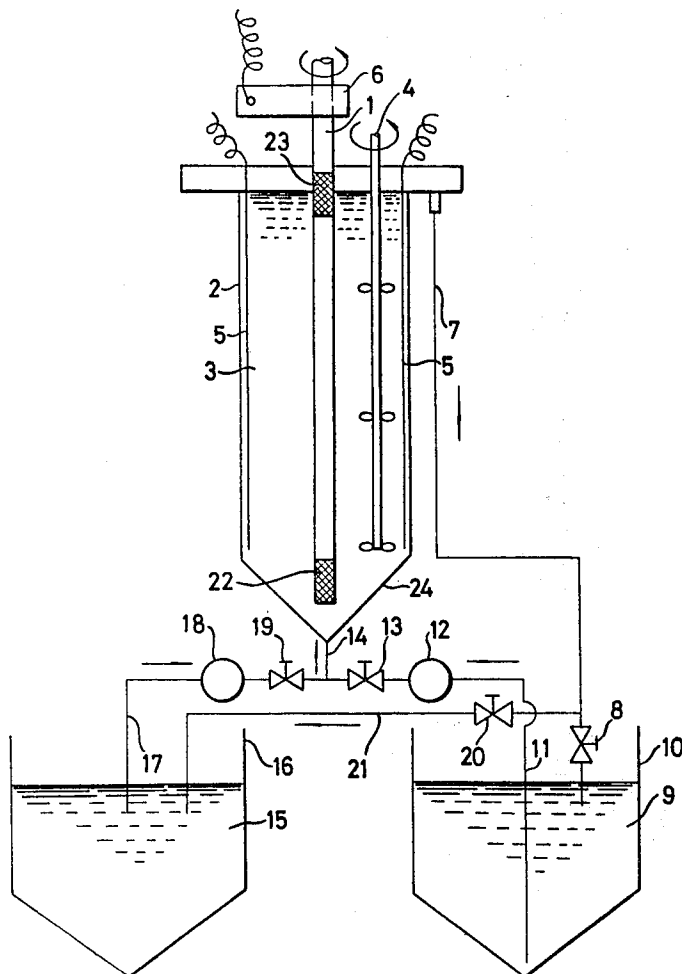


FIG. 1

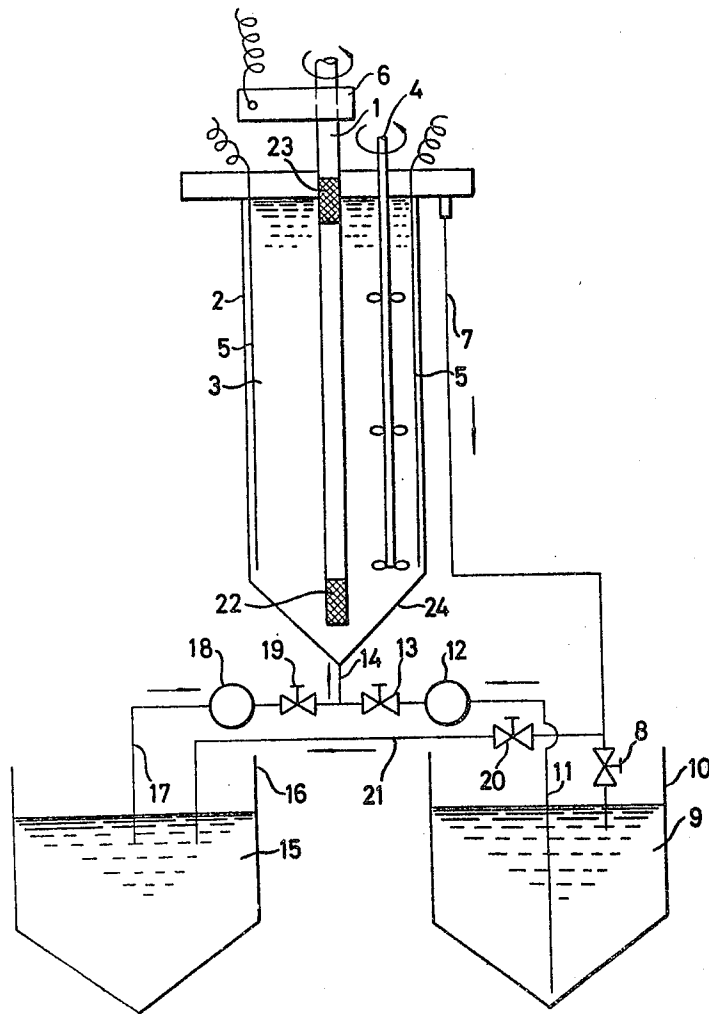


FIG. 2

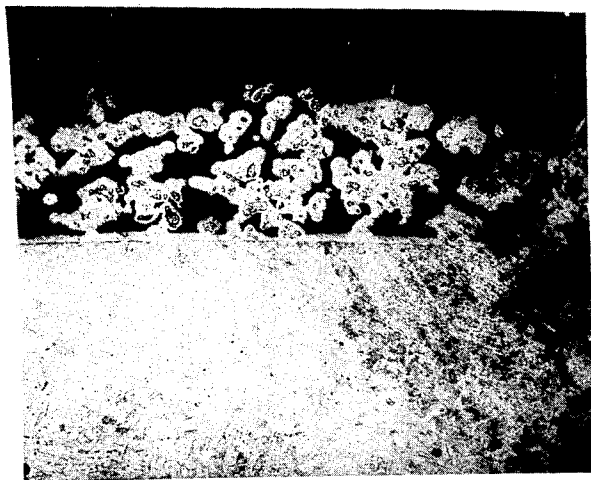


FIG. 4



FIG. 6

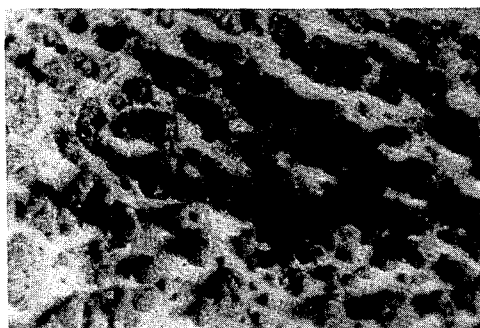


FIG.3

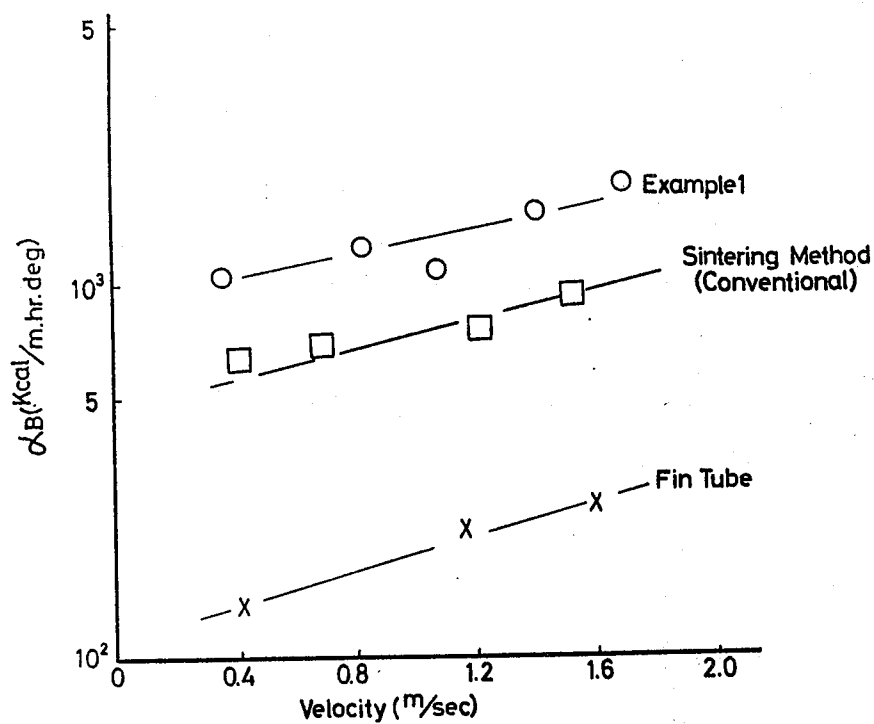
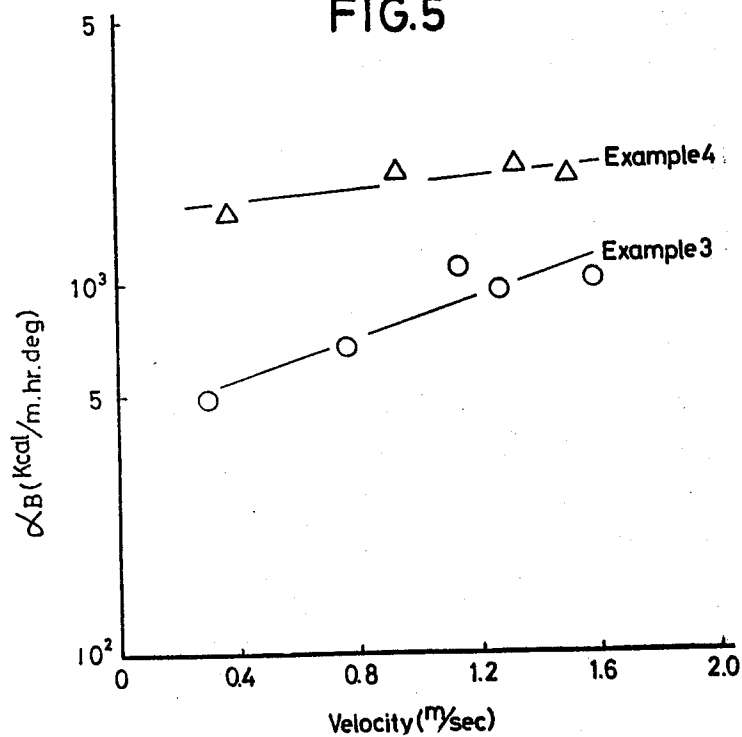


FIG.5



METHOD FOR PRODUCING A HEAT EXCHANGER ELEMENT

The present invention relates to an element for heat exchange purpose to heat or cool material by transferring heat energy and to a method of producing an improved heat exchanger element.

Heretofore the surface area of a heat exchanger element needed to be made as large as possible for conducting heat exchange effectively at high speed. Therefore such tubes for heat exchanger having a number of fins provided on the surfaces thereof are widely used, as well as tubes having a number of spikes, instead of said fins, provided on the surfaces thereof.

However, there has recently been required a heat exchanger element with larger surface area for the purpose of a heat exchanger utilizing nucleous boiling phenomenon and so on. For the requirement, a heat exchanger element having a thin porous metal layer formed on the surface thereof has been proposed instead of the above-mentioned fins or spikes. Such tubes or the like having a metallic porous layer formed in a thickness of several hundred micrometers on their surfaces by sintering method in powder metallurgy with or without use of soldering material, have begun to be used in an evaporator type refrigerator and a liquid vaporizing equipment.

These conventional heat exchanger elements and sintering methods thereof have the following disadvantages.

1. Metallic material of tubes or the like is softened by long treatment at a high temperature, so that its mechanical strength is lowered.

2. Because of a sintering phenomenon at a high temperature in which surface energy is lowered, the surface area shrinks, thereby lowering the speed of heat exchange.

3. Because the sintering method requires a long heat treatment at a high temperature and in a nonoxidizing atmosphere, it calls for costly equipment and high expenses.

The present invention is intended to eliminate said disadvantages of conventional heat exchanger elements and their methods, and is to provide a heat exchanger element with high performance characteristics which can be produced using inexpensive raw materials by an electrodeposition method at such a low temperature as ambient temperature or near room temperature.

That is, a strong porous layer with large surface area is formed by electrodeposition treatment in a metal-electrodepositing solution containing a source of the metal ions which are to be deposited and suspended finely divided electroconductive particles, with the substrate for the heat exchanger surfaces being connected as the cathode.

First, the metal electrodepositing solution used in the present invention consists of any finely divided metal particles such as copper, nickel, silver, iron, tin or alloy thereof, and a source of any metal ions which are to be deposited. Further, such semi-conductive substance as sulphides or celenides, etc. may be used as said particles in present invention as long as they are electrically conductive. And their particle size is limited to 0.5 to 500 μ , preferably 10 to 100 μ , and the concentration of the particles contained in the solution is limited to 5 to 500 g/l, preferably to 40 to 200 g/l. When either the particle size exceeds 500 or the concentration exceeds

500 g/l, a stable suspension can not be obtained in practical manner, and thus such is not suitable. On the other hand when the concentration does not reach 5 g/l, the desired porous layer is difficult to be obtained, while when the particle size does not reach 0.5 μ , gaps in the porous layer formed become small, thereby preventing the movement of the heat medium which is important for heat exchange, and thus such are not suitable.

According to the present invention, there is no limitation as to the shape of finely divided electroconductive particles. In order to obtain a heat exchanger element having a strong and uniform porous layer, the finely divided particles of any shape (hereinafter referred to as irregular shaped particles) other than spherical are advantageously employed. This is because the particles in the present invention work as nuclei of crystal growth in electrodeposition of porous layer, the more complicated projections the irregular shape particles have the more porous, electrodeposited layer obtained, resulting in developing electrodeposition in multiple directions. For example especially dendritic particles or spongy particles are desired. However, in order to obtain a heat exchanger element with a good agitating effect of fluid in contact with the heat exchange surfaces spherical shaped particles are suitably used, since they can form a number of porous projections. The particles in spherical shape or near spherical shape, being different from irregular shaped particles, cause electrodeposition preferentially at the direction of line of electric force, therefore such porous projections with the height of 0.05 mm or higher as necessary for the above-mentioned agitating effect can be easily formed on the surface of the heat exchanger element.

As the metal-electrodepositing solution, ordinary electrodeposition electrolyte for metal plating, electroforming, and refining, etc. for example various copper plating bath, nickel plating bath, silver plating bath, etc. can be employed, but is not necessarily limited to those. Out of various additives used in metal plating, etc., large amount of brightening agents prevent forming of porous layer, but certain kind of substance and a small amount of brightening agents advantageously affect formation of uniform and strong porous layer. For example, about 5 mg/l of thiourea will be effective for acidic copper sulphate bath containing in suspension electrolytic copper powder, but if such large amount of the same as several tens mg/l of them is added, an ordinary smooth and glossy metal plated surface is obtained, thus the object can not be achieved.

Out of electrolytic conditions, affecting the electrodeposited porous structure, there are cathode current density, bath temperature, and agitating condition. The more violently the bath is agitated, the more uniform and strong is the porous layer formed. While the current density and the bath temperature affect each other as in ordinary plating, higher current density and lower temperature than those in ordinary metal plating are desirable. The higher the current density and the lower the temperature, the more porous the layer obtained.

Since, as explained above the particles employed in the method of the present invention function as nuclei of crystal growth, the porous layer obtained consists of simultaneously deposited particles and electrodeposited metal. When the ratio in weight of the adhered particles to the electrodeposited metal is about one-third or less, especially when it is from 3/100 to 20/100, a

strong porous layer with large surface can be obtained. However when this ratio becomes larger than one-third it will have such fragile structure as not being practical. In this case, change of the solution composition or electrodeposition condition, for example lowering of the cathode current density, increasing of bath temperature, or addition of glue to the solution, etc. can effectively cause the ratio to lower, resulting in a strong and uniform porous layer. At the same time said object can be similarly achieved by effecting an electrodeposition treatment with suspension solution containing powder particles and an electrodeposition treatment with ordinary electrolytic solution not containing powder particles in a successive or an alternate manner.

As above-mentioned, when the ratio in weight of the particles in porous layer to the electrodeposited metal becomes one-third or more, said ratio can be lowered by adding to the solution glue, gelatine or hydrolyte of such additives. As they are apt to restrain the deposition of the particles, the amount of additives in this case is 1 to 500 mg/l, preferably 2 to 150 mg/l. When it is below 1 mg/l the above-mentioned effect can not be attained. On the other hand when it is over 500 mg/l the electrodeposited metal itself becomes hard and fragile.

Even when the electrodeposition is done in the suspension solution containing the particles and the above-mentioned ratio becomes one-third or more, thereby forming fragile porous layer, the ratio can be reduced down to less than one-third as a whole, by subsequently conducting ordinary metal plating treatment in the absence of any particles as a second step treatment.

When an excessively thick porous layer is formed in the first step treatment, the subsequent reinforcing metal can not be deposited in deep portions of the porous layer in the second step treatment. Therefore when thick porous layer needs to be obtained, it is necessary to repeat several times both of said treatments. When the metal plating in the second step treatment is done in too large quantity over that in the first step treatment, the porosity will be lost. Therefore, the ratio of a quantity of electricity employed in the second step to a quantity of electricity employed in the first step should preferably be in the range of 1/20 to 20 depending on the particle size used. It is also possible to adjust the degree of porosity by controlling said ratio.

In some cases it is effective in improving mechanical properties of the porous layer to carry out a heat treatment at or above a temperature at which the electrodeposited metal recrystallizes. This is because the contacting part between particles becomes large in sintering reaction and at a same time electrodeposition strain can be eliminated. Although its surface area is reduced to some extent, its flexibility is improved.

As has been explained above, the metal-electrodepositing solution employed in the present invention is nearly equal, apart from the solution containing suspended finely divided electroconductive particles, to any solution which is used for ordinary metal plating and electro-forming methods, and therefor according to the present invention, there can be used any equipment (power source, electrolysis tank, etc.) as employed in ordinary metal plating and electro-forming processes.

The substrate for heat exchange surface on which a porous layer is formed may be any electrically conductive metal surface; thus it may be in the form of a tube,

rod, plate, wire or a fabricated heat exchanger. Also also a heat exchanger element fixed with fins or spikes may be employed as the substrate, and consequently there is obtained a heat exchanger element fixed with fins or spikes on which a porous layer has been formed.

As raw material therefor, such metal as copper, copper alloy, aluminium, aluminium alloy, titanium, titanium alloy and other ordinary metal, further such non-metallic substances as plastics, etc. having electroconductive layer on its surface may be used. Said material has its clean surface exposed beforehand by degreasing, acid bath, etc., and in the case of aluminium, aluminium alloy, an ordinary pre-plating treatment (zincate treatment, bronze plating) is further given, and then said material is connected as the cathode in electrodeposition treatment in the present invention. The cathode should preferably be placed in rotating or reciprocating state, for example in the case of a tube the rotation with several r.p.m. to several hundred r.p.m. will be effective for formation of uniform porous layer. As an anode, in general, plate or particles both made of electrodeposited metal may be used but in some cases non-soluble anode may be used.

The speed of heat exchange depends on structure of porous layer or porous projections formed on the substrate, the layer or the projections serving as heat exchange surfaces, that is thickness of the layer (or height of the projections), degree of porosity, metal, and surface area, etc.

The thickness (or height) is affected not only by the quantity of electricity employed which can be expressed by the product of the current density by the electricity flowing time but also by all process conditions relating to the degree of porosity.

Especially the effect of the bath temperature and current density is large, and the lower the temperature and the higher the current density, the more porous and thicker is the layer obtained with a given quantity of electricity. Also the more irregular the shape of the particles, the more porous is the layer obtained. While the optimum structure of a porous layer varies depending on the condition of heat exchange, for example, kind of refrigerant and temperature difference between a refrigerant and heat exchange surfaces (degree of supersaturation), ordinarily the suitable thickness of the layer is from 0.05 to 2 mm. An excessively small thickness results in shortage in the surface area, on the other hand, an excessively large thickness causes and refrigerant bubbles not to flow smoothly and therefor in both cases the speed of heat exchange is lowered.

While it is difficult to clearly define the degree of porosity, larger degree of porosity is advantageous as long as mechanical strength is not impaired (concrete explanation shall be given to said relationship by example 2 below).

The porous layer according to the present invention, as compared with conventional sintering method, is characterised by delicately fine surface unevenness (roughness) which is peculiar to the surface of electrodeposition metal. This surface unevenness is considered to have an effect to promote generation of refrigerant bubbles.

On the other hand for independent porous projections formed by using spherical shape powder particles, the height is important. The projections less than 0.05 mm in height reduce the effect of increasing surface

area and of promoting turbulent flow, so that desired high speed of heat exchange can not be obtained.

As has been explained above, a heat exchanger element having porous layer with excellent mechanical strength and large surface area particularly useful for heat exchangers employing nucleus boiling phenomena can be easily produced at low cost by the present invention.

Now further concrete explanations will be given on examples of the present invention referring to the attached drawings.

FIG. 1 shows an outline of the apparatus used in one embodiment of the present invention.

FIG. 2 is a cross-sectional micro-photograph of a porous layer obtained by Example 1.

FIG. 3 shows results of actual measurement of nucleus boiling coefficient of the tube in Example 1.

FIG. 4 is a cross-sectional micro-photograph of the optimum porous layer in Example 2.

FIG. 5 shows results of actual measurements of the nucleus boiling coefficient of the tubes in Examples 3 and 4.

FIG. 6 is a photograph showing the appearance of the tube in Example 4.

EXAMPLE 1

FIG. 1 shows schematically the vertically cross-section of the apparatus to perform the method of the present invention. Valves 19 and 20 are shown to be in a closed state while a storage tank 15 is not used in this example. The pure copper tube which is a substrate of the porous layer obtained by the method of the present invention and works as a cathode is in rotatable state at about 30 r.p.m. by a motor which is electrically insulated from the tube, and is placed at a central position of an electrodeposition cell made of polyvinylchloride in a cylindrical shape with its lower end being in a funnel shape 24. The electrodeposition cell 2, contains metal-electrodepositing solution 3, and is provided with an electrically driven agitator 4, and an anode 5 consisting of copper plates along the inner walls of the electrodeposition cell, and the anode 5 is connected to the plus end of a direct current power source.

The tube 1 which works as a cathode is connected to the minus end of the direct current power source through a brush 6 positioned outside of the cell 2. The metal-electrodepositing solution 3 in the electrodeposition cell 2 overflows and pours into a storage tank 10 of the metal-electrodepositing solution 9, which contains in suspension electroconductive particle, through a pipe 7 and a valve 8. Said solution 9 flows from around the bottom of the storage tank through a pipe 11, a pump 12, a valve 13, a pipe 14, and goes into the electrodeposition cell 2 from the funnel shaped part 24 at the bottom of said cell, thus circulating through said route.

As pre-treatments of the tube 1 of pure copper which works as a cathode and has an outer diameter of 19.05 mm, a wall thickness of 1.0 mm, and a length of 1200 mm, the tube is degreased beforehand by trichloroethylene then immersed in an aqueous solution of nitric acid of 20 weight % for 30 seconds and then washed with water. The portion from the lower bottom up to 140 mm up from the bottom 22 is covered with insulating tape, further the portion of 1090 to 1100 mm as measured from the bottom end 23 is covered also with insulating tape, so that the center part of 950 mm

length is exposed for forming the intended porous layer. The metal-electrodepositing solution (3, 9) in the electrodeposition cell 2 and the storage tank 10 has the following composition:

Copper fluoborate	450 g/l
Hydrofluoboric acid	pH 0.3
Electrolytic copper powder (dendritic powder)	80 g/l
Thiourea	3 mg/l
Temperature	20°C

The electrolytic copper powder used is of average particle diameter of about 50μ passing through sieve of 100 mesh having irregular dendritic shape.

The solution (3, 9) is circulated by the pump 12 between the electrodeposition cell 2 in FIG. 1 and the storage tank 10 at a flow rate of 25 l/minute.

In the above method, when direct current of 85A, which is equivalent to the 15 A/dm² of cathode current density, was passed for 40 minutes, a uniform porous layer with a thickness of about 0.25 mm was formed. This layer was so strong that no copper powder was removed from the layer at all when rubbed violently by hand. Rings with 10 mm width were cut out of the thus obtained tube by cutting the same for the 10 mm from both upper and lower ends, and were placed in a vice then they were pushed and crashed completely to observe the bent portion. No peel-off was observed, thus good adhesion and workability were confirmed. A microscopic cross-sectional photograph ($\times 100$) is shown in FIG. 2.

A piece of the tube thus obtained was cut to a length of 910 mm and was attached to an experimental measuring device which copied an evaporator type heat exchanger which employs refrigerant R-11 (molecular formula CCl₃F), and the nucleus boiling coefficient (NBC) was measured. The method for said measurement was that the tube was retained horizontally and hot water of a constant flow volume V_h (m³/hr), a constant temperature ($t_{h1}=50.0^\circ\text{C}$) was flown through the tube and the outside of the tube was filled with R-11. While R-11 was boiled on the tube and condensed in a water cooler, the pressure then was held constantly at 0.5 kg/cm². The flowing amount of said hot water was regulated to between 0.2 to 1.5 m³/hr. and the temperature t_{h2} ($^\circ\text{C}$) of exit hot water was measured varying tube wall temperature. Thus heat quantity exchanger Q (Kcal/hr) was obtained.

$$Q = V_h \cdot \gamma_w \cdot Cp_w (t_{h1} - t_{h2})$$

γ_w : density of hot water (kg/m³)

Cp_w : specific heat at constant pressure (Kcal/kg.deg)

The tube wall temperature t_w ($^\circ\text{C}$) was an average value of the measured temperatures as measured by thermoelectric couples consisting of constantan of 0.3 mm diameter and a copper pipe buried and welded at the bottom of the porous layer, provided at a total of 9 places i.e. 3 places in the longitudinal direction of the tube and 3 places in the circumferential direction. The value of α_B (Kcal/m.hr.deg) of nucleus boiling coefficient per unit length of tube was calculated by the following formula using the saturation temperature t_s ($^\circ\text{C}$) of R-11.

$$\alpha_B = \frac{Q}{0.91 (t_w - t_s)}$$

As the α_B depends on the flow quantity V_h (m^3/hr) through the tube, thus depends on the difference between the saturation temperature t_s ($^{\circ}C$) and the tube wall temperature t_w ($^{\circ}C$), measurement was done at several spots within the scope of $V_h=0.15-1.5$ hr^3/hr . For comparison purpose a conventional copper tube with fins was also measured in a similar manner. The tube with fins had 16 fins per 25.4 mm length of the tube and a fin height of 1.48 mm.

FIG. 3 shows the results of such measurement. The product under the present invention shows the nucleus boiling coefficient of 0.7 to 1.6×10^3 Kcal/m.hr.deg which is about 8 times the value of the conventional fin tube.

Further, tubes on which a porous layer was formed by a sintering method were measured in a similar way. These tubes were produced by depositing almost spherical copper powder which passes through 200 mesh in a thickness of 0.30 mm on the same pure copper tube as in this example and by subjecting the thus obtained tube to heat treatment at $800^{\circ}C$.

FIG. 3 shows the results of measurement of NBC. Although these tubes show NBC of more than 3 times that of the fine tube, but show only about the half of that of the present example.

EXAMPLE 2

A similar tube as in Example 1 was treated in a similar manner in a similar electrodeposition equipment except that the metal-electrodepositing solution (3, 9) had following composition:

Industrial sulphuric acid	40 g/l
Industrial copper sulphate	60 g/l (Cu content)
Reduced copper powder (spongy)	40 g/l
Glue	45 mg/l

The reduced copper powder used was of commercially available spongy type with irregular shape with an average particle diameter of about 30μ passing through 100 mesh.

The electrodeposition condition was such that the quantity of electricity flowing is commonly set at $10A/hr/dm^2$, while the bath temperature and current density are set at following levels:

Bath temperature ($^{\circ}C$): 20, 35, 50
Current density (A/dm^2): 10, 20, 30, 40

From the tube with a porous layer thus obtained rings were cut out in a same manner as in the foregoing example, and were pushed and crashed to test its adhesion and at the same time its heat exchange characteristics were measured. The results thereof are shown in Table 1. The nucleus boiling coefficient was shown per unit area with such values (interpolated values) as in the case when the difference between the tube wall temperature and the saturation temperature of R-11 was $3^{\circ}C$.

Table 1

		NBC : $\times 10^4$ Kcal/ m^2 ·hr·deg			
		Adhesion : Good (O), Bad (X)			
Bath Temperature ($^{\circ}C$)		Current density (A/dm^2)			
		10	20	30	40
20	NBC	3.0	2.4	3.7	4.8
	Adhesion	O	O	X	X
35	NBC	—	2.8	3.6	3.4

Table 1-Continued

		NBC : $\times 10^4$ Kcal/ m^2 ·hr·deg			
		Adhesion : Good (O), Bad (X)			
Bath Temperature ($^{\circ}C$)		Current density (A/dm^2)			
		10	20	30	40
	Adhesion		O	O	X
50	NBC	—	—	2.2	3.2
	Adhesion			O	O

As the bath temperature is low and the current density is large, NBC increases. But, under the condition of excessively low temperature and high current density, the adhesion and workability lowers, thus there apparently exists the optimum condition. In this example it is $35^{\circ}C$, $30 A/dm^2$, wherein NBC is 3.6×10^4 Kcal/ m^2 ·hr·deg, and 2.04×10^4 Kcal/m.hr.deg per length. It shows about 15 times large value as compared with the conventional fin tube. This value is about 3 times larger than that of the tube produced by the sintering method referred to in Example 1. The microscopic cross-sectional photograph is shown in FIG. 4. It is derived from the results of the above table that the relationship between the current density (D_c A/dm^2) and the bath temperature ($T^{\circ}C$) which relationship affords the porous deposition with excellent adhesion will be approximately shown as:

$0.6T + 16 > D_c > 0.75T - 18$

EXAMPLE 3

In the same electrodeposition equipment as in the foregoing example, the anode 5 was replaced with nickel plate and the metal-electrodepositing solution had the following composition:

Nickel fluoborate (Commercially available for metal plating)	400 g/l
pH	2.2
Nickel powder	100 g/l
Temperature	$50^{\circ}C$

The nickel powder is commercially available electrolytic powder with average particle diameter of about 20μ passing through 250 mesh.

Direct current of 120 A which is equivalent to $20 A/dm^2$ was first passed for 3 minutes by the same procedure as in the foregoing example.

Next the passing of electricity was stopped and the pump 12 was stopped then the metal-electrodepositing solution 3 in the electrodeposition cell 2 was totally returned to the storage tank 10. Then the valves 13, 8 were closed while the valves 19, 20 were opened to operate the pump 18, thus the nickel-electrodepositing solution of the same conditions except that no nickel powder was contained, was contained in the storage tank 16, was sent to the electrodeposition cell 2, and was circulated at a speed of 25 l/min. The rotation of the agitator 4 and the pipe was same as before, and 90 A current which is equivalent to $10 A/dm^2$ was flown and electrodeposition was done for 4 minutes.

The above-mentioned electrodeposition operation with or without nickel powder was repeated for additional two times, thus for a total of 3 times. Thus a copper tube having on its surface a nickel porous layer with a thickness of 0.5 mm was obtained. Its adhesion and

workability were confirmed by a test conducted in the same manner as in the foregoing example. The nucleus boiling coefficient was shown in FIG. 5.

EXAMPLE 4

In the same equipment as in Example 3 a copper plate was used as an anode, and first the following metalelectrodepositing solution was circulated between the storage tank 10 and the electrodeposition cell 2 at speed of 25 l/min. (The length of the tube electrodeposited was 920 mm).

Industrial sulphuric acid	40 g/l
Industrial copper sulphate	80 g/l (Cu content)
Spherical shape copper powder	20 g/l
Glue	15 mg/l
Temperature	55°C

The spherical shape copper powder used therein was of commercially available type with an average particle diameter of 50 μ passing through 100 mesh produced by a special compressed gas spray method.

160 A Direct current electricity equivalent to 30 A/dm² was passed for 6 minutes to have copper projections electrodeposited on the entire tube surface immersed in the bath in a uniform manner with a diameter of a little less than 1 mm and a length of about 0.5 mm with an interval of about 1 mm.

Next the metal-electrodepositing solution containing in suspension copper powder was returned to the storage tank 10 by the same procedure as in the Example 3, then the solution in the storage tank 16 was circulated to the electrodepositing cell 2 by the pump 18.

Industrial sulphuric acid	40 g/l
Industrial copper sulphate	70 g/l (Cu content)
Glue	3 mg/l
Temperature	50°C

As the copper powder within the metal-electrodepositing solution in the foregoing example remained in a slight amount in the electrodepositing cell 2, the solution suction inlet from the storage tank 16 was provided as shown in FIG. 1 at a position a little higher than the tank bottom.

While the tube was rotated as in the foregoing example the metal-electrodepositing solution 3 within the electrodeposition cell 2 was agitated 4, electricity of 120 A was passed for 2 minutes.

Next, said metal-electrodepositing solution was removed and the first step metal-electrodepositing solution containing copper powder was brought in and circulated and the electrodeposition treatment was done for 15 minutes under the same condition as in the foregoing example. Then said solution containing copper powder was removed and the solution not containing copper powder was brought in and was circulated while electricity of 120 A was passed as in foregoing example for 1 minute.

By the above process a copper tube, having projections with a length of 2 to 3 mm, a diameter of about 1 mm were formed uniformly with intervals of about 1 mm along the entire length of the tube, was obtained. As the surface of this tube is observed in an enlargement by a microscope a number of holes are seen show-

ing that it is of porous nature. FIG. 6 is a photograph with 6.3 times enlargement. As the cross section of the projection was observed by a microscope with a magnification of 100 times, the electrodeposited copper completely encloses the copper powder as if a coral reef was expanded.

The nucleus boiling coefficient of this tube was measured in the same manner as in the foregoing example and the results are shown in FIG. 5. While the results are somewhat inferior to those in the optimum condition in Example 2, they show far better performance than that of a conventional fin pipe.

What is claimed is:

1. A method of producing a heat exchanger element having a porous surface layer containing electrodeposited metal and finely divided electroconductive particles, which comprises immersing a substrate for the heat exchange surfaces in a metal-electrodepositing solution containing a source of the metal ions which are to be deposited on the substrate and suspended finely divided electroconductive metal particles having an average particle size of about 0.5 to 500 microns in a concentration of 5 to 500 g/l, and creating a potential difference between the substrate, connected as the cathode, and an anode in the solution, under conditions satisfying the formula

$$0.6 T + 16 > D_c > 0.75 T - 18$$

wherein T is the temperature of the solution in °C and D_c is the cathode current density in A/dm² within the range of 10–40 A/dm², so as to deposit a mixture of the electroconductive metal particles and metal on the substrate in a weight ratio of particles to metal of not greater than 1:3 and form porous projections having a height of at least 0.05 mm on the substrate.

2. A method according to claim 1, wherein the finely divided electroconductive metal particles comprise irregular shaped powder.

3. A method according to claim 2, wherein the irregular shaped powder comprises dendritic powder or spongy powder.

4. A method according to claim 1, wherein electroconductive metal powder having spherical shape or substantially spherical shape is used as the finely divided electroconductive metal particles, thereby forming a porous layer having a number of porous projections.

5. A method of producing a heat exchanger element having a porous surface layer containing electrodeposited copper and finely divided electroconductive particles, which comprises immersing a substrate for heat exchange surfaces in a copper-electrodepositing solution containing a source of the copper ions which are to be deposited on the substrate, suspended finely divided electroconductive irregular-shaped metal particles having an average particle size of about 0.5 to 500 microns in a concentration of 5 to 500 g/l, and glue, gelatine or a hydrolyte thereof in a concentration of 1 to 500 mg/l, and creating a potential difference between the substrate, connected as the cathode, and an anode in the solution, under conditions satisfying the formula

$$0.6 T + 16 > D_c > 0.75 T - 18$$

wherein T is the temperature of the solution in °C and D_c is the cathode current density in A/dm² within the range of 10–40 A/dm², so as to deposit a mixture of the

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electroconductive particles and copper on the substrate in a weight ratio of particles to copper of not greater than 1:3 and form porous projections having a height of at least 0.05 mm on the substrate.

6. A method according to claim 5, wherein the copper-electrodepositing solution comprises such an amount of copper fluoborate sufficient to provide a copper content of 40 to 200 g/l and an amount of hydrofluoboric acid such that the pH of the solution is maintained in a range of 0.2 to 0.9.

7. A method according to claim 5, wherein the finely divided electroconductive irregular-shaped metal parti-

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cles comprise dendritic copper powder or spongy copper powder.

8. A method according to claim 7, wherein the finely divided electroconductive irregular-shaped metal particles are dendritic copper powder or spongy copper powder.

9. A method according to claim 5, wherein the electrodepositing solution is prepared using an amount of copper sulfate sufficient to provide a copper content of 40 to 100 g/l, and 5 to 200 g/l of sulphuric acid.

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