United States Patent

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[54] **HEAT EXCHANGE APPARATUS**
3 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **161/84, 165/95**
[51] **Int. Cl.** **F28d 11/06**
[50] **Field of Search** 165/1, 84, 86, 95, 55

[56] **References Cited**

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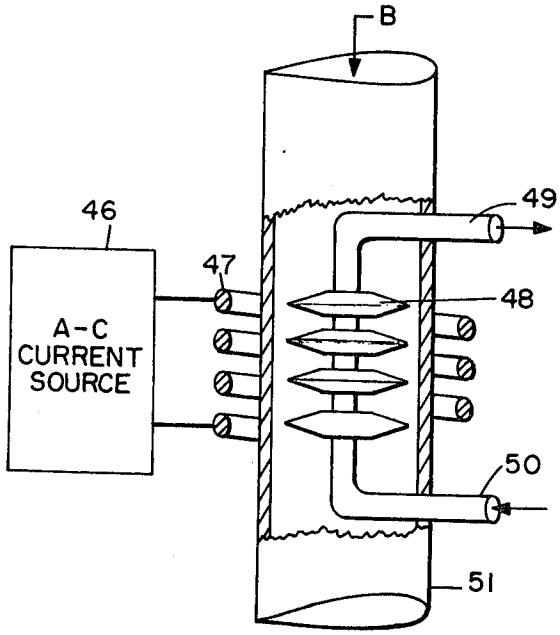
ABSTRACT: Heat exchange apparatus is disclosed in which the heat exchange surfaces are vibrated by electric eddy current means to enhance heat transfer between said surfaces and a medium.



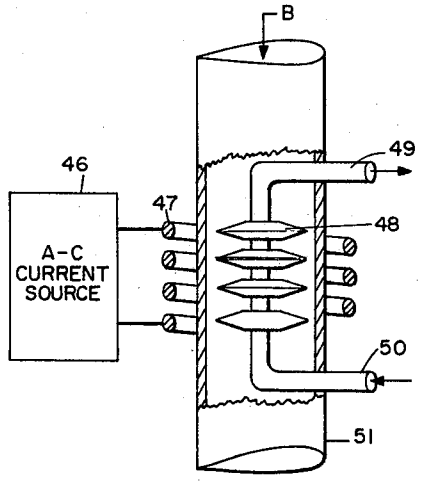


FIG. 1

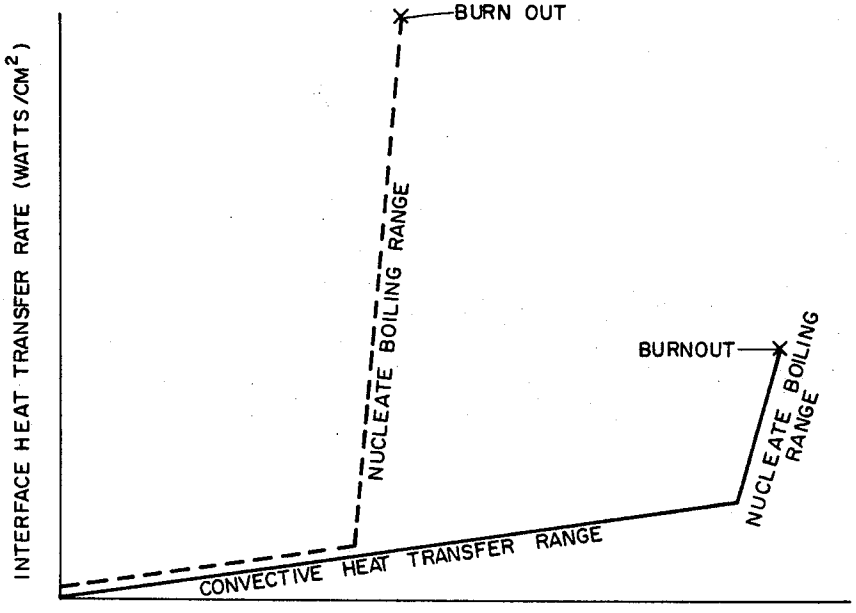


FIG. 2

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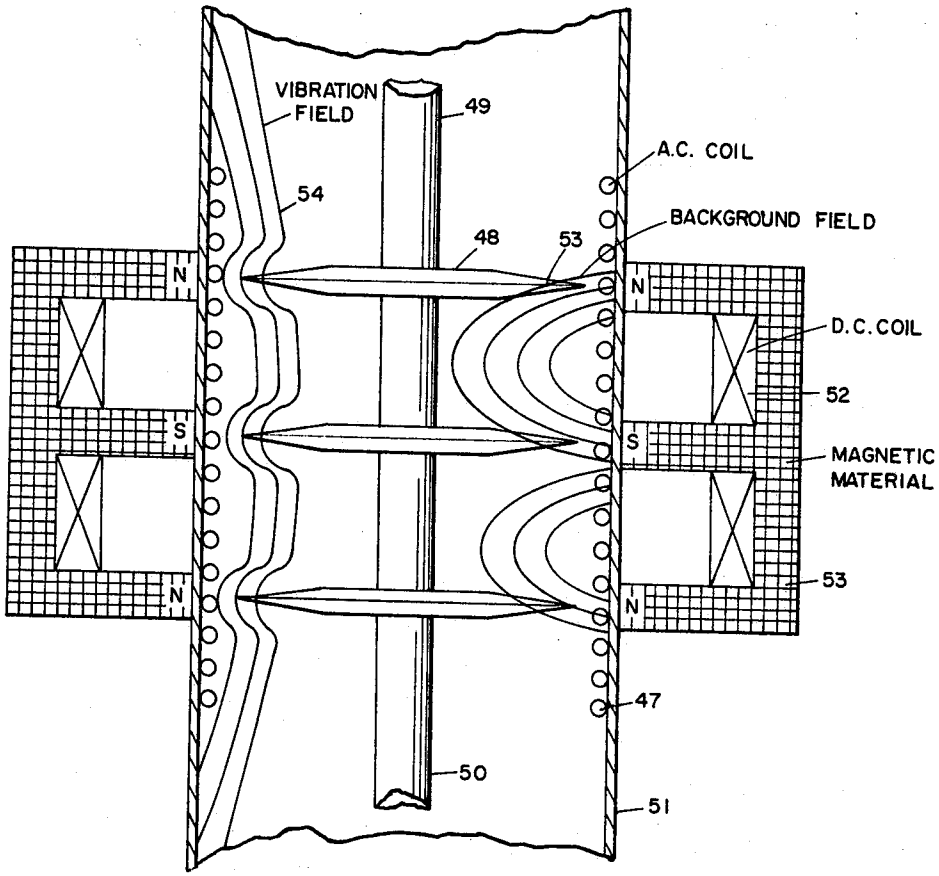

FIG. 3

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HEAT EXCHANGE APPARATUS

This is a continuation-in-part of application Ser. No. 761,048 filed on Sept. 20, 1968 in the name of the present inventor and is filed as a result of a requirement for restriction.

This invention was made in the course of work performed under a contract with the Air Force Office of Scientific Research.

The present invention relates to heat exchange apparatus wherein eddy currents are employed to enhance heat transfer.

In heat exchange apparatus, heat transfer between a solid liquid interface is substantially enhanced by the introduction of vibration at ultrasonic frequencies. Two mechanisms contribute to this enhancement: cavitation induces the onset of nucleate boiling at lower heat transfer rates, and ultrasonic energy prevents bubbles from growing to their normal size, thereby pushing the limit of film boiling and vapor blanketing, which results in total failure of heat transfer, to much higher heat flux rates. It has never been possible previously to introduce ultrasonic frequency vibration energy of sufficient intensity at the heat exchange interface of a practical device, because no mechanism has been available to transmit vibratory energy through the massive structure of such apparatus or the fluid without prohibitive attenuation. Accordingly, an object of the invention is to provide heat exchange apparatus in which eddy current means is used to effect vibration of the heat-transfer surface of heat exchange apparatus to effect break up of the stationary boundary layer that exists at the interface between the surface and the medium to which heat is transferred or from which heat is received, to induce the onset of bubbles below boiling temperature by local cavitation, and to prevent the normal growth of such bubbles and cause their premature disintegration.

Further objects are contained in the description to follow and are particularly pointed out in the appended claims.

By way of summary the objects of the invention are attained in a heat exchange apparatus in which the fins or other heat transfer elements of the apparatus are subjected to forces provided by electric eddy current means thereby to effect relative movement between the elements and a medium at the interface between the two to enhance heat transfer therebetween.

The invention will now be explained with reference to the accompanying drawing in which FIG. 1 is a schematic representation, partially cut away, of heat exchange apparatus including eddy current means adapted to vibrate the heat transfer surfaces thereof; FIG. 2 is a graph of heat transfer *v.* temperature differential at a solid-liquid interface; and FIG. 3 illustrates, schematically, a modification of the apparatus of FIG. 1.

Referring now to FIG. 1, heat exchange apparatus is shown comprising a plurality of heat exchange elements or fins **48** adapted to extend into water, air or some other medium to effect an exchange of heat energy between the elements and the medium. An eddy current means consisting of a coil **47** and an AC current source **46** is adapted to subject the fins **48** to periodic or time-varying vibratory forces thereby periodically to effect relative movement between the medium and the elements at the interface between the two to enhance heat transfer therebetween. The fins **48** may be made of copper or some other electrically conductive material and in operating apparatus are electromagnetically coupled to the coil **47**, the magnetic field of the coil being positioned substantially at right angles to the plane of the fins. The current source **46** may provide a single periodic alternating signal as the sinusoid discussed in said application, preferably in the high sonic or ultrasonic range, or a double field, as the fields there

discussed, in the frequency range mentioned. A fluid or other medium to be cooled is passed through a nonconductive pipe **51** in the direction of the arrow designated B to contact the thin flexible heat exchange elements **48**, a heat transfer fluid passing to the elements **48** through a tube **50** and away therefrom through a tube **49**.

The effect of introducing ultrasonic-frequency energy is illustrated schematically in FIG. 2, where the normal heat flux as a function of interface temperature difference is shown by a solid curve, and the behavior as modified by ultrasonic-frequency energy is shown by the broken curve. Vibration also enhances heat transfer at a solid-gas interface by disturbing the quiescent boundary layer, although the improvement in this case is not as dramatic. The device according to the present invention provides the first means for utilizing ultrasonic-frequency energy in a practical device for the purpose of enhancing heat transfer, particularly under extreme heat flux conditions. To achieve this the fins or ribs are driven into ultrasonic vibration directly by the induction of eddy currents of small skin depth in the presence of a background magnetic field. The AC magnetic field furnished by the coil **47** induces eddy currents in the fins flowing substantially in the circumferential direction. These induced eddy currents produce flexing vibration of the fins by interacting with a background magnetic field having a radial component to supply a fringing effect. This background field may be derived from the coil **47** or may be supplied by separate means as, for example, a second coil, a permanent magnet, a magnetic armature, or an electro magnet oriented to provide a background field having at least some radial component. The background field may be continuous or alternating in suitable phase relation to the AC magnetic inducing field. In FIG. 3 the background field represented by flux or field line **53** is provided by a DC coil **52** (energized by a DC power source, not shown) and a sintered or ceramic magnetic core **53**, the AC field being represented in FIG. 3 by the field lines labeled **54**.

Modification of the invention herein described will occur to persons skilled in the art.

I claim:

1. In heat exchange apparatus, a plurality of electrically conductive planar heat exchange elements adapted to extend into a medium, a coil wound about the elements and oriented to provide an eddy current inducing AC magnetic field having a component transverse to the plane of said elements, a source of electric current having an alternating frequency in the upper sonic to ultrasonic frequency range connected to supply current to the coil to induce eddy currents to flow in the plane of said elements, means for producing a further magnetic field having a radial component in said elements to act as a background field, said background field being either continuous or alternating in suitable phase relation to the AC magnetic eddy-current inducing field, flexing vibrations of the elements being provided by interaction between the induced eddy currents and the background field.

2. Apparatus as claimed in claim **1** in which the heat exchange elements are thin flexible fins mechanically attached and supported at axially displaced intervals along a heat conductive tube, the axis of the tube being parallel to the axis of said coil, the background field being supplied by a magnetic source separate from the coil.

3. Apparatus as claimed in claim **2** in which the fins-and-tube combination is disposed within and coaxial with a nonconductive pipe to carry a fluid, there being an exchange of heat between the fluid and the fins, the heat thereby exchanged being transferred to a further fluid in the tube for removal from the heat transfer region.