**United States Patent** [19]
**Rannow**

[11] **3,789,617**
[45] **Feb. 5, 1974**

# [54] THERMODYNAMIC SYSTEM

[75] Inventor: **Robert L. Rannow**, Jamaica, Vt.

[73] Assignee: **Thermocycle, Inc.,** Brooklyn, N.Y.

[22] Filed: **Jan. 13, 1972**

[21] Appl. No.: **217,467**

[52] **U.S. Cl.** .......... **62/115,** 62/119, 62/498, 62/527, 165/1, 165/184

[51] **Int. Cl.** .......... **F25b 1/00**

[58] **Field of Search** .......... 62/84, 115, 119, 52, 498; 165/1, 84

[56] **References Cited**

UNITED STATES PATENTS

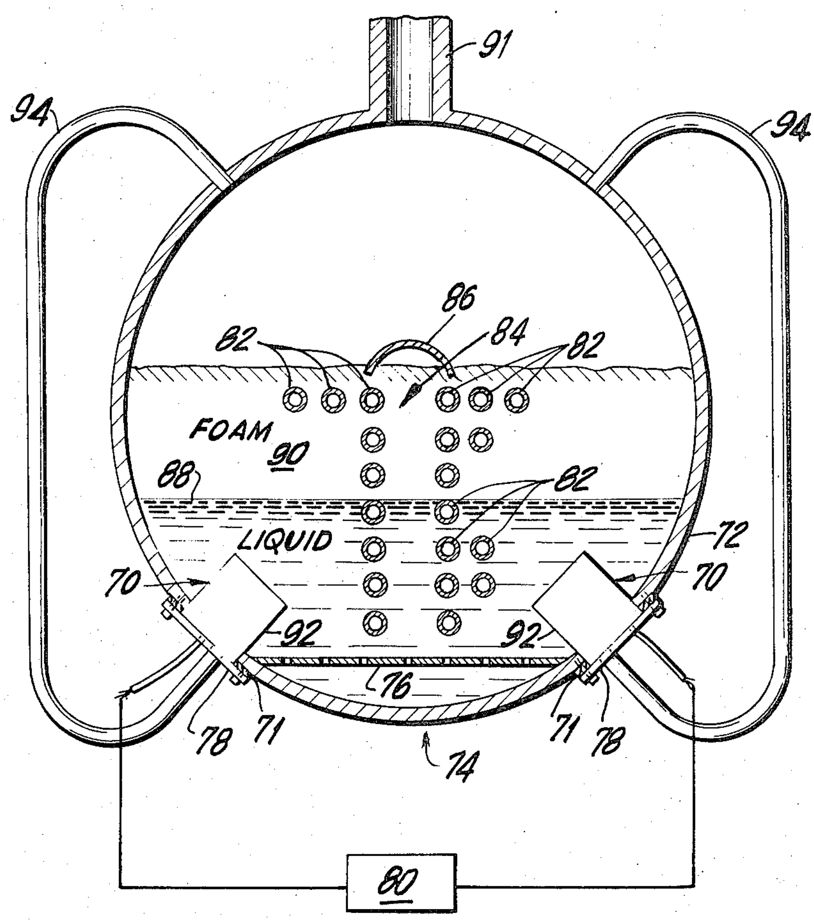
| | | | |
|---|---|---|---|
| 2,341,132 | 2/1944 | Waterfill | 62/527 X |
| 2,664,274 | 12/1953 | Worn et al. | 165/84 X |
| 3,368,610 | 2/1968 | Kartluke et al. | 165/84 X |
| 3,410,765 | 11/1968 | Bodine | 165/1 X |
| 2,900,801 | 8/1959 | Honegger | 62/84 |
| 2,153,644 | 4/1939 | Schierenbeck | 165/1 X |
| 2,718,766 | 9/1955 | Imperatore et al. | 62/527 X |

*Primary Examiner*—William F. O'Dea
*Assistant Examiner*—Peter D. Ferguson
*Attorney, Agent, or Firm*—Sandoe, Hopgood & Calimafde

[57] **ABSTRACT**

Transducers are utilized to produce vibrations within a thermodynamic system including an evaporator, a condenser, and a plurality of pipes connecting the evaporator and condenser so that the refrigerant can circulate therethrough. Other conventional cooling system components such as a compressor and a cooling tower may be included. Preferably one or more transducers are attached to the evaporator and may be enclosed within it. The vibrations reduce the refrigerant and water film coefficients, inhibit the formation of a film of bubbles on the tubes of the evaporator, increase foaming, and generally improve heat transfer throughout the system.

**18 Claims, 6 Drawing Figures**



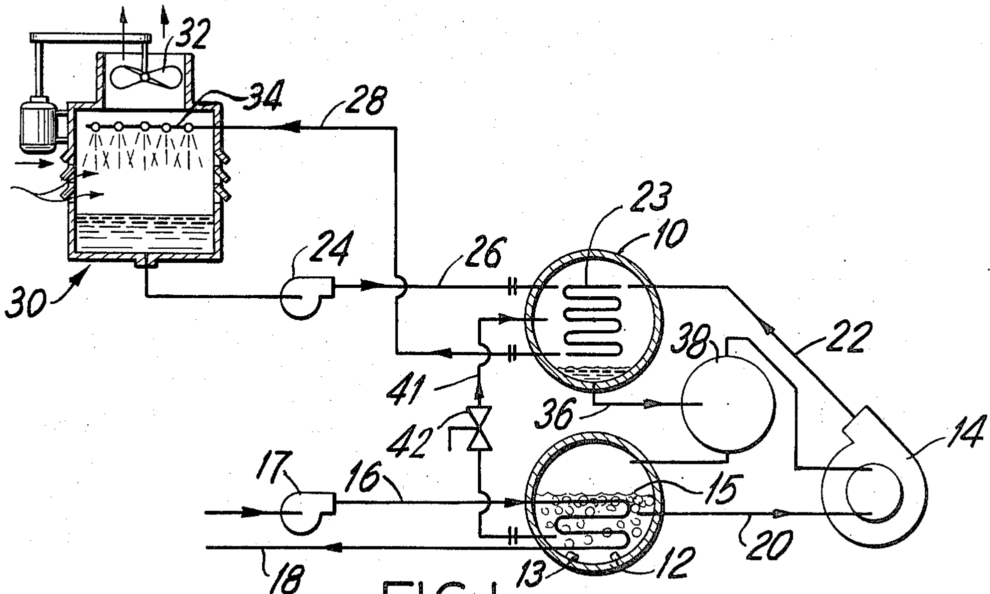



FIG. 1

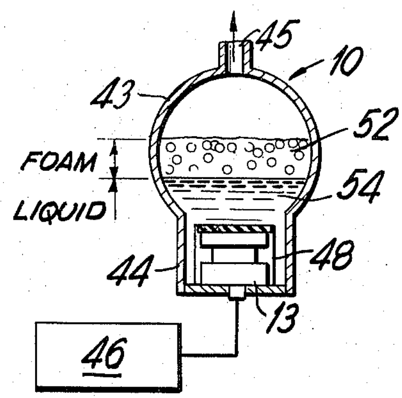



FIG. 2

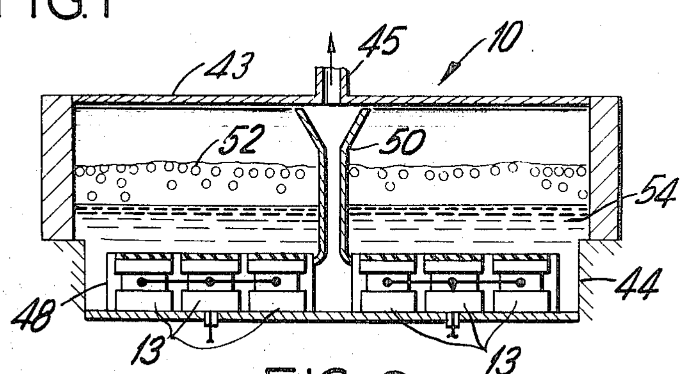



FIG. 3

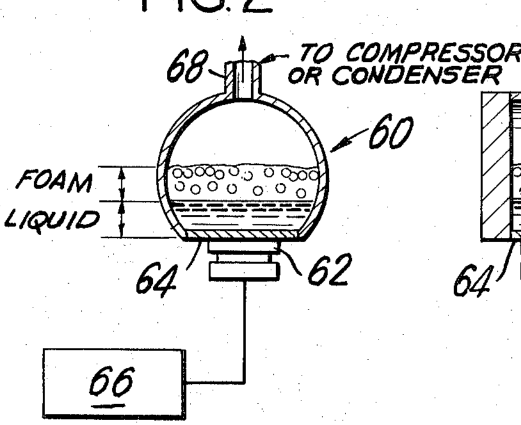



FIG. 4

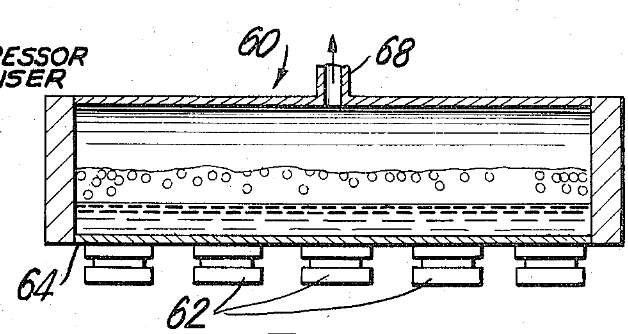



FIG. 5

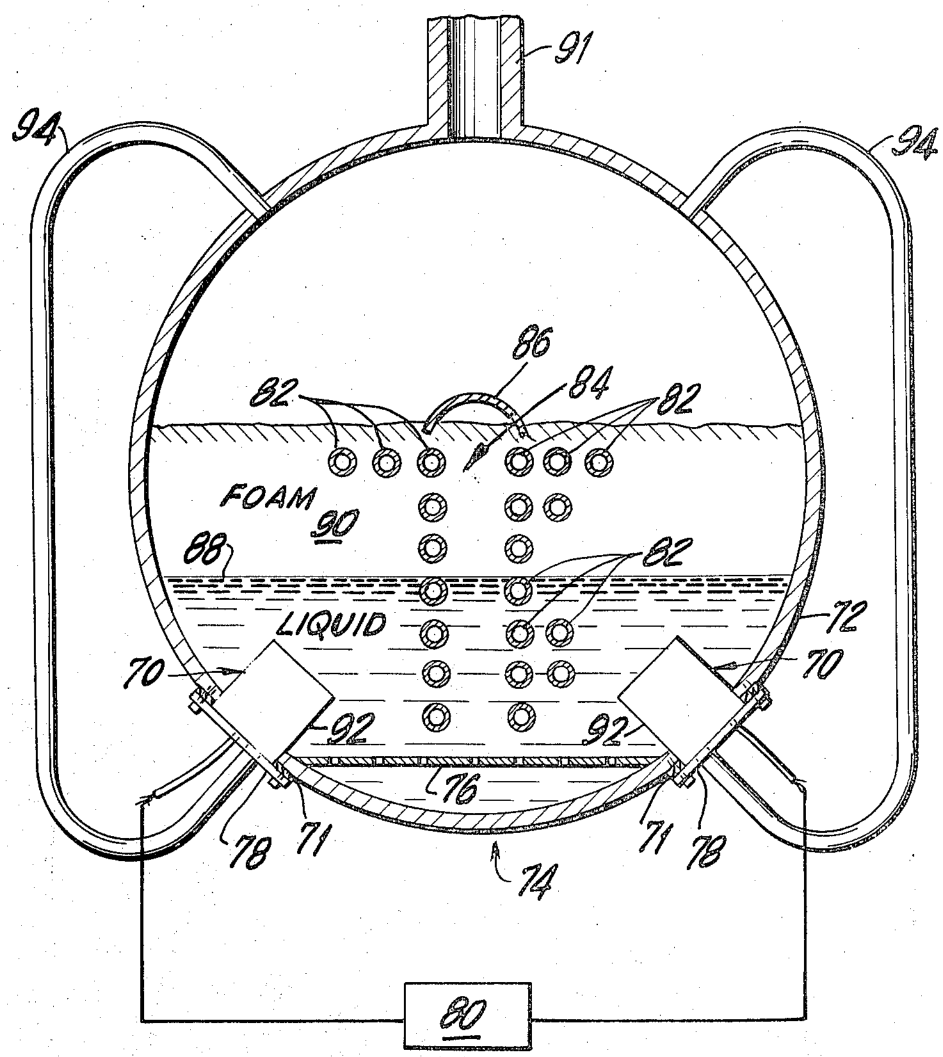

91
94
94
86
84
82
82
FOAM
90
88
82
LIQUID
72
70
70
92
92
76
78
71
71
78
74
80

FIG. 6

## THERMODYNAMIC SYSTEM

### BACKGROUND OF THE INVENTION

This invention relates to thermodynamic systems, and more particularly to systems in which heat transfer is improved by the use of vibrations.

The efficiency of a cooling system is, in large measure, a function of the rate of heat transfer between the apparatus of the system and the refrigerant which circulates therethrough. An increase in efficiency permits the utilization of a smaller system which is less expensive to manufacture and consumes less energy to do a particular job. This is true in the case of, for instance, conventional air conditioning systems that include a condenser, water chiller, and compressor, as well as in systems that omit the compressor, such as the one described in U.S. Pat. No. 2,718,766 to Imperatore, et al.

Particular attention has, in the recent past, been directed to the problem of improved heat transfer in the evaporator where a layer of bubbles tends to form on the evaporator tubes. These bubbles act as an insulator and substantially reduce the rate of heat transfer. Efforts have been made to improve heat transfer by stirring or spraying the refrigerant. The aforementioned Pat. No. 2,718,766 describes the use of a spray system for this purpose. U. S. Pat. No. 3,242,689 to Chubb, et al., describes a technique by which refrigerant gas is blown into the liquid refrigerant. Although these previously known techniques have met with some success, the rate of heat transfer has not been maximized.

An increase in the rate of heat transfer is of particular importance in systems that either omit the compressor or provide for the operation of the system without using the compressor. As the rate of heat transfer is increased, the range of operating conditions of this more economical method of cooling is increased accordingly.

The rate of heat transfer can be increased, to some extent, by allowing the evaporator tubes to be contacted by foam which forms on the surface of the refrigerant in the evaporator. Therefore, increased foam depth is desirable. The effectiveness of this foam is partially a function of bubble size. As the bubbles become larger, the amount of refrigerant included in the foam is reduced and its effectiveness is decreased accordingly.

Oil, when mixed with the refrigerant, serves as a foaming agent. However, the presence of oil also causes the size of the foam bubbles to increase. The recommended oil concentration in previously known systems is up to 2 percent by weight of the refrigerant in the evaporator. If the oil concentration increases beyond that level, it is known to inhibit heat transfer.

Oil is often present in conventional cooling systems because it is required to lubricate the compressor. However, if the amount of oil in these systems becomes too high (over 2 percent), it must be removed.

### SUMMARY OF THE INVENTION

The present invention consists of an improved thermodynamic system comprising an evaporator, a condenser, a plurality of pipes connecting the evaporator and condenser so that refrigerant can circulate therethrough, and a transducer means for producing vibrations in the system whereby the rate of heat transfer between the refrigerant and the apparatus of the system is increased. The term vibration, as used here, encompasses cavitation within the liquids of the system as well as vibrations in the apparatus of the system. Preferably, the transducer means is attached to the evaporator, and it may be enclosed by the evaporator and submerged in the refrigerant.

Although systems of this type are most often used for cooling and refrigeration purposes, they must be used as a heat pump, and the term thermodynamic system is used here to encompass both.

The present invention includes a method of cooling a fluid comprising passing a refrigerant through an evaporator where it is brought into heat exchange relationship with the fluid and whereby said fluid is cooled and the refrigerant is heated. The refrigerant is then passed through a condenser wherein the refrigerant is cooled. Vibrations are produced in the refrigerant whereby the rate of heat transfer is increased. The vibrations are most effective when induced directly in the evaporator, as by attaching a transducer means to a wall of the evaporator.

The vibrations produced should have a frequency between approximately 5,000 and 500,000,000 cycles per second. The optimum range lies between approximately 10,000 and 100,000 cycles per second. Ultrasonic vibrations are preferred because they do not produce undesired noise. Although the transducer means for producing vibrations is preferably located in the evaporator, the vibrations are transmitted throughout the system, and the transducer means may have other locations.

The vibrations tend to prevent the accumulation of a film of bubbles on the evaporator tubes, encourage the formation of gas in the refrigerant by nucleation, and increase the rate of degassing of the refrigerant bath. Another desirable effect of the vibrations is that they increase the depth of the foam on the surface of the refrigerant in the evaporator. As the depth of the foam increases, a larger number of evaporator tubes are contacted by the refrigerant and, thus, heat exchange takes place over a larger surface area. The added foam which is attributable to the presence of the vibrations is formed by relatively small bubbles that result in a high rate of heat transfer.

The presence of vibrations enhances the effect of foaming agents mixed with the refrigerant in a synergistic manner. A quantity of foaming agent, preferably an oil, in the evaporator which is equal to between approximately 0.5 and 10 percent of the weight of the refrigerant in the evaporator is desirable. Accordingly, it is not necessary to limit the presence of oil in the evaporator to less than 2 percent by weight of the refrigerant as has been the practice in the past.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed understanding of the method and apparatus of the invention, reference may be made to the following detailed description taken in conjunction with the accompanying drawings wherein:

FIG. **1** is a schematic diagram of a cooling system constructed in accordance with the invention;

FIGS. **2** and **3** show, in cross-section and in greater detail, the evaporator and attached transducers of FIG. **1**;

FIGS. 4 and 5 show, in cross-section, an alternative arrangement of an evaporator and transducers for use in the system of FIG. 1; and

FIG. 6 shows, in cross-section, a third arrangement of an evaporator and transducers for use in the system of FIG. 1.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

A cooling system incorporating the concept of the invention is shown in FIG. 1. It includes a condenser 10 and an evaporator 12 through which the refrigerant is arranged to flow by various connecting pipes. A transducer means 13 is provided for producing continuous vibrations within the system whereby the rate of heat transfer between the apparatus of the system and the refrigerant is increased.

The system may be operated with or without a compressor 14. When the compressor 14 is in use, water from the area to be cooled is supplied to the tubes 15 of the evaporator 12 by a pipe 16 and withdrawn by a pipe 18 under the force of a pump 17. As the water passes through the tubes 15, it is brought into heat exchange relationship with a refrigerant in the shell of the evaporator 12. Accordingly, the water is chilled as the refrigerant is heated and vaporized. The vaporized refrigerant from the shell of the evaporator 12 is supplied by a pipe 20 to the compressor 14, and the compressed refrigerant is supplied by a pipe 22 to the shell of the condenser 10 where it is brought into heat exchange relationship with water flowing through the tubes 23. This water is supplied to the condenser 10 by a pump 25 through a pipe 26 and then withdrawn through a pipe 28. For purposes of defining the invention, the refrigerant may be referred to as the first fluid and the water to be cooled as the second fluid.

As the water flows through the tubes of condenser 10, it is heated by the refrigerant which is thus cooled and liquified. The heated water temperature is lowered toward the ambient wet bulb temperature in a conventional cooling tower 30 which includes a blower 32 and a spray system 34. A pipe 36 supplies liquid refrigerant from the condenser 10 to an intercooler 38 from which is supplied by a pipe 40 to the evaporator 12.

The system of FIG. 1 is capable of operating without the compressor 14 in the manner disclosed in the aforementioned Pat. No. 2,718,766. This mode of operation is employed when the demands on the system are relatively low. Refrigerant vapor from the evaporator 13 is supplied by a pipe 41 through a gas bypass valve 42 to the condenser 10 without compression. It is liquified by the loss of heat to the water from the cooling tower 30 flowing through the tubes 23 of the condenser 10 and is returned to the evaporator 12 via the intercooler 38.

If the expected range of ambient temperature is such that the compressor 14 is not needed, it may, of course, be eliminated from the system entirely. Conversely, if it is expected that the compressor 14 will be needed at substantially all times, the line 41 and the bypass valve 42 may be eliminated. The effect of vibrations is of special importance in systems that operate without a compressor, because they increase the operating range of this more economical method of cooling.

The evaporator 10 of the system of FIG. 1 is shown pictorially and in greater detail in FIGS. 2 and 3. The upper portion 43 of the heat exchanger 10 is generally cylindrical in shape. The lower portion 44 is trough-like and contains the transducer means 13. Refrigerant vapor is supplied to the condenser 10 and the compressor 14 through an opening 45.

In this embodiment the transducer means comprise a plurality of submersible transducers driven by one or more generators 46. The number and size of these transducers is, of course, dependant upon the requirements of an individual installation.

The transducers 13 are enclosed within a liquid-proof housing 48. The transducers 13 are, nevertheless, considered to be submerged as they are located within the evaporator 10, and the vibrations need not be transmitted through the relatively heavy exterior wall of the evaporator 10 with a resulting loss of power. The transducers 13 are vented through a tube 50 to the refrigerant vapor in the shell of the evaporator 10. Thus, the transducers 13 need not operate across the pressure differential between the inside and the outside of the evaporator 10 with a further resulting loss of power.

FIGS. 2 and 3 show the formation of refrigerant foam 52 on the surface of the liquid refrigerant 54 in the shell of the evaporator 10. The tubes 15 of the evaporator 10 are not shown in these figures to avoid unnecessary complexity in the drawings. For optimum performance, the tubes 15 should be arranged so that they are all covered by the liquid 54 or the foam 52 of the refrigerant.

An alternative evaporator and transducer arrangement 60 is shown in FIGS. 4 and 5. Here, a plurality of transducers 62 are attached to the lower wall 64 of the evaporator 60, but are not submerged in the refrigerant. Instead, they are mounted in exterior fashion. However, in this arrangement, as in the arrangement of FIGS. 2 and 3, the vibrations are induced directly in the evaporator. The vibrations could be induced at another point in the system and transmitted to the evaporator, but this would be less efficient. One or more generators 66 drive the transducers 62. The shell of the evaporator 60 is generally cylindrical in shape except for the lower wall 64 which is flat to accommodate attachment of the transducers 62. Refrigerant vapor is supplied to the condenser 10 or the compressor 14 through an opening 68.

Another evaporator and transducer arrangement that can be used in the system of FIG. 1 is shown in FIG. 6. This arrangement, as compared to those of FIGS. 2 and 4, is particularly well suited for relatively large installations. The transducers 70 are attached to the walls 72 of a cylindrical evaporator 74 just above a perforated diffusion plate 76 that extends horizontally across the bottom of the evaporator 74. The transducers 70 are each attached by a plate 78 which is bolted to a companion flange 71 on a wall 72 and powered by one or more generators 80.

The tubes 82 of the evaporator 74 pass through the lower portion thereof and are arranged in groups to facilitate connections between the tubes and in water boxes (not shown) at the ends of the evaporator. This arrangement of tubes leaves an open vertical channel 84 between the groups of tubes 82. There is a tendancy for the bubbles formed in the liquid refrigerant to rise through this opening, whereas heat transfer and foaming are improved if they are dispersed throughout the tubes 82 as they rise. Therefore, a blocking member 86 is disposed above the open vertical channel 84. Similar blocking members should be disposed above any other channels through which bubbles tend to rise. The liquid refrigerant level **88** is below the uppermost tubes **82** which are contacted by the refrigerant foam **90.**

The refrigerant vapor is supplied from the evaporator **74** to the condenser **10** or the compressor **14** of the system of FIG. **1** through an opening **91.** The transducers **70,** which are each enclosed in a liquid-proof housing **92** similar to the housing **48,** are vented by lines **94** to the upper portion of the evaporator **74** where the pressure of the refrigerant vapor is present.

In a typical installation, a four foot section of an evaporator may contain, for example, perhaps a sufficient number of transducers to provide 1000 watts of output. Instead of the type of transducer represented in the drawings, it would be possible to employ whistles or sirens for the transducer means.

The vibrations produced by the transducer means **13** improve heat transfer throughout the system. This effect is particularly beneficial with respect to heat transfer from the evaporator tubes **15** to the refrigerant. There is a tendancy for bubbles to accumulate around the tubes **15** that are enclosed by liquid refrigerant, and these bubbles act as an insulating layer. The formation of bubbles on these tubes **15** is believed to be greatly reduced by the vibrations.

Another beneficial effect of the vibrations is that the depth of the foam **52** (shown in FIGS. **2** through **6**) is increased significantly and the size of the bubbles is kept advantageously small. This enables a larger number of evaporator tubes **15** to be brought into effective contact with the refrigerant.

Vibrations have been found to increase the rate at which gas is formed in the liquid refrigerant by nucleation. It is believed that heat transfer between the evaporator tubes **15** and the water therein is also improved. Similar effects take place in the condenser **12** to the extent that vibrations are present there.

The optimum vibration frequency depends upon the configuration and construction of the particular system. The frequency may vary from approximately 5,000 to 500,000,000 cycles per second. If the frequency is too low the system will be noisy: if it is too high the transducers will consume too much power. The preferred frequency range is from approximately 10,000 to 100,000 cycles per second. Ultrasonic vibrations are preferred because of the lack of undesired noise. Commercially available transducers that operate at 25,000 and 40,000 cycles per second have been found to perform well and do not result in excessive noise.

The effect of the vibrations is synergistic when combined with the presence of a foaming agent mixed with the refrigerant in the evaporator **10.** Oil is generally a good foaming agent for this purpose. The quantity of oil in the evaporator should be equal to between approximately 0.5 and 10 percent of the weight of liquid refrigerant in the evaporator. Accordingly, the foaming agent is effective to produce bubbles of the desired size in concentrations in excess of 2 percent by weight of the refrigerant in the evaporator, whereas this is above the intended concentration of other systems. This relatively high concentration of foaming agent has not been effective in previously known systems.

The preferred embodiment described above is merely exemplary and is susceptable of variation and modification by those skilled in the art without departing from the spirit and scope of the invention. For instance, although the deployment of the transducers in the positions shown in FIGS. **2** through **5** is advantageous, the transducers could be attached to the system at other locations. In fact, the vibrations may be transmitted from the transducer means **13** through the water that flows through the tubes of the evaporator or the condenser. Therefore, the invention is not deemed to be limited except as defined in the appended claims.

I claim:

**1.** A cooling system including an evaporator in which a first fluid is boiled and a second fluid is cooled, a means for cooling and condensing the boiled first fluid after it leaves said evaporator, and means for returning the first fluid to said evaporator wherein the improvement comprises transducer means for producing vibrations at a frequency between approximately 5,000 and 500,000,000 cycles per second within said first fluid while it is in said evaporator whereby the rate of heat transfer between said first and second fluids within said evaporator is increased substantially.

**2.** The cooling system of claim **1,** further comprising a foaming agent mixed with the first fluid whereby the amount of refrigerant foam produced is substantially increased by the interaction of said vibrations and said foaming agent.

**3.** The system of claim **2,** wherein the foaming agent is an oil and the quantity of the foaming agent is equal to at least 2 percent by weight of refrigerant in the evaporator.

**4.** The cooling system of claim **2,** wherein said evaporator includes a plurality of tubes through which said second fluid passes arranged so that some tubes are immersed in liquid refrigerant and others are not, substantially all of those tubes which are not immersed being covered by refrigerant foam when the system is in operation.

**5.** The cooling system of claim **1,** wherein said vibrations are produced substantially continuously while said system is in operation.

**6.** The cooling system of claim **1,** wherein said evaporator is of the tube and shell type having the tubes thereof arranged in groups with at least one open vertical channel defined between said groups wherein the improvement further comprises a blocking member disposed across said channel to disperse bubbles that tend to rise therethrough.

**7.** The system of claim **1,** wherein the vibrations produced have a frequency between approximately 10,000 and 100,000 cycles per second.

**8.** A cooling system comprising an evaporator wherein a first fluid is boiled and a second fluid is cooled, a means for condensing the boiled first fluid without compressing it after it leaves said evaporator, means for returning said first fluid from said condensing means to said evaporator, and transducer means for producing vibrations at a frequency between 5,000 and 500,000,000 cycles per second in said first fluid while it is in said evaporator whereby the rate of heat exchange between said first and second fluids within said evaporator is increased substantially.

**9.** The cooling system of claim **8,** wherein the vibrations produced have a frequency between approximately 10,000 and 100,000 cycles per second.

**10.** The cooling system of claim **8,** further comprising a foaming agent mixed with the first fluid whereby the amount of refrigerant foam produced is substantially increased by said vibrations.

11. The system of claim 10, wherein the foaming agent is an oil and the quantity of the foaming agent is equal to between approximately 0.5 and 10 percent by weight of refrigerant in the evaporator.

12. The system of claim 10, wherein the foaming agent is an oil and the quantity of the foaming agent is equal to at least 2 percent by weight of refrigerant in the evaporator.

13. A method of cooling a liquid including passing a refrigerant through an evaporator in which it is brought into heat exchange relationship with said liquid, whereby said liquid is cooled and said refrigerant is boiled, and passing the boiled refrigerant through a condenser wherein said refrigerant is cooled, wherein the improvement comprises producing vibrations in the refrigerant whereby the rate of heat transfer is increased substantially, said vibrations having a frequency between approximately 5,000 and 500,000,000 cycles per second.

14. The method of claim 13, wherein said vibrations are induced directly in a wall of said evaporator and thus transmitted to said refrigerant.

15. The method of claim 13 further comprising mixing a foaming agent with the refrigerant in the evaporator, the foaming agent being an oil and being present in a quantity equal to between approximately 0.5 and 10 percent by weight of the refrigerant in the evaporator, the combined effect of said foaming agent and said vibration substantially increasing the depth of refrigerant foam in the evaporator.

16. The method of claim 13 further comprising mixing a foaming agent with the refrigerant in the evaporator.

17. The method of claim 13, wherein the vibrations have a frequency between approximately 10,000 and 100,000 cycles per second.

18. The method of claim 13 wherein the refrigerant is condensed without compressing it.

* * * * *