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[54] **DYNAMIC BARRIER FOR HEAT PIPE**

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[52] **U.S. Cl.** **165/32**, 165/105
[51] **Int. Cl.** **F28d 15/00**
[58] **Field of Search** 165/96, 105, 32

[56] **References Cited**

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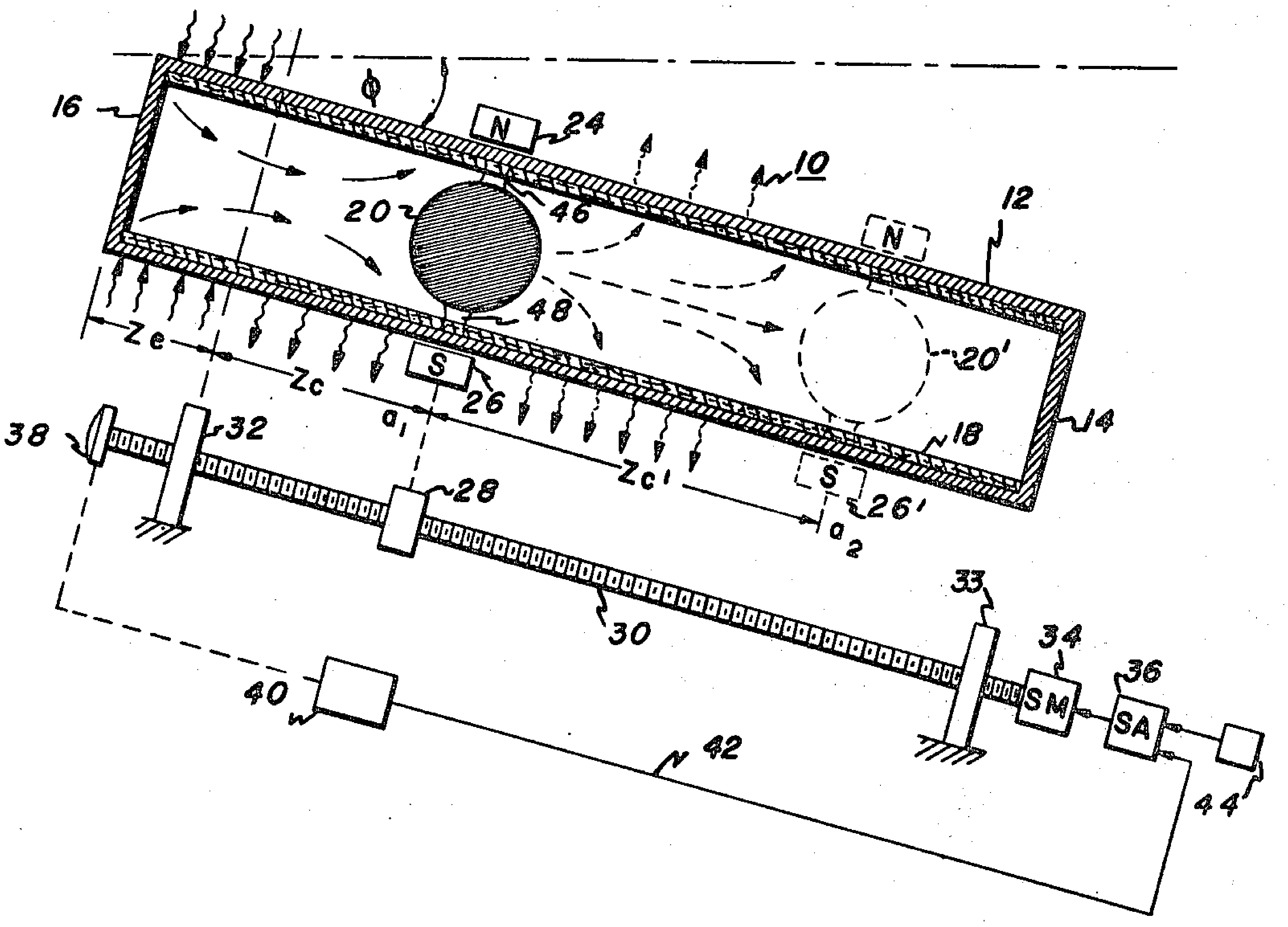
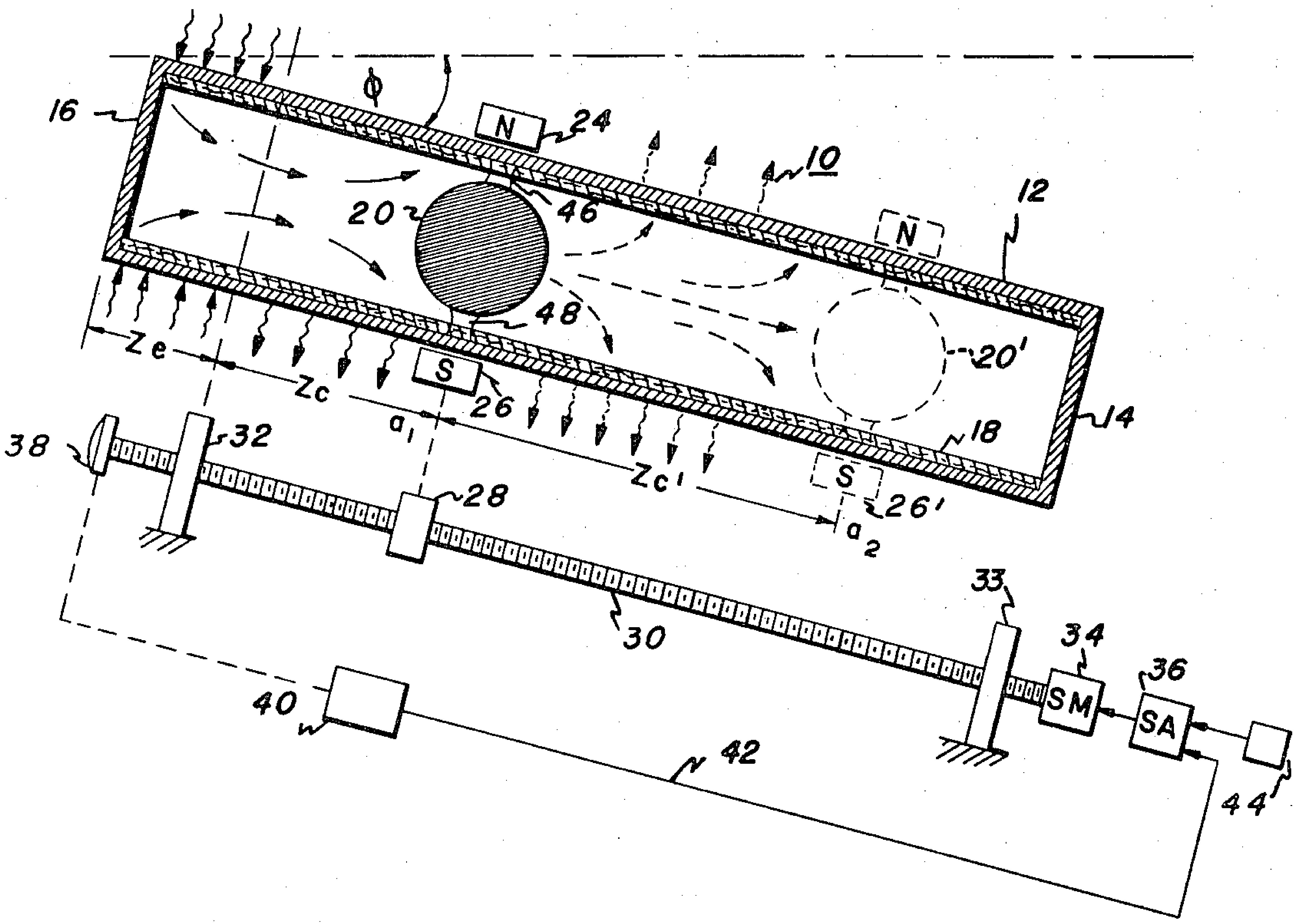
Primary Examiner—Albert W. Davis, Jr.

[57] **ABSTRACT**

A heat pipe in which the operating temperature and pressure of the vaporized working fluid is adjustable by means of a dynamic barrier inside the heat pipe. A magnetizable member, in conjunction with a working fluid which is magnetizable, form a hermetic seal, or barrier, at predetermined positions along the length of the heat pipe. The hermetic seal, in the preferred embodiment, is positioned to a point along the heat pipe length whereby the vaporized working fluid is at a desired operating temperature and pressure.

14 Claims, 1 Drawing Figure

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DYNAMIC BARRIER FOR HEAT PIPE

BACKGROUND OF THE INVENTION

Heat pipes or heat pipe-type devices are essentially closed, evacuated chambers whose inside walls are lined with a capillary structure, or wick, that is saturated with a volatile working fluid. A heat source, positioned adjacent the evaporator portion of the heat pipe vaporizes the working fluid, the vapor moving toward the condenser portion of the heat pipe where the vapor condenses on the inside wall of the heat pipe. The condensate returns to the evaporator by capillary action to complete the cycle. The function of the working fluid within the heat pipe is to absorb the heat energy received at the evaporator section, transport it through the pipe and release this energy at the condenser end.

Prior art techniques for temperature control of heat pipes include the utilization of a noncondensable gas reservoir which allows the heat pipe vapor - noncondensable gas interface to adjust itself in such a manner as to hold the heat pipe temperature constant under varying heat loads; the restriction, or limitation, of the wick whereby a portion of the wick is effectively removed from the condensate flow path for a predetermined period of time, heat pipe operation ceasing during this time period; or inhibiting the vaporized working fluid from reaching the condenser portion of the heat pipe whereby heat pipe operation ceases for the period of time that the vapor path is blocked.

U.S. Pat. No. 3,414,050 to Anand exemplifies the prior art implementation of the latter two techniques. In one embodiment, the flow of condensate liquid is interrupted by the action of a tube member having a wicking material on its exterior surface. When the interior temperature is higher than desired, the tube member is caused to expand whereby the exterior wicking material completes the return path of the condensate, therby maintaining normal heat pipe operation. When the temperature of the system being controlled is lowered to the desired temperature, the tube member contracts and breaks the liquid circuit, terminating heat pipe operation.

In another embodiment, the vapor flow from the evaporator section to the condenser section is regulated by a damper type valve in accordance with the temperature of the system being controlled.

The control techniques as exemplified by Anand are directed to controlling the temperature of a system external to the heat pipe.

Although the heat pipe is a versatile device, it must operate within certain design limitations. One important limiting factor governing the operation of the heat pipe is the maximum and minimum useful temperature for a given working fluid. For a particular working fluid, there is a minimum temperature below which the rate of evaporation becomes insufficient to effect a smooth transfer of thermal power. There is also a maximum operating temperature of the working fluid that is based on the maximum safe vapor pressure allowed and the heat transfer properties of the fluid within the heat pipe.

A technique for controlling the operating temperature of a heat pipe, within the minimum and maximum allowable temperature for a particular working fluid, is therefore desired. The technique should be simple, inexpensive and versatile whereby a single heat pipe

structure can be used without the necessity of redesigning the heat pipe to accommodate various working fluids.

SUMMARY OF THE PRESENT INVENTION

The present invention provides method and apparatus for controlling the operating temperature of a heat pipe in a simple and economical manner.

In particular, the heat pipe of the present invention includes a magnetizable member which is movable within the walls of the heat pipe, a magnetic fluid being utilized as the working fluid. The magnetic fluid and magnetizable member are magnetizable from an external magnetic field and form a hermetic seal in the wick and vapor passage areas of the heat pipe. The operation of this system is such that the condenser length is variable, thereby providing heat pipe control via operating temperature and pressure, by positioning the magnetizable member by simply moving the external magnetic field to a predetermined position along the length of the heat pipe.

It is the object of the present invention to provide method and apparatus for controlling the operating temperature and pressure of a heat pipe by providing a magnetizable member within the walls of the heat pipe, the position of which within the walls may be adjusted, thereby controlling the effective length of the condenser portion of the heat pipe.

It is still an object of the present invention to provide method and apparatus for controlling the operating temperature and pressure of a heat pipe which includes a magnetizable working fluid and a magnetizable member which together form a barrier to the condensate flow along the wick and vapor flow within the walls of the heat pipe at a predetermined position along the length of the heat pipe.

DESCRIPTION OF THE DRAWING

For a better understanding of the invention, as well as other objects and further features thereof, reference is made to the following description which is to be read in conjunction with the accompanying drawing which consists of a single FIGURE illustrating the method and apparatus of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing, a cylindrical heat pipe, shown in section, is generally illustrated at **10**. The heat pipe, although shown as cylindrical in shape, may be designed in various other geometries. Heat pipe **10** includes a side wall **12** which is closed at its ends by end walls **14** and **16**. A sleeve **18** of wicking, or capillary, material extends through the length of heat pipe **10** and overlies the inner surface of the wall **12**. The wicking material may comprise sintered porous matrixes, woven mesh, fiber glass, longitudinal slots and combinations of these materials and structures in various geometries. In the preferred embodiment, wicking material **18** is a composite screen comprising compressed layers of mesh. The heat pipe comprises two sections, an evaporator section of length Ze and a condenser section of length Zc.

The heat pipe **10** can operate at any angle ϕ to the horizontal ($0 \leq \phi \leq 360°$) as long as the basic heat pipe equation is satisfied, i.e.:

$$P_C \geq P_L + P_V + P_G$$

wherein:

P_C=capillary driving force,

P_L=pressure loss due to working fluid,

P_V=pressure loss due to vapor

P_G=pressure loss due to gravity

A magnetizable member **20**, such as an iron ball or plug of sufficient size to substantially block the flow of vapor between the evaporation and condenser sections when the heat pipe is operative, is inserted within heat pipe **10** as shown. The working fluid which saturates the wick structure **18** is a magnetic fluid. In particular, a magnetic fluid, as is well known, is composed of magnetic particles of subdomain size colloidally dispersed in a condensable liquid carrier. Typical liquid carriers include silicone, water, kerosene and fluorocarbons. The magnetic particles are prevented from clustering to each other by a monomolecular layer of surfactant, such as oleic acid, which envelops each particle. The layer (typically 20A) also confers compatability with the carrier solvent and thermal agitation prevents settling. The particle concentration is extremely large (on the order of 10^{18} particles/cm) with a typical lineal dimension being 100A. As a result, the mixture may always be treated as a fluid continuum and is responsive to magnetic fields while retaining its fluid characteristics. Thus, the magnetic particles remain suspended in the liquid even when adjacent magnets **24** and **26**.

Ferrofluids Corporation, Burlington, Massachusetts supplies working fluids of the aforementioned composition. The particles are small enough to flow in an axial direction between the compressed mesh layers comprising the wicking material **18**, the separation of layers being selected to allow the magnetic particles to flow therethrough.

The heat pipe **10** can be made, for example, of glass, ceramic, copper, stainless steel, tungsten, molybdenum and various alloys.

The magnetic field is generated by permanent magnets **24** and **26**. Magnets **24** and **26** are mechanically coupled to a member **28** coupling of magnet **24** not shown, which is mounted for movement on threaded shaft **30**, shaft **30** being mounted for rotation in journal members 32 and 33. Shaft **30** is rotated by servomotor **34** in response to the output signal from servoamplifier **36**. The rotation of shaft **30** is coupled, via gearing mechanism **38**, to the input of feedback means **40**. Feedback means **40**, i.e., a feedback potentiometer, generates an electrical signal on lead **42**, representing the position of member **28** (and therefore magnets **24** and **26**) along shaft **30**. Input means **44** applies a signal to the other input of servoamplifier **36** which corresponds to the desired condenser length Zc, which in turn corresponds to the desired operating temperature (and pressure) of heat pipe **10**.

In operation, magnetic members **24** and **26** are initially positioned to point a_1, corresponding to condenser length Zc, by appropriate selection of the input signal generated by input means **44**. The magnetic fluid, in forming meniscus **46** and **48**, and the magnetized member **20**, form a hermetic seal by forming a barrier in the wick and the vapor passage at position a_1.

FOr illustrative purposes, the heat transfer (via conduction) characteristics of heat pipe **10** can be described by the formula:

$$Q = kA(T_2 - T_1)/L$$

wherein:

Q = heat radiated from the surface of the heat pipe,

k = thermal conductivity of the heat pipe material,

A = radiating surface area of the heat pipe,

L = thickness of wall **12**,

T_2 = average temperature at the interior surface of wall **12**,

T_1 = temperature at the exterior surface of wall **12**.

In the heat pipe **10** illustrated, Q is assumed to be equal to the rate of heat input at the evaporator section. It is further assumed that Q is radiated from the condenser section with minimal heat loss. If the heat pipe is utilized, for example, in a spacecraft, the temperature at the exterior surface of wall **12**, T_1, may be assumed to be extremely low. The rate of heat transfer through the surface area of heat pipe **10** is therefore proportional to the average temperature T_2 at the inner surface of wall **12**, which in turn is proportional to the temperature of the vapor within the heat pipe walls.

If the heat Q to be radiated from the spacecraft, is constant, temperature T_2 is therefore dependent on area A. Since the surface area A of the heat pipe **10** is proportional to the length of the condenser area, Zc, positive temperature (and vapor pressure) control of the gas vapor is achieved by controlling the length Zc.

Referring once again to the FIGURE, if it is desired to decrease the temperature of the gas vapor within the walls of the heat pipe **10**, an input signal corresponding to the desired temperature is applied to servoamplifier **36** via input means **44**. The positioning apparatus (i.e. servomotor **34**, servoamplifier **36**,. . .) moves the magnetizable member **20** to position a_2, indicated by the dashed lines. Position a_2, equal to the sum of lengths Zc and Zc′ corresponds to the new condenser length for radiating heat Q at the lower gas operating temperature.

The ability to vary the condenser length therefore provides heat pipe control via operating temperature and pressure.

The strength of the magnetic field produced (by the permanent magnets illustrated in the FIGURE, electromagnets, or any combination of the two) provides a technique for controlling the operating temperature of the heat pipe **10**. For example, changes in heat input to the evaporator section would tend to increase the temperature and pressure of the heat pipe. If the magnetic field is weak (magnetic field tapered or lengthened), the change in pressure would tend to move the magnetic member **20**, thus readjusting the condenser length and allowing it to dissipate more heat to compensate for evaporator heat inputs greater than those corresponding to the selected operating temperature. Obviously, in this "weak" field configuration, the closed loop positioning system would be disengaged (by means not shown) after the initial positioning of member **20**. This allows the working fluid vapor to position member **20** to a point within the heat pipe walls whereby the condenser radiating surface dissipates the excess heat input.

If the magnetic field is concentrated, magnetic member **20** would not move and the vapor pressure and temperature within the heat pipe would increase.

While the invention has been described with reference to its preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for controlling the operating temperature and pressure of a heat pipe comprising:

a heat pipe having an evaporator section and a condenser section, said evaporator section being exposed to a source of heat and said condenser section having a heat radiating surface,

a magnetic working fluid which is condensable in said heat pipe and movable upon vaporization by heat from said heat source from the evaporator section towards the condenser whereat the vapor condenses,

means in the heat pipe for returning the fluid condensed in said condenser section to said evaporator section,

a magnetizable member positioned within the heat pipe, the heat radiating surface of said condenser section being determined by the position of said magnetizable member within said heat pipe, and

means for producing a magnetic field adjacent said heat pipe, said magnetic field acting on said magnetizable member, the position of said magnetic field corresponding substantially to the position of said magnetizable member within said heat pipe, a magnetic fluid meniscus being formed at a position corresponding substantially to the position of said magnetic field, the magnetic fluid meniscus forming a barrier to condensate flow in said returning means, said magnetic fluid meniscus and said magnetizable member forming a barrier to vapor flow.

2. The apparatus as defined in claim 1 further including means to position said magnetic field to a predetermined position corresponding to a desired heat pipe operating temperature and pressure, said magnetizable member moving to said predetermined position in response to the movement of said magnetic field.

3. The apparatus as defined in claim 1 wherein said magnetic fluid comprises a liquid carrier and magnetic particles suspended therein.

4. The apparatus as defined in claim 3 wherein said liquid carrier comprises water.

5. The apparatus as defined in claim 3 wherein said liquid carrier comprises kerosene.

6. The apparatus as defined in claim 3 wherein said liquid carrier comprises silicone.

7. The apparatus as defined in claim 3 wherein said liquid carrier comprises a fluorocarbon.

8. The apparatus as defined in claim 1 wherein the magnetic field is of a strength to allow said magnetizable member to be moved by the vapor pressure produced when the magnetic working fluid is vaporized.

9. The apparatus as defined in claim 1 wherein the magnetic field is of a strength to inhibit said magnetizable member from being moved by the vapor pressure produced when the magnetic working fluid is vaporized.

10. A method for controlling the operating temperature and pressure of a heat pipe comprising the steps of:

providing a magnetic working fluid for utilization in a heat pipe, said heat pipe having an evaporator section and a condenser section, said evaporator section being exposed to a source of heat and said condenser section having a heat radiating surface, said magnetic working fluid being condensable in said heat pipe and movable upon vaporization by heat from said heat source from the evaporator section towards the condenser whereat the vapor condenses,

returning the fluid condensed in said condenser section to said evaporator section,

positioning a magnetizable member within the heat pipe, the heat radiating surface of said condenser section being determined by the position of said magnetizable member within said heat pipe, and

producing a magnetic field which acts on said magnetizable member, the location of said magnetic field corresponding substantially to the position of said magnetizable member within said heat pipe, a magnetic fluid meniscus being formed at a position corresponding substantially to the position of said magnetic field, the magnetic fluid meniscus forming a barrier to condensate flow in said returning means, said magnetic fluid meniscus and said magnetizable member forming a barrier to said vapor flow.

11. The method as defined in claim 10 further including the step of positioning said magnetic field to a predetermined position corresponding to a desired heat pipe operating temperature and pressure, said magnetizable member moving to said predetermined position in response to the movement of said magnetic field.

12. The method as defined in claim 10 wherein said magnetic fluid comprises a liquid carrier and magnetic particles suspended therein.

13. The method as defined in claim 10 wherein the magnetic field is of a strength to allow said magnetizable member to be moved by the vapor pressure produced when the magnetic working fluid is vaporized.

14. The method as defined in claim 10 wherein the magnetic field is of a strength to inhibit said magnetizable member from being moved by the vapor pressure produced when the magnetic working fluid is vaporized.

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