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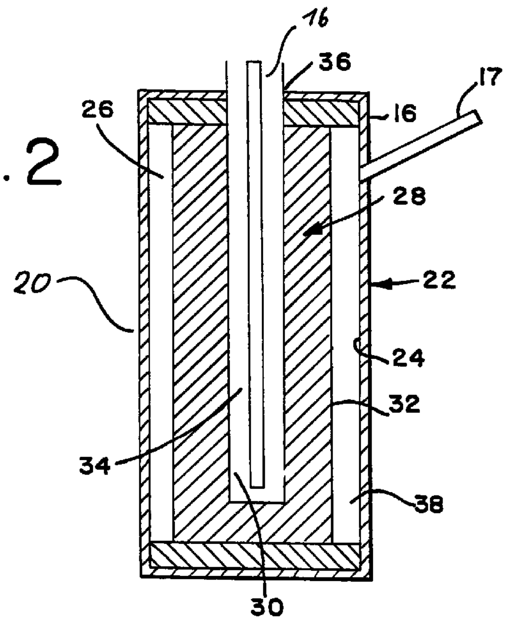
(54) **Heat transfer vaporizer**

(57) A vaporizer (28) comprises a first surface (30) and a second surface (32). The first surface (30) is in contact with a heat transfer fluid and the second surface (32) evaporates the heat transfer fluid. The vaporizer (28) comprises a ceramic material. Accordingly, a heat transfer apparatus comprises at least one evaporating chamber (38), said vaporizer (28) disposed within said evaporating chamber (38) and a condensor (14), in communication with the evaporating chamber (38).

FIG. 2



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Description

BACKGROUND OF THE INVENTION

The invention generally relates to heat transfer devices, and more particularly to vaporizers suitable for use in heat transfer devices.

The use of heat transfer devices is necessary to transfer excess heat from a heat source to another location to dissipate the heat. For example, in spacecraft applications, large amounts of heat are usually required to be dissipated from many sources, such as high power amplifiers, digital electronics and other energy dissipating equipment, to ensure the proper functioning of the equipment on-board the spacecraft.

Capillary-driven thermal control devices, such as loop heat pipes (LHP) and capillary-pumped loops (CPL), are well known in the art to transfer excess heat to a heat sink. These devices use the capillary head provided by depressed menisci in the porous vaporizer to pump a heat transfer fluid around a loop. The vaporizer is usually configured so that the fluid enters one side of the vaporizer in the case of a slab vaporizer or the inner radius in the case of an annular vaporizer. The fluid flows through the porous vaporizer and is evaporated by the heat input at the other surface of the vaporizer. The maximum depression of the fluid menisci at the heated surface of the vaporizer is given by the pore radius. The capillary pumping provided by the vaporizer is given by the equation $\Delta P_{cap}=2\sigma/r_{pore}$, where ΔP_{cap} is the capillary pressure head, σ is the surface tension, and r_{pore} is the average pore radius. Thus, for a given heat transfer fluid having a fixed relationship between σ and temperature, the smaller the pores of the vaporizer, the greater the capillary pumping available.

To initiate flow in the loop heat pipe, a temperature difference must be established from the inside to the outside of the vaporizer. When the thermal conductivity of the vaporizer is decreased, this temperature difference may be attained with lower heat input. Thus, if the vaporizer has a low thermal conductivity, fluid flow can be initiated within the LHP or CPL at lower heat input.

Vaporizers in capillary driven devices have been fabricated from a variety of materials. One type of material is a sintered metal, such as nickel or titanium. The sintered metal vaporizers usually have pore sizes ranging from about 1 to 2 microns or more. Because of the relatively large pore sizes, the pumping capacity of the heat transfer device is substantially limited, reducing the amount of heat that can be transferred. Further, the manufacturing and process techniques usually constrain the length of the sintered metal vaporizers to less than 12 inches. The thermal performance of the heat transfer device is substantially limited because of the limited length available for heat transfer, resulting in higher heat flux and correspondingly higher thermal resistance.

Vaporizers have also been constructed from sintered ceramics. However, sintered ceramic vaporizers may physically and chemically degrade in use, causing contamination of the working fluid and blockage in the heat transfer device. Furthermore, sintered ceramic vaporizers are difficult to manufacture in certain desired forms.

Vaporizers have further been fabricated from polymeric materials, such as porous polyethylene plastic (POREX). However, polymeric vaporizers have pore sizes of about 10 to 15 microns. The large pore sizes of the polymeric vaporizers substantially limits the pumping capacity of the heat transfer device and the ability to transfer heat away from a heat source. Further, porous plastic, such as porex, has a maximum temperature of about 80°C, which substantially limits its upper operating temperature and the manufacturing techniques available for fabricating the porous plastic vaporizers.

There is, therefore, a need for a vaporizer that can dissipate a higher heat load. It would be desirable if the vaporizer were compatible both chemically and physically with the heat transfer fluid. It would also be beneficial to provide an apparatus that would enable heat transfer devices to be lighter and more flexible. It would further be desirable to have a vaporizer with smaller pore sizes and lower thermal conductivity.

SUMMARY OF THE INVENTION

The present invention achieves the above benefits by providing improved heat transfer capacity in heat transfer applications. The vaporizer of the present invention provides greater capillary performance enabling heat transfer devices to reject larger amounts of undesired heat. The vaporizer also allows heat transfer devices to use a transfer line with a smaller diameter, allowing lightweight, flexible, and portable heat transfer devices. Further, the vaporizer of the heat transfer device is resistant to chemical attack by the heat transfer fluid and does not chemically contaminate the heat transfer fluid. In addition, the vaporizer is inexpensive and easy to manufacture so that it can be made to conform to heat transfer devices having any geometrical shape and does not degrade in heat or in cold temperatures. The vaporizer preferably has a small pore radius and reduced thermal conductivity allowing for easier start-up at lower temperatures.

One aspect of the invention relates to a vaporizer having a first surface contacting a heat transfer fluid and a second surface evaporating the fluid. The vaporizer includes a porous and permeable ceramic material that is thermally insulating and chemically compatible with the fluid.

Another aspect of the invention relates to a heat transfer apparatus having an evaporator with an inner surface, and a vaporizer having a ceramic material. The vaporizer has a first surface and a second surface. The first surface is in communication with a heat transfer fluid and the second surface is in contact with the inner surface of the evaporator to form at least one chamber. The at least one chamber is in communication with a vapor transfer line.

In another aspect of the invention, a method of transferring heat is provided. The method includes the steps of applying heat to an evaporator having a heat transfer fluid, evaporating the heat transfer fluid through a ceramic vaporizer to form a vapor, condensing the vapor into the heat transfer fluid, and supplying the heat transfer fluid to the evaporator.

A further aspect of the invention relates to a heat transfer apparatus that includes an evaporating chamber. A ceramic vaporizer is disposed within the evaporating chamber, and a condenser is in communication with the evaporator.

These and other features and advantages of the invention will become apparent upon a review of the following detailed description of the presently preferred embodiments of the invention, taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic representation of a heat transfer apparatus, including the vaporizer of the present invention.

FIG. 2. is a cross-sectional view of the vaporizer of FIG. 1.

FIG. 3 illustrates one predicted performance of a loop heat pipe containing a vaporizer according to the present invention as a function of the elevation between the bottom of the condenser and the top of the evaporator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings in detail, and more particularly to FIG. 1, a heat transfer device 10 is shown. The heat transfer device 10 includes a fluid management system 12, a condenser 14, a vapor transfer line 17, a liquid transfer line 16, a heat transfer fluid (not shown), and an evaporator 20. As shown in FIG. 2, the evaporator 20 has an interior surface 24 and exterior surface 22. The exterior surface 22 of the evaporator 20 is adapted to be in thermal communication with a heat source (not shown). The interior surface 24 of the evaporator 20 defines a cavity 26 therein.

The cavity 26 of the evaporator 20 contains a vaporizer 28 of capillary material, such as a porous wick. The capillary material may consist of a ceramic alumina or a drain casted ceramic material. Preferably, the capillary material is made from Filtros F-90 electrolytic diaphragms manufactured by Ferro Corporation. It is also contemplated that the vaporizer 28 could be implemented as a small-pored alumina material of the type that is commercially available for use as a filter. The capillary material of the vaporizer preferably has an average pore size of 0.5 microns, yielding an average pore radius of 0.25 microns. The capillary material also preferably has a thermal conductivity of about 2.2 W/mK and a permeability of about 1.5×10^{-14} m^2. A suitable capillary material, constructed according to the disclosed embodiments of the present invention, may be made by methods known in the art, such as drain casting.

In one preferred embodiment, the vaporizer 28 has a first surface 30 and a second surface 32. The first surface 30 of the vaporizer 28 defines a passage 34 that collects and supplies the heat transfer fluid to the first surface 30 of the vaporizer 28. The passage 34 of the vaporizer 28 is in communication with a liquid transfer line 16 that is capable of allowing liquid entry of the heat transfer fluid in the evaporator 20. The passage 34 of the vaporizer 28 is also in communication with a fluid management system 12, such as a reservoir or compensation chamber, that is capable of supplying or storing heat transfer fluid during changes in operational mode. The liquid transfer line 16 extends from the passage 34 of the vaporizer 28 through an opening 36 in the exterior of the evaporator 20.

The vaporizer 28 is preferably positioned coaxially in the cavity 26 of the evaporator 20 so that the second surface 32 of the vaporizer 28 is in contact with the interior surface 24 of the evaporator 20. A channel 38 for venting vapor is formed between the second surface 32 of the vaporizer 28 and the interior surface 24 of the evaporator 20. The channel 38 is preferably formed by fabricating axial grooves in the interior surface 24 of the evaporator 20. The channel 38 may also be formed by fabricating axial grooves in the second surface 32 of the vaporizer 28 while the interior surface 24 of the evaporator 20 remains substantially smooth or has circumferential grooves. The channel 38 is in communication with the vapor transfer line 17.

The transfer lines according to the present invention preferably include a vapor transfer line 17 and a liquid transfer line 16. The transfer lines may be made of any suitable material that is compatible with the heat transfer fluid. The vapor transfer line 17 is in communication with the condenser 14, and is intended to transmit the heat transfer fluid in a vapor phase to the condenser 14.

The condenser 14 is utilized to cool the vapor as it flows through the condenser 14. The condenser 14 includes a housing 40 having an interior portion 42. Within the condenser 14, the vapor condenses back into the liquid form. Preferably, the condenser 14 is in thermal communication with a heat sink to dissipate the heat. The condenser 14 could be cooled by air flow, refrigeration, thermal radiation, or the like. After the vapor condenses back into the heat transfer fluid, the heat transfer fluid is transferred through the liquid transfer line 16 to the evaporator 20 and the fluid management device 12.

The fluid management device 12, such as a compensation chamber or reservoir, allows the heat transfer device 10 to operate under a wide range of temperatures and in a variety of heat transfer applications. The fluid management device 12 includes an accumulator (not shown) that provides a chamber for holding excess fluid. For example, when the heat transfer fluid is heated, it may expand such that the passage 34 in the vaporizer 28 may not be able to hold all of the heat transfer fluid. As a result, the heat transfer fluid may flow into the accumulator. The fluid management device 12 is in communication by the transfer lines with the condenser 14.

In using the heat transfer device according to the preferred embodiment of the invention, the evaporator 20 is placed near or adjacent to a heat source. When heat is conveyed to the exterior surface 22 of the evaporator 20, the evaporator 20 absorbs the heat. As the temperature rises in the interior of the evaporator 20, the heat transfer fluid changes from a liquid state to a vapor state, thereby absorbing heat. The vapor collects in the channel 38, then flows into the vapor transfer line 17 as a result of the capillary pressure head of the vaporizer 28. The vapor flows through the vapor transfer line 17 to the condenser 14 where it begins to cool and condense.

As the vapor cools, heat is released and the vapor changes from its vapor state into a liquid state. The pressure exerted by the capillary head of the menisci causes the fluid to flow back toward the evaporator 20 through the liquid transfer line 16. The fluid then returns to the evaporator 20. The capillary action in the vaporizer 20 causes the fluid to be continually supplied to the first surface 30 of the vaporizer 28 for evaporation. Preferably, the heat transfer fluid is ammonia. The heat transfer fluid could be any of the known commercially available heat transfer fluids.

Referring to Figure 3, a diagram is shown illustrating a predicted performance of a loop heat pipe having a vaporizer according to the present invention as a function of the elevation between the bottom of the condenser and the top of the evaporator. The model predicts that at 70°C, where the conventionally wicked ammonia loop heat pipe (LHP) can transport 1.2 kw in zero-g and 600 watts over an adverse elevation of 2 meters, the same LHP with the alumina wick can transport 3.9 kW in zero-g and 600W over 15.1 meters of adverse elevation. The LHP in this analysis had an evaporator length of 12 inches and a wick outer diameter of less than 1 inch. All geometric parameters for the system, including line lengths, line diameters, and condenser configuration were identical from case to case.

The markedly increased pumping capacity of the heat transfer device 10 according to the present invention enables spacecraft to have larger deployables with greater flexibility. For example, the smaller pores of the vaporizer 28 enables a factor of four increase in the available pumping head of the loop heat pipe, and a 40-fold increase in the capillary pumped loop. Thus, the vaporizer 28 allows significantly greater heat transport capabilities. This greater pumping capacity allows the operation of cooling systems under increased gravity or acceleration loads such as in missiles, aircraft, launch vehicles, high-speed automobiles or in rotating systems, such as Hughes® Aircraft spin-stabilized spacecraft, such as HS376™, for heat transfer from an inner radius heat source to an outer radius heat sink.

The heat transfer device 10 also enables heat pipe configurations to be used with greatly reduced constraints as to the relative locations of the heat source and heat sink. For example, the heat transfer device according to the present invention can transport 1000 watts of heat at an adverse elevation of about 14 meters in a loop heat pipe configuration. In a terrestrial application, this would allow heat to be acquired almost anywhere in a 3-story building and be delivered to a heat sink, either a conventional cooler or thermal storage, at or below ground level.

The low thermal conductivity of the vaporizer 28 of the heat transfer apparatus allows the device, if configured like an LHP, to initiate flow at a lower heat input level. In addition, the manufacture techniques for the ceramic material are not constrained to a length of 12 inches or less. Thus, longer evaporators may be manufactured having lower temperature drops or higher thermal conductance.

Although the present invention has been described in detail by way of illustration and example, various changes and modifications may be made without departing in any way from the spirit of the invention and scope of the appended claims.

Claims

1. A vaporizer, comprising a first surface (30) and a second surface (32), the first surface (30) contacting a heat transfer fluid and the second surface (32) evaporating the heat transfer fluid, characterized in that the vaporizer (28) comprises a ceramic material.

2. The vaporizer of claim 1, characterized in that it is a ceramic vaporizer (28).

3. The vaporizer of claim 1 or 2, characterized in that it comprises a porous and permeable ceramic material that is thermally insulating and chemically compatible with the heat transfer fluid.

4. The vaporizer of any of claims 1 - 3, characterized in that it is cylindrically shaped with an opening (36) therein.

5. The vaporizer of any of claims 1 - 4, characterized in that the first surface (30) is an interior surface of the vaporizer (28) and the second surface (32) is an exterior surface of the vaporizer (28).

6. The vaporizer of any of claims 1 - 5, characterized in that the pore size of the vaporizer (28) is about 0,5 micrometer.

7. The vaporizer of any of claims 1 - 6, characterized

in that the thermal conductivity of the vaporizer (28) is about 2,2 W/mK.

8. The vaporizer of any of claims 1 - 7, characterized in that the permeability of the vaporizer (28) is about $1{,}5 \times 10^{-14}$ m^2.

9. The vaporizer of any of claims 1 - 8, characterized in that the heat transfer fluid comprises ammonia.

10. The vaporizer of any of claims 1 - 9, characterized in that the ceramic material is drain casted.

11. A heat transfer apparatus, comprising at least one evaporating chamber (38), a vaporizer (28) disposed at or preferably within said evaporating chamber (38), and a condensor (14) in communication with the evaporating chamber (38), characterized in that said vaporizer (28) comprises a ceramic material.

12. The heat transfer apparatus of claim 11, characterized in that the vaporizer (28) is the vaporizer (28) of any of claims 1 - 10.

13. The heat transfer apparatus of claim 11 or claim 12, characterized in that the vaporizer (28) is in thermal communication with a heat source.

14. The heat transfer apparatus of any of claims 11 - 13, characterized in that it comprises an evaporator (20) having an inner surface (24), a second surface (32) of the vaporizer (28) is in contact with the inner surface (24) of the evaporator (20) to form said at least one evaporating chamber (38), the evaporating chamber (38) is in communication with a vapor transfer line (17), and a first surface (30) of the vaporizer (28) is in communication with a heat transfer fluid.

15. The heat transfer apparatus of any of claims 11 - 14, characterized in that it comprises a fluid management device (12) in communication with the evaporator (20).

16. A method of transferring heat, comprising the steps of:

applying heat to an evaporator (20) having a heat transfer fluid;
evaporating the heat transfer fluid through a ceramic vaporizer (28) to form a vapor;
condensing the vapor into the heat transfer fluid; and
supplying the heat transfer fluid to the evaporator (20).

FIG. 1

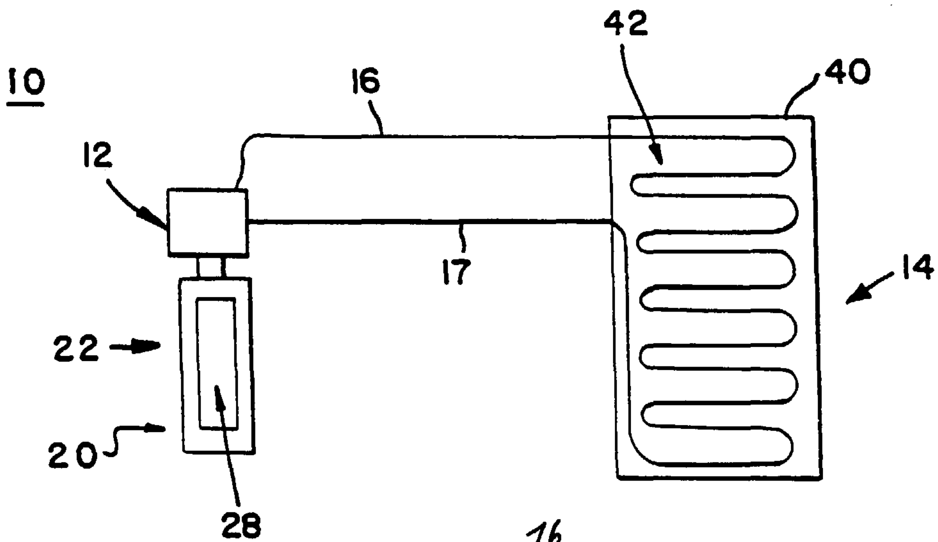


FIG. 2

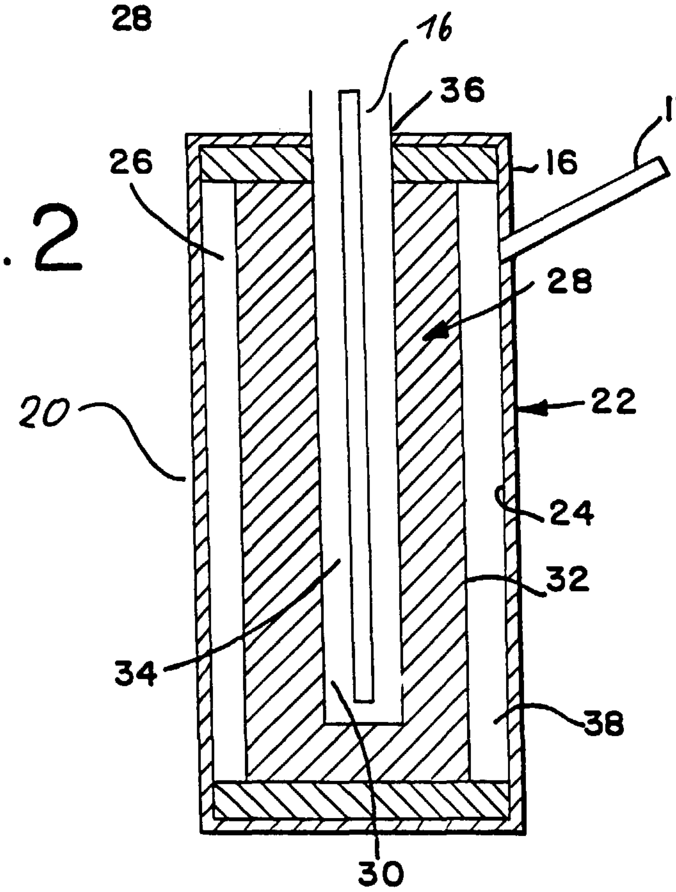
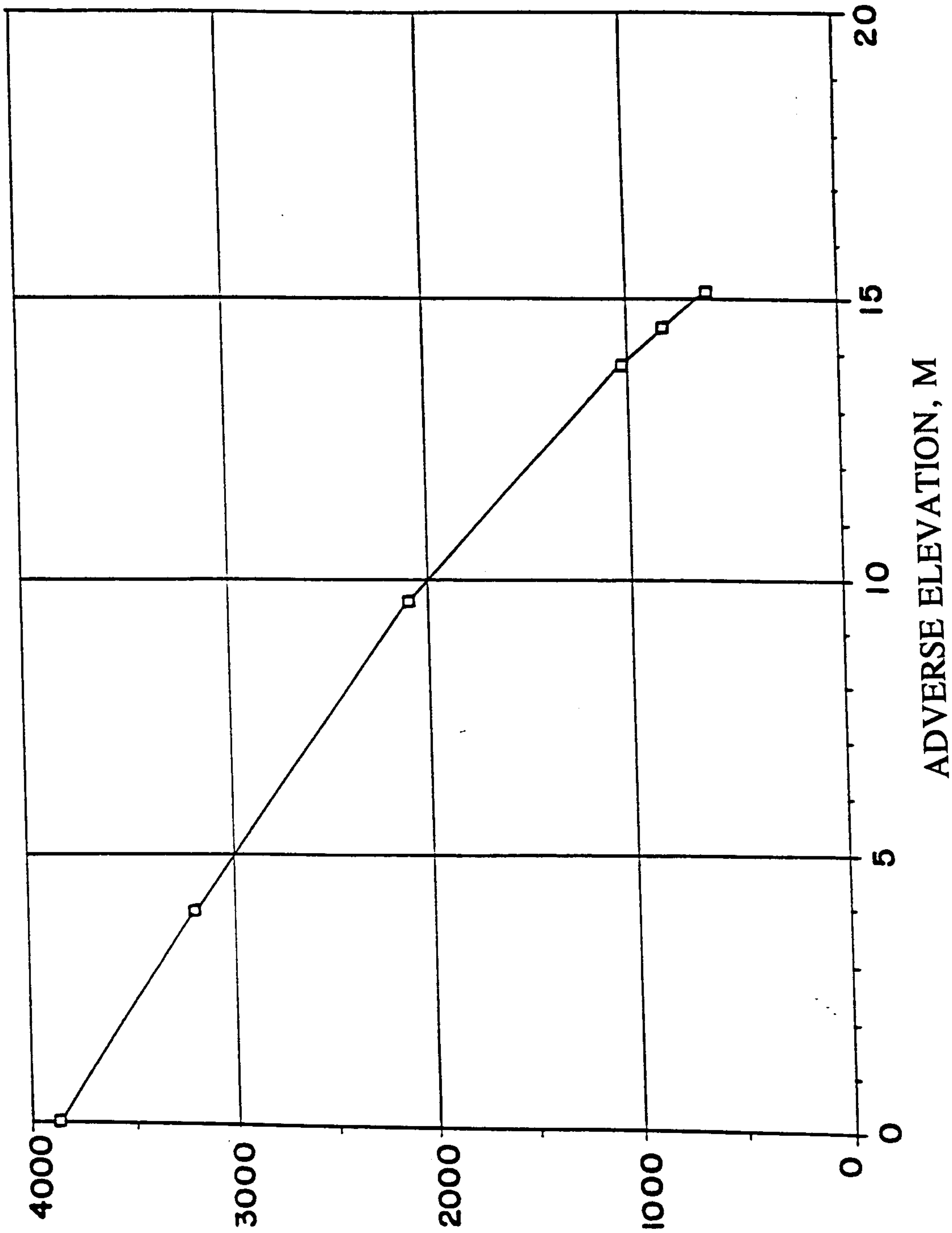


FIG. 3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