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Heat utilisation technologies: A critical review of heat pipes

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ABSTRACT

In electrical or thermal appliances, heat (thermal energy) must either be added into or removed from a system to maintain operational stability. Heat pipes can enhance the heat transfer capabilities without needing a significant temperature gradient between heat sources and heat sinks. The effectiveness of heat pipes is due to the latent heat of phase change of the working fluid within (i) condensation and (ii) evaporation stages. The latent heat of phase change greatly exceeds the sensible heat capacity. Heat pipes may rely on gravity, wicks, centrifugal force or in some cases even a magnetic field to help return condensate flow from the condenser to the evaporator. Wicks in heat pipes are classified into three groups: sintered, groove and mesh types. This review attempts to cover various types of heat pipes such as thermal diodes, variable conductance, pulsating, etc. The application of nanotechnology in heat pipes can be separated into two groups: nanoparticles and nanobubbles, with the latter receiving considerably less attention than the former. The hybridisation of heat pipe technology is also possible and has been discussed along with its future research potential.

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1. Introduction

70% of the energy that the world uses is in the form of heat. Due to increasing energy prices, it is very important to enhance heat transfer processes and reduce irreversibility (emanating from heat and frictional losses), to reduce energy usage and carbon footprint [1]. There are two methods to achieve this reduction in the form of heat exchangers or heat pipes. This paper will attempt to review and investigate the diversity of heat pipes.

The benefits of heat pipes (Fig. 1) include high thermal conductivity, high heat flux and is a passive heat transfer device which does not require large temperature gradient between heat source and heat sinks [2] for efficient heat transfer. Heat pipes are effective because the latent heat of phase change of the working fluid greatly exceeds its sensible heat capacity. Heat pipes have two important sections, i.e. the evaporator and the condenser. The vapour moves rapidly from the evaporator to the condenser because the vapour pressure of the working fluid at the evaporator is higher than the vapour pressure at the condenser. Liquid movement is in the opposite direction to vapour movement, where the movement of the liquid from the condenser to the evaporator is facilitated either by capillary force using wick [3] or gravity induced/type effect.

At the heat source, heat is extracted due to latent heat of evaporation where the working liquid phase-changes to vapour at the evaporator, while heat is released at the heat sink where the vapour phase-changes back to liquid (releasing latent heat of condensation) at the condenser. There have been many applications in various industries such as chemical and petrochemical, power generation, HVAC (heating, ventilation and air conditioning) systems, metallurgical, ceramics and cement, electronic, mechanical, and aeronautical [4]. The charge ratio of a heat pipe is a parameter that defines the volume of liquid in the heat pipe to the total overall volume of the heat pipe.

Heat pipes are usually denoted by two types of critical heat fluxes, i.e. nucleate boiling (see Fig. 2) and dry-out [5]. Nucleate boiling occurs when surface temperature of the heat pipe wall is a few degrees centigrade above saturated fluid temperature. When dry-out starts to occur, the droplets are continually torn from and re-join the thin liquid film around the channel wall due to rapid convection. At the location of the dry-out, the liquid film gradually disappears, causing the heat transfer coefficient to drop off drastically.

A heat pipe is created by removing air from the empty heat pipe and then filling it with a fraction of a working fluid which matches the desired operating temperature of the heat pipe. Alternatively, the pipe is heated until the working fluid boils and then sealed while it is hot.

For selection of the working fluid, surface tension is an important property. Higher surface tension will increase the capillary effect and it must be chemically stable in the presence of wicks. Depending on the type of heat pipes used (which will be described in the next section), wicks can be optional. Wicks provide extra surface area to exert capillary pressure on the liquid phase of the working fluid to direct it back to the evaporator end. The wick structure is typically a sintered metal powder or a series of grooves parallel to the pipe axis. The heat pipe may not need a wick structure if gravity or other sources can overcome surface tension, therefore causing the condensed liquid to flow back from the condenser to the evaporator. Heat pipes that use gravity for assistance are called thermal diodes or thermosyphons. Alternative techniques apart from gravity and capillary actions include centripetal forces and osmosis. Sharp angled corners are sometimes used to provide capillary pressure too.

The heat pipe can be a highly effective tool for thermally managing and controlling chemical processes that are exothermic or endothermic as they provide: (i) separation of heat source and heat sink, (ii) keeping temperature uniform and constant, and (iii) temperature control, i.e. fast response time [6].

Heat pipes can be used in various temperature ranges. Yang et al. [2] grouped the heat pipes into four categories:

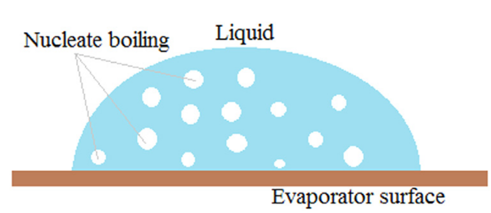

Fig. 2. Nucleate boiling.

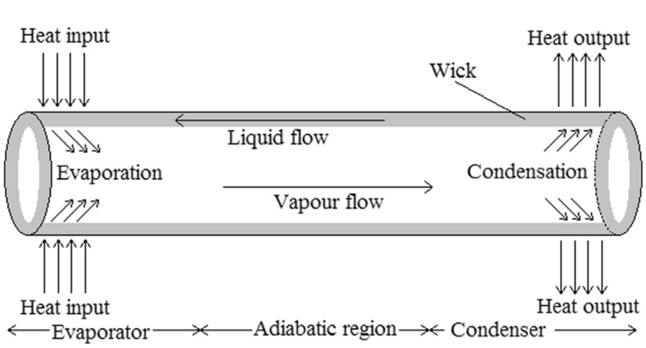

Fig. 1. The structure of a heat pipe.

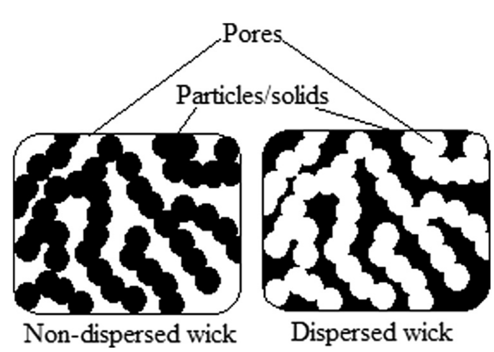

Fig. 3. Illustration of non-dispersed and dispersed porous wicks [9].