CHAPTER II

REVIEW OF HEAT PIPE

Historical Development

In most obvious success of the heat pipe is the wide range of application, in which its unique properties have proved beneficial. Some of these applications include the following:electronics cooling, diecasting and injection moulding, heat recovery and other energy conserving used, cooking, cooling of batteries, control of manufacturing process temperature, and as a means of transferring heat from fluidized beds, etc.

The heat pipe concept was first put forward by R.S. Gauler of the general Motors Cooperation, Ohio USA. In a patent application dated December 21 st, 1942, and publish (1) as US Patent No. 2350348 on June 6th 1944, the heat pipe was decribed as applied to a refrigeration system. The heat pipe as proposed by Gauler was not developed beyond the patent stage, as other technology currently available at that time was applied to solve the particular thermal problem at General Motors Cooperation.

Grover's patent (2), filed on behalf of the united States Atomic Energy Comission in 1963, coined the name "heat pipe" to describe devices essentially identical to that in the Gaugler patent. Grover, however included a limited theoretical analysis and presented results of experiments carried out on stainless steel heat pipes incooporating a wire mesh wick and sodium as the working fluid. Lithium and silver were also mentioned as working fluids.

An extensive programme was conducted on heat pipe at Los Alamos Laboratory, USA, under Grover, and preliminary results were reported in the first publication on heat pipes (3). Following this, interest in the heatpipe has grown considerably. Work was started on liquid metal heat pipes by Dunn at the United Kingdom Atomic Energy Laboratory and by Neu and Busse at the Joint Nuclear Research Centre, Ispra, in Italy. The work at Ispra built up rapidly and the laboratory become the most active centre for heat pipe research outside the US.

The first commercial organisation to work on heat pipes was RCA (4,5), during the two-year period from mid-1964 to mid-1966 they made heat pipes using glass, copper, nickel, stainless steel, molybdenum and TZM molybdenum as wall materials. Working fluids included water,caesium, sodium, lithium and bismuth.

During 1967 and 1968 several articles appeared in the scientific press, USA. One point stressed was the vastly increased thermal conductivity of the heat pipe when compared the solid conductors such as copper, a water heat pipe with a small wick having an effective conductivity several hundred times that of a copper rod of similar dimensions.

By now the theory of the heat pipe was adequatedly developed, based largely on the work of Cotter (6), also working at Los Alamos. In 1969 Cheung (7) listed over 80 technical papers on all aspects of heat pipe development. He was able to conclude that the reliability of liquid metal heat pipe under long term operation (9000 hr) at elevated temperatures (1500 C) had been demonstrated.

The early 1970's saw a considerable growth in the application of heat pipes to solve terrestial heat transfer problems. One of the major engineering projects of the 1970's, the construction and operation of the Trans-Alaska oil pipeline, made use of heat pipe technology. More recently, specialized international conferences have been held on heat pipes. The first of these was in Stuttgant (West Germany) in 1973, the second in Boloya (Italy) in 1976, and the third in San Francisco (USA.) in 1978, and so on.

The interest in heat pipes comes from the whole range of outstanding properties which such heat conductors possess. Most important is high degree towhich they are isothermal. In fact, pipes with liquid metal heat transfer media can have an effective heat conductivity a thousand or even tens of thousands times greater than that of the best metallic heat conductors, silver and copper. Even low-temperature pipes can have a thermal conductance several tens times more than the best metallic conductors. Heat pipes also work efficiently under terrestial conditions. Gravitational forces can assist the transfer of the working fluid and appreciably increase the heat transfer capacity of these devices. Heat pipes can be used over a very wide temperature range, from low, cryogenic temperatures (starting from 1 K) to the highest (2500-3000 K). By 1977 it has become established as a most useful device in many mundane applications, as well as retaining its more glamorous status in spacecraft temperature control (8).

Work On Heatpipe Startup

Heat pipe startup behavior is difficult to predict and may vary considerably depending on many factors. The effects of working fluid and wick behavior and configuration on startup behavior has been obtained by J.E. Kemme in 1966. During startup, vapor must flow at a relatively high velocity to transfer heat from the evaporator to the condenser, and the pressure drop through the centre channel will be large. Since the axial temperature gradient in a heatpipe is determined by the vapor pressure drop, the temperature of the evaporator will be initially much higher than that of the condenser. The temperature level reached by the evaporator will, of course, depend on the working fluid used. If the heat input is large enough, a temperature front will gradually move towards the condenser section.

During normal heatpipe startup, the temperature of the evaporator will increase by a few degrees until the front reaches the end of the condenser. At this point the condenser temperature will increase by a few degrees until the front reaches the end of the condenser. At this point the condenser temperature will increase until the pipe structure becomes almost isothermal.

Heat pipes with screen covered channels behave normally during startup as long as heat is not added too quickly. Kemme found that the heat pipes with open channels did not exhibit straight forward startup behavior. Very large temperature gradients were measured, and the isothermal state was reached in a peculiar manner.

In some instances during startup, when the vapor density is low and its velocity high, the liquid can be prevented from returning to the evaporator. This is more likely to occur when open return channels are used for liquid transfer than when porous media are used.

More recent work by van Andel (9) on heatpipe startup has enabled some quantitative relationships to be obtained which assist in assuring that satisfactory startup can occur. This is based on the criterion that burn-out does not occur, i.e. the saturation pressure in the heated zones should not exceed the maximum capillary force. If burn-out is allowed to occur, drying of the wick results, inhibiting the return flow of liquid.

Since for low values of heat flux the heat will be transported to the liquid surface partly by conduction through the wick and liquid and partly by natural convection. Evaporation will be from the liquid surface. As the heat flux is increased, the liquid in contact with the wall will become progressively superheated and bubbles will form at nucleation sites. These bubbles will transport some energy to the surface by latent heat of vaporization and will also greatly increase convective heat transfer. With furthur increase of flux a critical value will be reached, burnont, at which the wick will dry out and the heat pipe will cease to operate because in order for the heat pipe to operate the maximum capillary pumping head (ΔP_c) max must be greater than the total pressure drop in the pipe. This pressure drop is made up of three components

(a) The pressure drop ΔP_l required to return the liquid from the condenser to the evaporator.

(b) The pressure drop ΔP_v necessary to cause the vapor to flow from the evaporator to the condenser

(c) The gravitational head ΔP_g which may be zero, positive or negative

Thus

$$(\Delta P_c)_{max} > \Delta P_l + \Delta P_v + \Delta P_g$$

If this condition is not met, the wick will dry out in the evaporator region and the pipe will not operate.

It is important to meet startup criteria when a heatpipe is used in an application which may involve numerous starting and stopping actions, for example in cooling a piece of electronic equipment or cooling brakes. One way in which the problem can be overcome is to use an extra heat source connected to a small branch heatpipe when the primary role of cooling is required, thus reducing the number of startup operations.

AVAILABLE WORK ON HEATPIPE STARTUP

1. MATHEMATICAL MODEL AND EXPERIMENTAL STUDY OF THE STARTUP REGIMES OF UNCONTROLLED AND GAS-CONTROLLED LOW-TEMPERATURE HEAT PIPES

   By V.V. BARSUKOV, V.I. DEMIDYUK and G.F. SMIRNOV

   Abstract: A mathematical model of the startup regimes of uncontrolled and gas-controlled heat pipes is developed and the results of experiments are given. The experimental data are compared with the calculations.

2. TRANSIENT THERMAL IMPEDANCE OF A WATER HEAT PIPE

   By S.W. KESSLER, Jr.

   Abstract: A silicon rectifying junction was used as a heat source to study the transient thermal impedance of water heat pipes. The temperature of the evaporator, the vapor space, and the condenser of the heat pipes were monitored. The operation of the heat pipes was observed during the time period of 8.3 ms to 1,000 s. After 200 s, th heat pipes were operating in a steady-state mode. The heat pipes were successfully started with peak heat fluxes of 105 w/sg.cm. with the working fluid frozen as well as in a liquid state. An analysis was made of both startup conditions. The heat pipes were also pulsed to a power density of 2,500 w/sq.cm.

3. HEAT PIPE CAPABILITY EXPERIMENTS

By J.E. KEMME

Abstract: Axial heat transfer limits were determined for several heat pipe systems, having the same outside dimensions, but different wick configurations. Measurements were made at temperatures from 450 to 850 C by using potassium and sodium as working fluids. The wick consisted of many axial channels, evenly spaced around the inside circumference of each container tube. Different size channels were studied; and, in some tests, a layer of fine screen was used to cover the channels and separate them from the vapor passage. The experiments were chosen to show some possible methods for wick improvement and to check the validity of existing heat pipe equations.

At higher test temperatures, good asgreement was obtained between measured and calculated heat transfer limits. At low temperatures, however, heat transfer capability was below that predicted by theory, and startup difficulties were encountered with the open channel systems. These problems appear due to an interaction between low density, high velocity vapor and returning liquid. Th screen covering helped startup and substantially increased heat transfer capability at all operating temperatures.

4. ENGINEERING METHODS OF LOW-TEMPERATURE HEAT PIPE DESIGNING CALCULATIONS

By G.F. SMIRNOV, V.V. BARSOOKOV, L.N. MISHCHENKO

Abstract: Engineering methods of designing calculations and a mathematical model of start-up conditions for gas-controlled and non-controlled low-temperature heat pipe operation were developed and an example of designing calculations for a cooling system with heat pipes was demonstrated.

5. SONIC LIMITATIONS AND STARTUP PROBLEMS OF HEAT PIPES

By J.E. DEVERALL, J.E. KEMME, AND L.W. FLORSCHUETZ

Abstract: In the design of heat pipes, consideration must be given not only to the internal structure and fluid dynamics of the pipe but also to the external conditions imposed on it. Several tests of heat pipes were made under different operating conditions to demonstrate the effect of sonic vapor velocities and related startup problems which influence heat-pipe design. Derivations are presented for the pressure, temperature, and density relationships encountered in the vapor flow stream, and tolds of sonic limits for various heat-pipe fluids are included.