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Studies on Operation of Ammonia Heat Pipe with Multiple Heat Sources

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Abstract: -- The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by gaugler in 1942 until its independent invention by groover (1960s). The heat pipe is similar in some respects to the thermosyphon. Most commonly used heat pipes for Spacecraft applications use Ammonia as the working fluid and are made up of an Aluminum extrusion with axillary grooved that works as the wick. This study attempts to understand the operation of Ammonia heat pipes with multiple heat sources.

Keywords: Heat pipe, Multiple heat sources, Thermo syphon, Thermal conductance.

I.INTRODUCTION

A. Heat pipe

A heat pipe is a device or equipment of higher thermal conductance, used to maintain thermal equilibrium of electronic equipment.

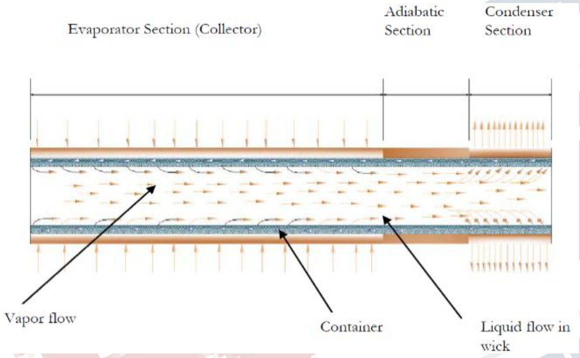

Fig.1. Heat pipe[1]

The above Fig. 1 gives a typical view of a standard heat pipe which comprises of evaporator section which is called as heat collector, adiabatic part and condenser section where heat is liberated, liquid flow inside the heat pipe is shown which is discussed in depth on proceeding s of this report.

The idea of heat pipe is initially come to picture in 1944 by the scientist called Gaugler and in 1962 by Trefethen. After this scientist by name Groover and his working friends at the Los Alamos in the lab investigated and again invented the conceptual principle of heat pipe.

Groover also practically demonstrated effectiveness of heat pipe as high performance energy (in the form of heat) transferring unit called it as heat pipe and further he also developed the applications of the heat pipe. After Groover, Dunn has started research on liquid metal heat pipe at Harwell and Neu and Busse at Ispra where both of this team was in investigation a developing Nuclear-powered thermionic generators and these concentration towards the heat pipe development resulted in heat pipe for terrestrial and space applications. Groover idea of Heat pipes was taken by NASA and in 60's, invented heat pipes particularly for space applications. The main problem in space applications was to transport the heat from the inside of higher concentration to the outside of lower concentration, because the heat conduction in a vacuum is extremely limited during operation. The conceptual idea behind this is to create a fluid flow field which passes heat from section point/part to other by way the convection, because convective thermal energy transporting is much greater than conduction and then by rejecting heat to space by radiation [13].

The heat pipe includes a closed circular hollow tube which is made of a metal which is acceptable with operating fluid as said in proceedings in this report for suitable material the suitable fluid used.

B. The operating fluid

The conceptual development of heat pipe initially comes up with the selection of correct working fluid. For selection of operating fluid, we must consider the many of factors. The operating temperature is the first factor to be fulfilled by the working fluid for the effective operation. In solar collector, this will be the important step since it determines the upper and lower temperature of heat pipe operation. The following are the some of the factors to consider for the selection of right working fluid.

- Suitable agreement with the wick and the tube material
- Better and acceptable thermal stability for good operation
- Liquidability of wick and wall materials in practical

- Not too high or low vapor pressure over working temperature range
- Very high latent heat for effective operation
- Higher and better thermal conductivity for better transport
- Lower liquid viscosity with lower vapor viscosity for low resistance operation

For the heat pipe to be in operation, its structure of wick should be saturated with working fluid liquid state. The working substance from cryogenic fluids to liquid metals have already been developed based on this heat pipes can be divided into cryogenic, medium temperature (-240F or 122K), fluid metal heat pipes (670F or 628K) these are logical since

- The normal boiling point of working gases such as H2, neon, N2, O, and CH4 lies below the -240F/122K.
- Metals working fluids like potassium, sodium, cesium, lithium and silver lies mercury, greater than 670F/628K.
- Refrigerants and liquid as water, ammonia, Freon and methanol all boils less than one standard atmospheric pressure at temperature of -240F/122K.

B. Wick structure

Wick is the structure/layer imparted to provide the capillary action to overcome gravitational force in space application thus ensuring perfect movement of the working fluid in working conditions.

The purpose of the wick can be said as

i. The required path of passage for coming back of the condensate liquid during operation.
ii. To provide pores at the surfaces for establishment of capillary pumping pressure in required pattern at the liquid-vapor interface.
iii. To create the heat flow passage in between the container inner wall and liquid vapor interface

Some of the materials used as wick are Mesh screen, fiberglass and sintered porous metal and narrow grooves at inner surface of the container wall.

Table 1 Properties difference of Cryogenic, moderate-temperature and Fluid metal heat pipes at normal boiling conditions [10].

C. Concept of working of heat pipe

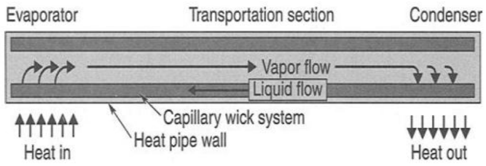

Fig.2. operating principle of a heat pipe

One must understand the concept and operation principle of heat pipe for better knowledge of the heat pipe. The figure 1.3 standard heat pipe with major parts and figure 1.4 shows the heat pipe with liquid and vapor flow paths.

Table 1
Properties of some working fluids

Properties	Fluid		
	Nitrogen	Ammonia	Sodium
Normal boiling temperature, 0F	-321	-28	1621
Liquid density, lbm/ft^2	50.61	42.5	46.1
Liquid surface tension, lbf/ft	6.1 x 10^{-4}	2.3 x 10^{-3}	7.9 x 10^{-3}
Liquid viscosity lbm/ft-hr	0.38	0.65	0.42
Liquid Thermal conductivity, Btu/lbm	0.080	0.32	31.8

Vapor density, lbm/ft^3	0.288	0.056	0.017

Heat pipe is attracting and much useful devices in the field of spacecraft cooling and thermal stabilization since they have very less weight a major advantage in higher altitude, very less problems, and reliability in reality. Maintaining constant temperature structures thus for maintaining thermal equilibrium is an important task under the adverse solar heating when satellite orbiting in space. Thus, one portion of the space machine is facing to heavy non purified solar radiation which is like evaporator and remaining is open to free space which is cooler side. Heat pipes have used here to maintain thermal equilibrium due to heat rays irradiated by the sun in a way to maintain the temperature of the structure.

The major components/parts the heat pipes as in fig.2 has are listed below

- Evaporator (heat source)
- Wick structure (capillary structure)
- Condenser (heat sink)
- Adiabatic section

NOMENCLATURE

μ = gravitational parameter
G = universal gravitational constant
m1 and m2 = mass of first and second body
r = position vector
k = thermal conductivity

II. SATELLITE THERMAL MANAGEMENT

When the motion of two bodies is considered in an inertial frame of reference, solely due to the mutual gravitational attraction between the two bodies, the path of one body relative to the other is a conic section (circle, ellipse, parabola, or hyperbola). The first body, relative to which the motion of the second body is considered, is called the primary body and the secondary body is called a satellite (of the primary body).

The equation of motion of a two-body probe is given as

$$\ddot{r} = -\frac{\mu}{r^3} r$$

Where,

$$\mu = G(m_1 + m_2)$$

is called as the gravitational parameter, G refers to universal gravitational constant and m1 and m2 are masses of two bodies where r is the position vector.

The primary body lies at one of the foci of the conic section that describes the path of the secondary body (satellite) relative to the primary body. The path of the secondary body is called an orbit.

The most “obvious” examples of one body orbiting another are Sun-Earth system and Earth-Moon system. In both cases, the orbiting body, Earth in the former and Moon in the latter, are called natural satellites. Objects or bodies placed into orbits around natural heavenly bodies by human beings are called artificial satellites. In the present work, the word “satellite” refers to an artificial satellite unless otherwise specified

III. NEED FOR THERMAL MANAGEMENT

Each and everything that involves transfer of energy or conversion of energy from one form to another produces heat due to the inherent inefficiencies associated with the processes of transfer and conversion. This is true for the human body, automobiles, chemical processes, power plants, and satellites. An “efficient” method of rejecting this “waste” heat is essential for the successful and safe operation of all systems. The absence of heat removal would eventually result in overheating and a catastrophic failure.

If the temperature limits of the satellite is maintained to a limit which it was designed and assembled for, then the operation of the satellite will be better and thus the performance of the satellite also. Thus for this the thermal management of the satellite system is very important. Thermal controlling of satellite is concerned with knowledge and practice in which this temperature gradient is created and the main job of a thermal engineer is to look into these parameters and identifying the influencing factors for these and manage them to get sati factional working of the whole satellite system. And there are some unique methods to analyze for this process to be carried out.

Thus satellite thermal management must start with establishing thermal specifications in which the satellite present in its various stages of its life for overcoming the obstacle of thermal control after which can be proceeded further. After this thermal design should be carried out with previously specified values particularly in orbit before which the analysis studies and tests to be carried out. When the satellite and it's all components perform better with integrity and satisfactorily for the short period temperature which is greater than expected then one can be in confident that thermal management will be of good quality when the same satellite is subjected to the long term operation in space [12].

IV. HEAT PIPES IN SATELLITE THERMAL RADIATORS

The only mode of heat rejection in a satellite is by radiation to deep space (2.73K). Heat dissipating components on a satellite are placed on thermal radiators that can reject heat by radiation. To increase the efficiency of thermal radiators, heat tubes are placed in the thermal radiator in a gridded pattern. The high effective conductivity provided by the heat pipes result in an isothermal radiator thereby improving the efficiency of heat rejection.

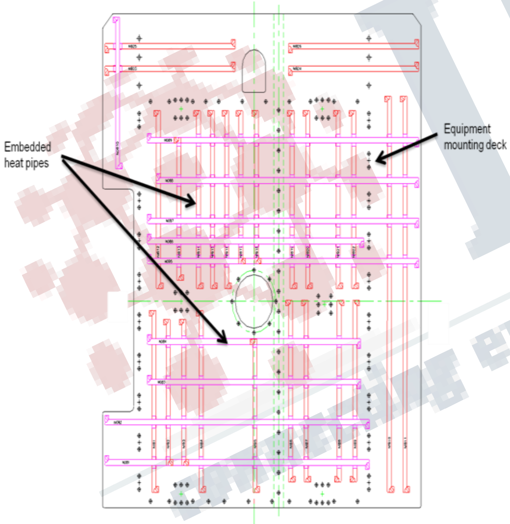

Fig.3. Satellite equipment deck with embedded heat pipes [1]

Fig.3 shows the satellite equipment deck with the embedded heat pipe as we can see there are number of heat pipes are embedded based on the source of heat from the satellite electronics.

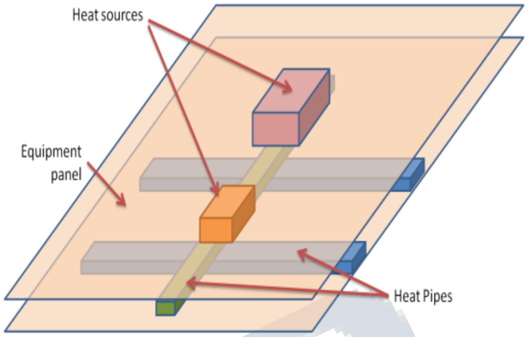

Fig.4. Embedded heat pipes in a honeycomb sandwich

The fig.4 shows the embedded heat pipes in a honeycomb sandwich with equipment panel and multiple heat sources from different satellite electronics as shown.

V. CONFIGURATION OF SATELLITE EQUIPMENT DECK WITH HEAT PIPES

The sample problem considered for the present study is a section of a satellite equipment deck with embedded heat pipes. There are three main heat pipes and six spreader heat pipes. Each main heat pipe has two electronics units mounted on one side. The heat dissipation in electronics 1 is 50W and in electronics 2 it is 25 W. The overall size of the deck is 1m x 0.5 m.

The configuration of the deck is shown in fig.5

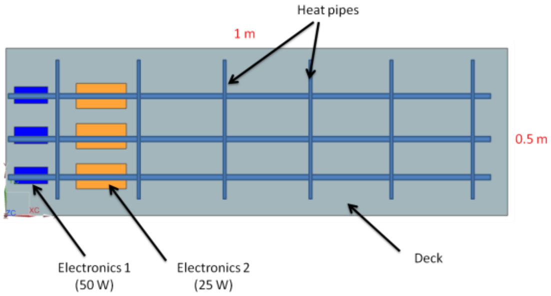

Fig.5. Equipment deck considered for analysis

Thermal radiator area of size 950 mm x 500 mm is provided on the other end of the deck. The remaining portion of the deck is provided with multi-layer super-insulation

The heat pipe cross-section is given in fig.6

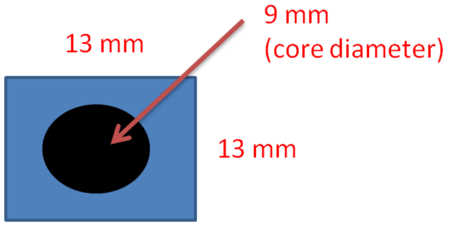

Fig.6. Cross section of heat pipe

VI. THERMAL MODELING AND ANALYSIS OF THE EQUIPMENT DECK

A thermal model of the calculation domain is prepared in Siemens NX 8.5. The FE mesh of the overall model is shown in fig. 7 Steady-state thermal analysis is done to estimate the temperatures and temperature balance of the heat pipe zone.

Table 2
The input parameters used for the analysis are summarized in the table below.

Parameter	Value
Deck size	1.50 m x 0.50 m
Deck thickness	13 mm
Deck skin thickness	0.3 mm
Deck material	Aluminium alloy
Deck out of plane conductivity	1.5 W/m K
Heat pipe cross section	13 mm x 13 m
Heat pipe type & casing material	Axially grooved ammonia heat pipe, aluminium alloy
Length of heat pipe	1.5 m
Electronics 1 heat dissipation	50 W
Electronics 2 heat dissipation	25 W
Radiator emittance	0.88
Sink temperature	2.73 K

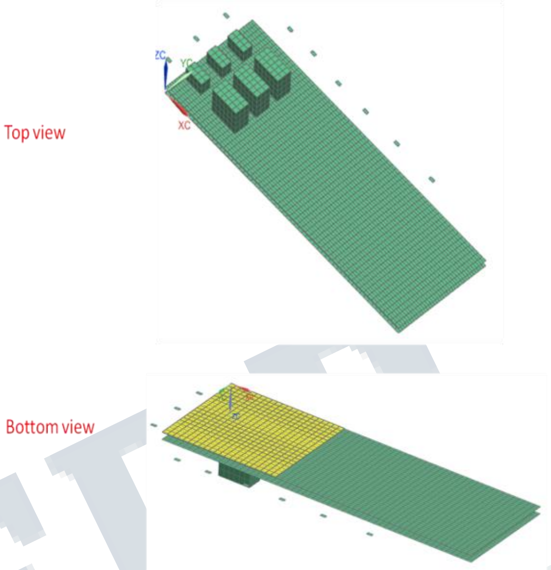

Fig.7. Finite element mesh of the solution domain

Steady-state temperature distribution on the equipment deck is shown in fig.8 from which we can come to know the distribution of temperature in the panel as given.

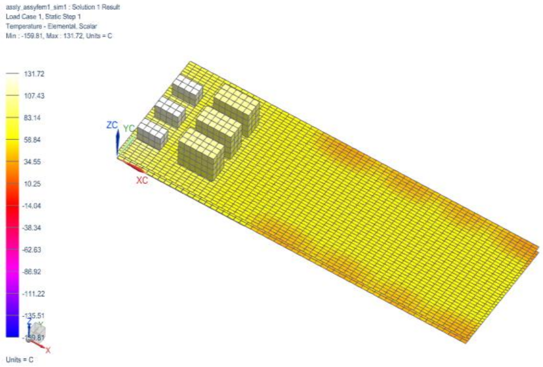

Fig.8. Temperature distributions on the equipment deck

Since the heat pipe in the center has symmetric boundary conditions, the input parameters for further modeling are derived from this heat pipe. The temperature distribution on the skin of the heat pipe is given in fig.9

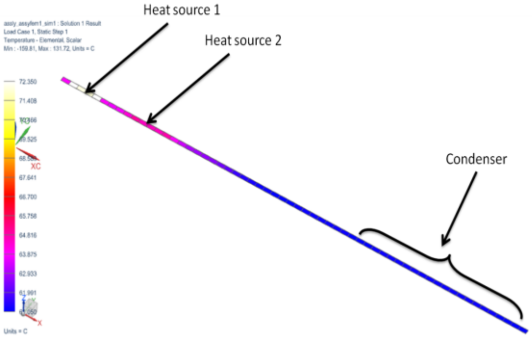

Fig.9. Distributions of temperature on the heat pipe

Inputs for modeling of heat pipe

The following inputs are derived from the above analysis for application of model by Shabgard and Faghri. The following table 3 gives the inputs and other details of specifications of heat tube as shown.

Table 3

1 Heat pipe inputs with specifications [5]

Parameter	**Value**
Evaporator	
Le_1,1	25 mm
Le_1,2	125 mm
Le_2,1	210 mm
Le_2,2	360 mm
Heat input 1	31.7 W
Heat input 2	13.5 W
Condenser	
Lc1	725 mm
Lc2	1500 mm
Cross-section of heat pipe	
r_0	13 mm
r_w	10 mm
r_v	8.5 mm
Heat pipe material and working fluid	
Casing material	Aluminium alloy
Wick type	Axially grooved
Working fluid	Ammonia
Operating pressure	8 bar

B.Mathematical model of the heat pipe with multiple sources

Assumptions made in the analysis of mathematical model of cylindrical heat pipe are [5]

- There is a steady state fluid flow and heat transfer
- Constant thermo physical properties of wall, wick and working fluid
- Axisymmetric heating and cooling of heat pipe
- There is a liquid saturated wick
- One-dimensional heat conduction in wick
- The gravitational force is neglected

The calculation domain is shown in following figure 10 below with two evaporators. Adiabatic boundary is assumed for end caps of heat tube and the geometrical parameters are as per table 3.

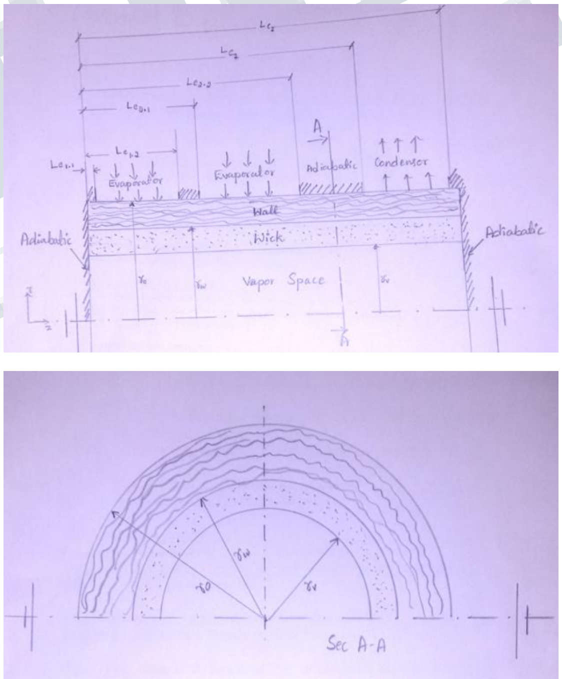

Fig.10. Sketch of Cylindrical heat pipe with two heat input.

VII. RESULTS AND DISCUSSION

In this analysis, casing temperature is evaluated using equations and compared with the distribution from the system level analysis.

system level analysis.

For the axially grooved heat pipe (no explicit wick material) the blow assumptions were done to simplify the analysis and use existing analytical solution presented in the previous section.

The thermal conductivity of the wick is approximated employing the relation,

$$k_{wick} = (1 - \epsilon)k_{wall} + \epsilon k_f$$

Where, k_f is the thermal conductivity of the working substance.

The wick-wall interface equivalent heat transfer coefficient is evaluated using

$$h = \frac{k_{wick}}{k_{wall} r_w log\left(\frac{r_w}{r_v}\right)}$$

The equations are solved in SCILAB for n=0 to 200. The heat pipe length is subdivided in 10 equal nodes.

The wall temperature distribution from the system level FE analysis is shown in fig.11 and the distribution obtained from the analytical analysis of heat pipe is given in fig.12.

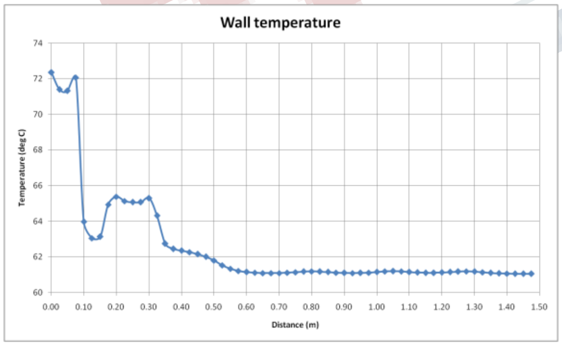

Fig.11. Wall temperature distribution from system level analysis

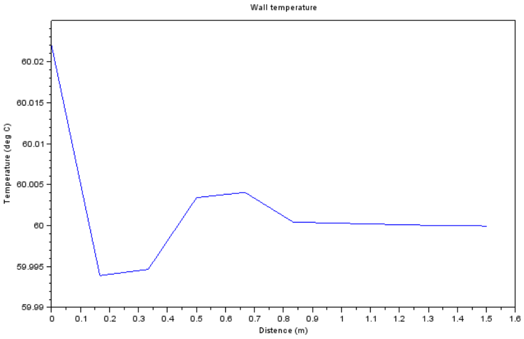

Fig.12. Wall temperature distribution from analytical model of heat pipe

The results are in partial agreement in terms of temperature levels; however, the profile of temperature along length of heat tube appears to follow a similar trend.
The difference in the results of the two analysis can be attributed to the 3-D heat flow in the system level analysis throughout the length that is not considered on analytical model.

VIII. CONCLUSION

A technique for analyzing operating responses of heat pipes with number of sources of heat in satellite thermal radiator applications has been demonstrated.
Results from system level thermal analysis of the satellite thermal radiator has been used to derive inputs for studying the working of main heat pipes with two heat inputs.
The present work applies the mathematical model presented by Shabgard and Faghri to estimate the operating condition of the heat pipe under steady-state operation.

IX. SCOPE FOR FUTURE WORK

In future continuation of the present work, liquid and vapor flows have to be modeled in addition to temperature profiles to get a complete understanding of the processes taking place in the heat pipe, Further, several other models available in literature can be applied to analyze the operating condition of heat pipes in similar applications.
Further, experimental validation of the results obtained by analysis can be carried out.

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