Design and Experimental Investigations of Single and Multi-Stage SPC- Cascade High Temperature Heat Pipe

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Abstract

This research article focused to design and experimental investigation of single and multi-stage heat pipes and focused to high temperature applications. Selected suitable materials and fluid for single and cascade heat pipes. Experiments done separately with Sodium, potassium and Cesium and combination of (SPC) heat pipe experiments. Both single and cascade heat pipe experiments used with variable heat inputs like 1000, 1500, 2000 and 2500 W and predicted performance. Axial temperatures difference measured by using contact and non-conduct temperature measurement instruments with Agilent Data Logger and integrated with Computer DAQ. Experiments results showed that, steady state temperature attained each stage after 35 seconds. Thermal resistance, heat transfer co-efficient and efficiency for both single and cascade system predicted, and found the working range. Single stage heat pipe with sodium, Potassium and Cesium experiments results showed that the operating range of heat Pipe varies from 650 to 720 deg C. The SPC cascade heat pipe was suitable for the range of 400 to 750 deg C. Heat transfer rate and efficiency of SPC cascade heat pipe increased 16 to 18% compared to single stage heat pipe and also suitable for variable heat input and different working temperature range.

Keywords:, Design of high temperature heat pipe, single and multi-stage fluid Heat Pipe, efficiency analysis, Heat Transfer Analysis.

I INTRODUCTION

Low temperature heat pipe is broadly used for different device like energy storage device and many computer processers, micro processes, electronics devices, electrical drives, solar energy storage device, super capacitor and ultra-capacitors for maintaining low temperature [1]. Hence, Sodium, potassium and Cesium (SPC) combination heat pipes research focused to study of increasing the efficiency, selection of suitable materials, compatibility of working range and high heat transport characteristics at high temperature area.[1][2]. SPC multistage high temperature heat pipe focused to predict the long time and high heat transfer characteristics. Hence required to develop the suitable multistage high performance heat pipe for different applications[3]. A 316L stainless steel material tube selected for both single and multistage stage heat pipe. Heat pipe wick structure sintered with porous nickel material for both single and multistage, and brazed with cartridge heaters. Heat pipe experiment was successfully operated with the range of 600 to 700 °C without and signs of damage and failures[4][5][6]. The previous research article showed that, the heat pipe fabricated with an Inconel 718 envelope with stainless steel screen wick and used with different applications. Some of them operated at nearly 700 °C with hybrid (gas-fired and solar) heat pipe with Haynes 230 envelopes. Wick structure was developed by sintered porous nickel materials and operated for about 22,000 hours at nearly 750 °C without signs of any failures and deprivations [7][8]. However, previous heat pipe was not suitable for the variation of heat load with respect to given design value[9]. Hence, this research article focused to design the suitable cascade high temperature heat pipe with variable heat load input. [1][10]. Based on the requirement the following four process are required to selection of suitable materials for both heat pipes, fluid property, and geometry parameters. They following design procedure are : 1) Selection of both single and multistage heat pipe materials namely the outer body and inner container, 2) selection of Tube materials for high temperature zone and high heat transfer, 3) selection of wick materials for working high temperature working fluids, 4) selection of suitable materials for given volume of condenser, evaporator[11] [12][13]. Subsequently, multistage heat pipe design process are involved many of the decisions for predict the suitable parameters. Both single and multistage heat pipe design and construction required for attaining given suitable working range. Selection procedures are interrelated for the design and performance process and attained for high heat transfer in high temperature working environment. Both single and multistage high temperature heat pipes are functioned between 400 and 1100°C.

II. DESIGN METHODOLOGY AND EXPERIMENTAL SETUP OF HIGH TEMPERATURE SINGLE AND SPC-CASCADE HEAT PIPE

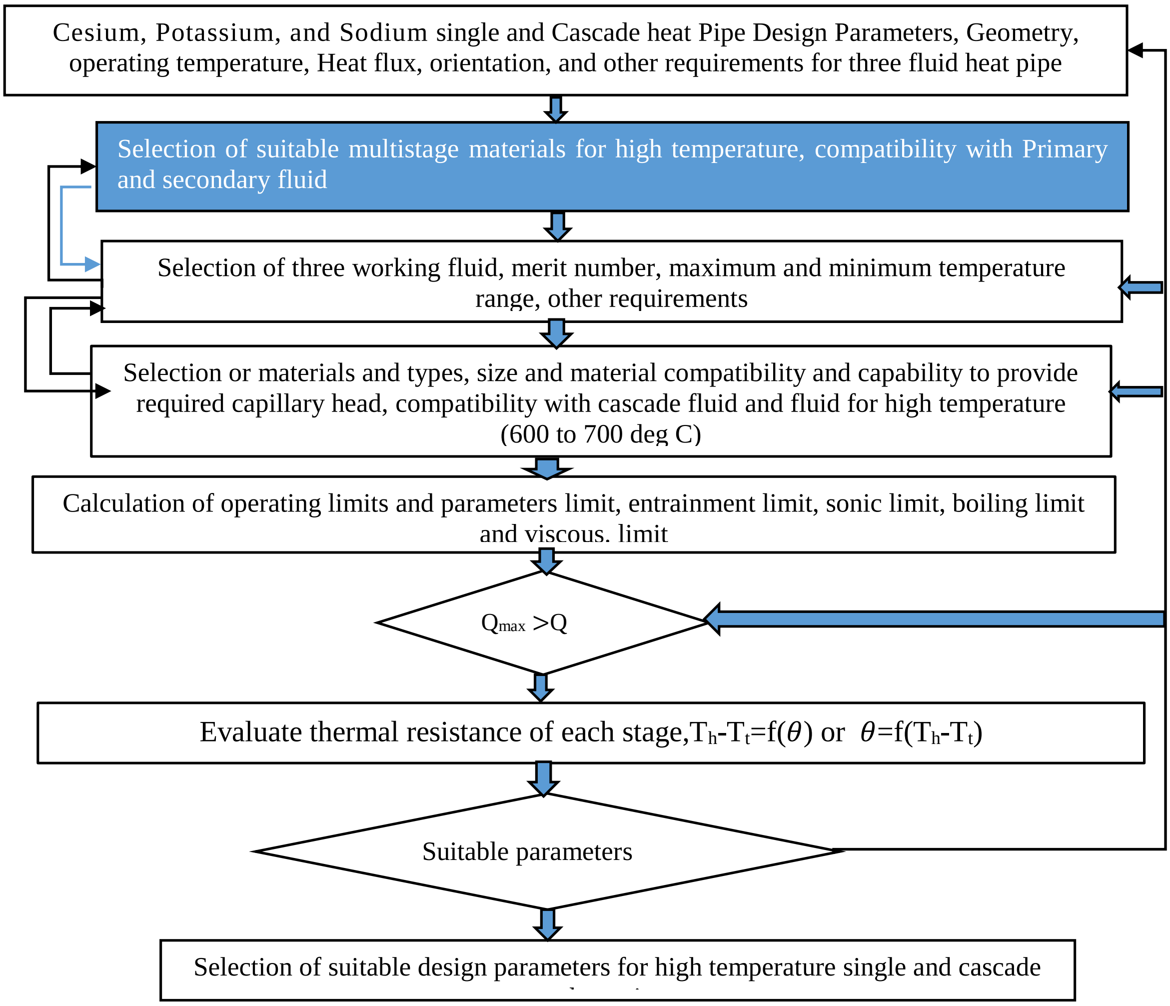

Figure 2.1 Design Procedure methodology for SPC cascade high temperature heat pipe

However, heat pipe fluid properties like SPC for too much across this wide temperature range, for suitable requirements for three fluids. Separately like Cesium, Potassium, and Sodium and combination of SPC three fluids used to cover this working range; both single and multistage heat pipe operating range for each fluids are required. The following fluid like Cesium working range from 300 to 600°C (572 to 1,112°F), Potassium working range 400 to 1000°C (752 to 1,832°F) and Sodium working range 500 to 1100°C (932 to 2,012°F) was required. The following applications are namely, Steam, Stirling, Brayton, and Rankine cycles, Heat Engine Receivers (HER), Solar Thermal power station, different high heat transfer Heat exchangers, High Mac Number wing leading edges, WHR boilers, Nuclear power plant, TEG-sectors and constant temperature furnace elements required to store the energy for high temperature applications with heat pipes for energy storage. The concept of design procedure and parameter selection methods of both single and cascade heat pipes are impotent for selection suitable device and procedures shown in figure 2.1. The design procedure followed systematically and required materials and fluids properties shown in table 1 and 2. Heat pipe research have many intensive investigations are done and resulted in rapid development and commercial production and used for different applications. Working fluid and suitable operating temperature range is very important for heat transfer applications. Based on the detailed reference used to the fluid the chosen of the operating range, tube materials, wick, and materials selected for high heat transfer applications. Authors suggested that, suitable working fluids and compatible with these materials was decided for selection of given applications and conducted suitable experiments [14][15]. The type of wick martials are suitable and capable of providing of the required capability head, and selected in the given temperature range.

A. Design Procedure of High Temperature single and SPC- cascade heat pipe

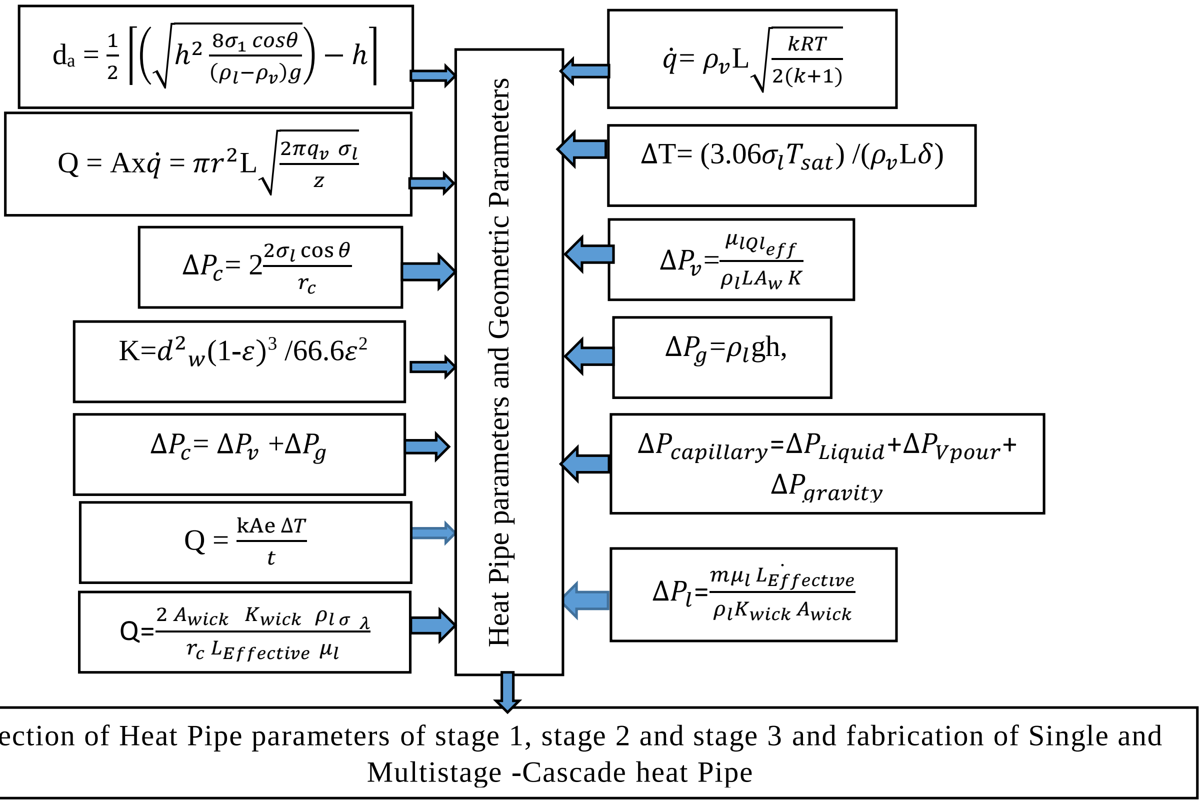

Figure 2.2 High temperature single and (SPC) cascade Heat Pipe Design Procedure

Both single and cascade high temperature heat pipe was designed, fabricated, and predicted required parameters predicted by the systematic procedure and equations shown in Figure 2.2. The requirement of given parameters not suitable, these cycle is repeated until the requirement is satisfied. The temperature drop of the condenser and evaporator was predicted for the maximum allowable value[16]. The detail design procedure taken up once these conditioned are satisfied. The specification of the heat pipe, condenser and evaporator are predicted[15].

Both single and Cascade heat pipe design and fabrication is based on the some important steps are elaborate they are: The maximum diameter "da" of the heat Pipe is calculated by the below procedure and predicted all geometrical parameters. Where d_a is the maximum diameter of the artery, h- is the vertical height to the base of the artery, θ- is the contact angle of the fluid, σ_l - is the surface tension of the fluid, ρ_l- and ρ_v- are the densities of the liquid and vapour. Heat Pipe design procedure can be easily understood by flow chart shown in Figure 2.1 and 2.2, the following parameters and detail of the specification of heat pipe, which include the geometry, operating temperature, heat load, orientation and other details like where it is to be used as in space are determined. The maximum heat flux (Q_{max}) without entrainment is checked[17].

$$Q_{max} = \text{Ax}\dot{q} = \pi r^2 \text{L}\sqrt{\frac{2\pi q_v \ \sigma_l}{z}} \quad (1)$$

Where Z is the characteristic dimension of the liquid and vapour interface having value of about 0.16. It is required to predict the Q and equal to compare with Q_{max} or higher than the heat load of the pipe to be designed, than the fluids pass this limit[12]. In addition to that working limit is checked based on the Merit Number shown in Table 1. To avoid nucleation in the wick ΔT is calculated shown Figure 2.2 Where δ is thermal layer, having a value of $15\mu m$. The fluid having the highest value for ΔT is the most suitable one for the application. Priming Factor for the fluid is determined from plots of Temperature verses, priming factor.

The type of wick is selected based on the some parameters, and develop the homogeneous wick and arterial wick. The capillary pressure is calculated using design procedure. ΔP_c. Where r_c is the wick radius and θ is the contact angle equal to zero for wetting fluids. The pipe will work, if this pressure equals the sum of pressure drop for vapour flow and gravitational pressure. Predict the Vapour Pressure required for vapour flow is calculated by the equation shown Figure 2.2. ΔP_v , A_w =is the wick area and K is calculated, l_{eff}-is the length of pipe-1/2(Length of evaporator+ length of condenser) by using equation (2).

$$K = d^2{}_w(1-\varepsilon)^3 / 66.6\varepsilon^2 \quad (2)$$

d_w is the wick diameter, ε is the volume fraction of solid phase in the wick. The value is substituted in equation (2), The pressure required for movement against gravity, $\Delta P_g = \rho_l \text{gh}$, Where h is the height of movement against gravity. The P_c calculated by using the equation (3)

$$\Delta P_c = \Delta P_v + \Delta P_g \quad (3)$$

The wick area A_w is calculated, as all quantities except A_w is known in equation. In case, A_w is larger than the pipe diameter. The equation for heat flow across the wick is used and determine the thickness of the wick. Heat transfer (Q) to the evaporator is predicted by the equation. Where t (m) is the thickness Q is the heat load, A_e is the evaporator area ΔT is the allowable temperature drop. The conductivity k is the combined conductivities of the sold material in the wick and the working fluid in the wick. The maximum value of pressure drop is calculated from the basic equation ΔP_c=sum of other pressure drops. The number of arteries are also decided using these equations. The design of the heat pipe require a large number of data about properties of the liquid and the wick. These are not readily available and one has to search through the literature and handbooks for the same. The amount of power that a heat pipe can carry is governed by the lowest heat pipe limit at a given temperature. For a given heat pipe, the Merit number ranks the maximum heat pipe power when the heat pipe is capillary limited[12]. (The capillary limit generally controls the power in the mid-range, while other limits control at higher and lower temperatures).

The capillary limit is reached when the sum of the liquid, vapor, and gravitational pressure drops is equal to the capillary pumping capability and predicted by using equation .The merit number neglects the vapour and gravitational pressure drops and assume that the capillary pumping capability is equal to liquid pressure drop. The liquid pressure drop was calculated by using given equation Shown in Figure 2.2. Where ΔP_l is the Liquid pressure drop assumed equal to the wick pumping capability, $L_{Effecitive,}$ is the effective length, K_{wick} is the wick permeability, A_{wick} is the wick area, the mass flow rate is the heat transfer rate divided by the $\dot{m}=\frac{Q}{\lambda}$, The wick pumping capability is $\Delta P_l=\frac{2.\sigma}{r_c}$, Where r_c is the pore radius. Combining the above the three equations and solving for Q, the maximum heat transfer when only the liquid pressure drop is considered by using this equation.

TABLE 1 OPERATING TEMPERATURE, OPERATING MAX TEMPERATURE WORKING FLUID AND ENVELOP MATERIALS FOR HEAT PIPE

Operating Temperature Range ^{0}C		Working Fluid	Heat Pipe Materials	Requirements, and not compatible
Minimum	Maximum			
410	620	Cesium	Inconel, Titanium, steel	Monel, Copper, and Copper-Nickel
450	750	Potassium	Inconel, Titanium, steel	Monel and Copper
550	850	NaK	Haynes ,Inconel, Titanium, steel	Monel and Copper
650	1100	sodium	Haynes ,Inconel, Titanium, steel	Monel and Copper
950	1800	Lithium	Tungsten, Niobium. Molybdenum, TZM	Lithium not compatible with Super alloys.

TABLE 2 LIST OF WORKING FLUIDS BOILING POINT, USE FUEL RANGE AND MERIT NUMBER FOR SPC- HEAT PIPES

Sl.No	Description of fluids	Boiling points, ^{0}C	Useful range , ^{0}C	Merit number W/m^2	Thermal Conductivity K (W/m-K)
1	Mercury	361	250 to 650	$1.63x10^9$	
2	Cesium	670	450 to 900	$2.1x10^9$	35.9
3	Potassium	774	500 to 1000	$8.0x10^9$	100.0
4	Sodium	892	600 to 1200	$1.8x10^9$	142.2
5	Lithium	1340	1000 to 1800	$64087x10^{15}$	
6	Silver	2212	1800 to 2300		

Based on the design procedure and method of calculations and required materials selection based on some experiments comments, The materials list as shown based on operating low and Maximum temperature are shown in table1. The design and materials selection are done by using design Methodology. Some conflicts are mainly depends on material deterioration of one of component and

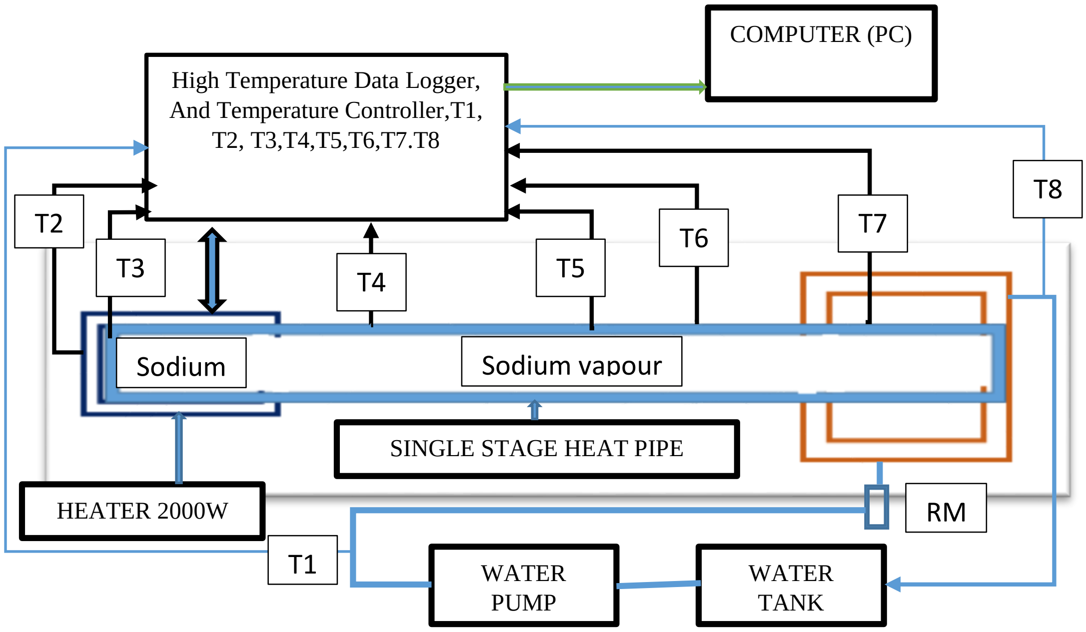

Figure 2.3 Experimental Layout of high Temperature single stage heat pipe setup

other component parameter selection procedure. Compatibility with wick and container materials, good thermal stability, wettability of wick and wall surface, suitable vapour pressure not too high or too low, Large latent heat, Good thermal conductivity, High surface tension, Low viscosity of liquid as well as vapour and acceptable freezing and pour points are predicted and list of working fluid as shown in Table 2. Heat pipe require to considering a single property, fluids are evaluated by a combination of properties influencing the working of heat pipes called Merit number, it is defined as $\boldsymbol{N_l} = \frac{\sigma_l L \rho_l}{\mu_l}$ **W/m², Where** σ, ρ, μ and L being the surface tension, density, viscosity and Latent heat of the fluid. The dimension of merit number is W/m$^{2.}$ Effectively merit number indicates the heat transport capacity of the fluid[18]. The sectional area required for transporting a given thermal load is directly proportional to the merit number. The merit number as function of temperature is shown in Figure 2 for a number of typical heat pipe working fluids[18][19]. From the figure, it is very clear why is chosen as the heat pipe working fluid whenever possible[15]. Its merit number is approximately equal 10 times higher than everything else except the liquid metal is and it is meaning that, it will carry ten times more power than other working fluids. More than two dozen fluids are in use as working fluid. Similarly, the arrangement and material for wick also vary as per the applications. In order to be compatible with the various fluids more than a dozen materials are use. The above difficulty always arises in the selection of suitable combination of material and fluid.

B. Experimental lay out of single and SPC - cascade heat Pipe

The experimental lay out shown in Figure 2.3.and 2.4 they are 1) The working fluid, 2) The wick and capillary structure and container. Both single and cascade heat pipes are required to work at various temperature from 4k to 2300k, different fluids are required for different temperature bands.

T1-Water inlet Temperature, T2- Heater Temperature, T3- Evaporator Temperature, T4, T5, and T6- Axial Adiabatic section Temperature, T7- Condenser Temperature, T8- Water outlet temperature. RM-Rotameter water flow control.

From the Figure 2.3 shows the temperature measurement and cooling water circulation and Heat Input controlling and measurement System. The schematic diagram of the single stage heat pipe experiments setup is shown in Figure 2.3. The components in the experimental setup in which there is evaporator and condenser.

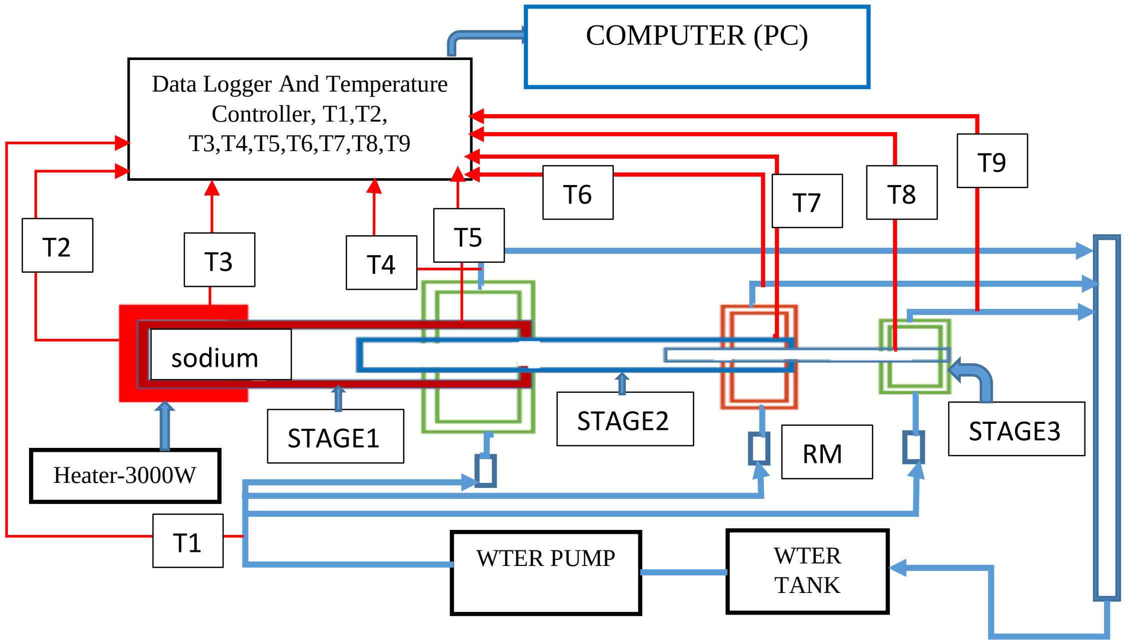

Figure 2.4 Experimental Layout of High temperature SPC- cascade heat

T1-Water inlet Temperature, T2- Heater Temperature, T3- Evaporator Temperature, T5,T7 and T8- Stage 1,2 and 3 condenser Temperature, and T4, T6,T9- Stage1, 2 and 3 water outlet Temperature , T7- Condenser Temperature, T8- Water outlet temperature, T8- Water outlet temperature.RM-Rotameter water flow control.

The schematic diagram of the multistage stage experiment setup shown in Figure 2.4. The components in the experimental setup in which there is evaporator and condenser. The first stage heat Pipe condenser was used to second heat pipe and second heat pipe heat is used to third stage heat input shown in Figure 2.4.The components in the experimental setup in which there is a primary heat pipe stage 1 and the second stage heat pipe is inserted in to the first stage. In the setup a heater for the experimental purpose, in which a stable watt supplied to the system with a regulator by which amps, replaces the electrical component and volt input is controlled. This heater is fixed at the bottom of the primary reservoir

TABLE 3 SPECIFICATION OF HIGH TEMPERATURE SINGLE AND (SPC) CASCADE HEAT PIPE

Parameters	Specifications Stage 1	Specification stage 2	Specification stage 3
Heater Electrical Power	3.5kW		
Working Fluid	**Sodium(100 grams)**	**Potassium(100grams)**	**Cesium (100 grams)**
Heat Pipe envelope materials	Stainless steel 316L	Stainless steel 316L	Stainless steel 316L
Wick materials	150+300 mesh Nickel	100+200 mesh ,Nickel	100+200 mesh ,Nickel
Total Height	1 M	0.6m	0.6m

Heat Pipe height	0.6m	0.6m	0.6m
Support Height	0.25 m	-	-
Heat Pipe diameter	0.08m	0.06m	0.03m
Number of Heaters	2 (2 No, 1 kW heater)	-	-
Heater Power	1000 W	-	-
Evaporator Length	0.15m	0.15m	0.15m
Condenser Length	0.15m	0.15m	0.15m
Adiabatic section length	0.03m	0.03m	0.03m
Heated length	0.015m	-	-
Heat Pipe envelope	Welded	Welded	Welded

II EXPERIMENTAL SETUP LAYOUT OF SINGLE AND SPC- CASCADE HEAT PIPE

The schematic diagram and setup of single and SPC cascade heat pipe shown in Figure 2.3 and 2.4. The components in the experimental setup in which there is evaporator and condenser. The primary and secondary working fluid with SPC combinations. The heater of 1000W is attached to bottom of the primary reservoir of area 65mm*80 mm 192.308*10^3 w/m^2 is the maximum amount of heat flux can be provided to the system. The heater fixed to the system by clamping with the primary reservoir.

Heat pipe was experiment was focused to two phase, first one was single stage with variable heat load and second one was multistage heat pipe (Cascade heat pipe) with variable heat load conditions. A 1000 mm long, 30 mm diameter of copper tube used to fabricate single stage heat pipe, and both ends sealed with end caps. One end cap provide by filling tube for charging the working fluids. Wick section was made by A 4-layer 50/cm mesh copper screen was fixed on the inner tube which was held in a fixed positions by a guide setup. The heat pipe evacuated by using the vacuum pump and 10^{-4} bar pressure maintained at 120 C for about 4 hours to remove the non –condensable present in the tube. Then the heat pipe cooled by applying ice and the working fluid of desired quantity (210 ml) injected through a capillary tube by adjusting the vacuum valve (7.38 kPa).

The capillary tube was then crimped and sealed. The evaporator, adiabatic and condenser sections are of length 100, 600, and 300 mm respectively. The heat pipe adiabatic section maintained by isothermal boundary conditions and ensured by using glass wool insulation and increased heat transfer capacity of the heat pipe with augmented by 40 number (70x70) of flat fins each of 0.6 mm thickness mounted on the condenser section by bracing. The same procedure followed and fabricated cascade (Multi stage) heat pipe and three stage was fabricated, tested, and shown in Figure 2.3. The specifications are presented for single and multi-stage shown in table 1. The experimental setup, Fig. 2.3 consists of resistance heater of 1500W power output, wattmeter and an auto transfer was provide the necessary power supply to the heaters. The national instruments (NI) based system was used to recorded the thermocouple readings at different positions of the heat pipe. Thermo-couples of K-type (10 numbers) used to measure the temperature response at the different position of the axial distance. The layout of thermocouples presented in Fig. 3.

III EXPERIMENTAL PROCEDURE OF SINGLE AND SPC - MULTISTAGE HEAT PIPE

Single and multistage heat pipe components like evaporator, adiabatic, condenser was fabricated by given length 150, 300and 150 mm respectively, and specifications are shown in Table 3. The both single multistage heat pipe adiabatic section was maintained by isothermal boundary conditions and ensured by using glass wool insulation and increased heat transfer capacity of the heat pipe with augmented by 42 number

(170x170) of flat fins each of 1mm thickness mounted on the condenser section by bracing. The same procedures are followed and used to fabricate the cascade (Multi stage) heat pipe was fabricated, tested, and shown in Figure 2.2.

The specification of single and multi-stage the heat pipe shown in in table 1. The experimental setup, Fig. 2.2 consists of resistance heater of 1500W power output, wattmeter and an auto transfer was provide the necessary power supply to the heaters. The national instruments (NI) based system was used to recorded the thermocouple readings at different positions of the heat pipe. Thermo-couples of K-type (10 numbers) used to measure the temperature response at the different position of the axial distance. The layout of thermocouples presented in Fig. 3. The inlet and outlet temperatures of the cooling water measured by using two-K type thermocouple and integrated with data logger. The mass flow rating of cooling water at steady state measured by using control valve. The heater and the adiabatic sections were insulated by 1.0 cm thick glass wool and then the power supply controlled by autotransformer. The heat input is varied by using the variable transformer from 60 to 300 W. The inlet and outlet temperature of the cooling water and the temperature of heat pipe measured by using the data acquisition system. Water mass flow rate was measured when the heat pipe operates under steady state. The same procedure was used to conduct the experiment three different fluids and results are used to analysis. The experiment of cascade heat pipe was conducted with stage 1, 2 and 3 fluid like water, ethanol and acetone.

VI RESULTS AND DISCUSSION

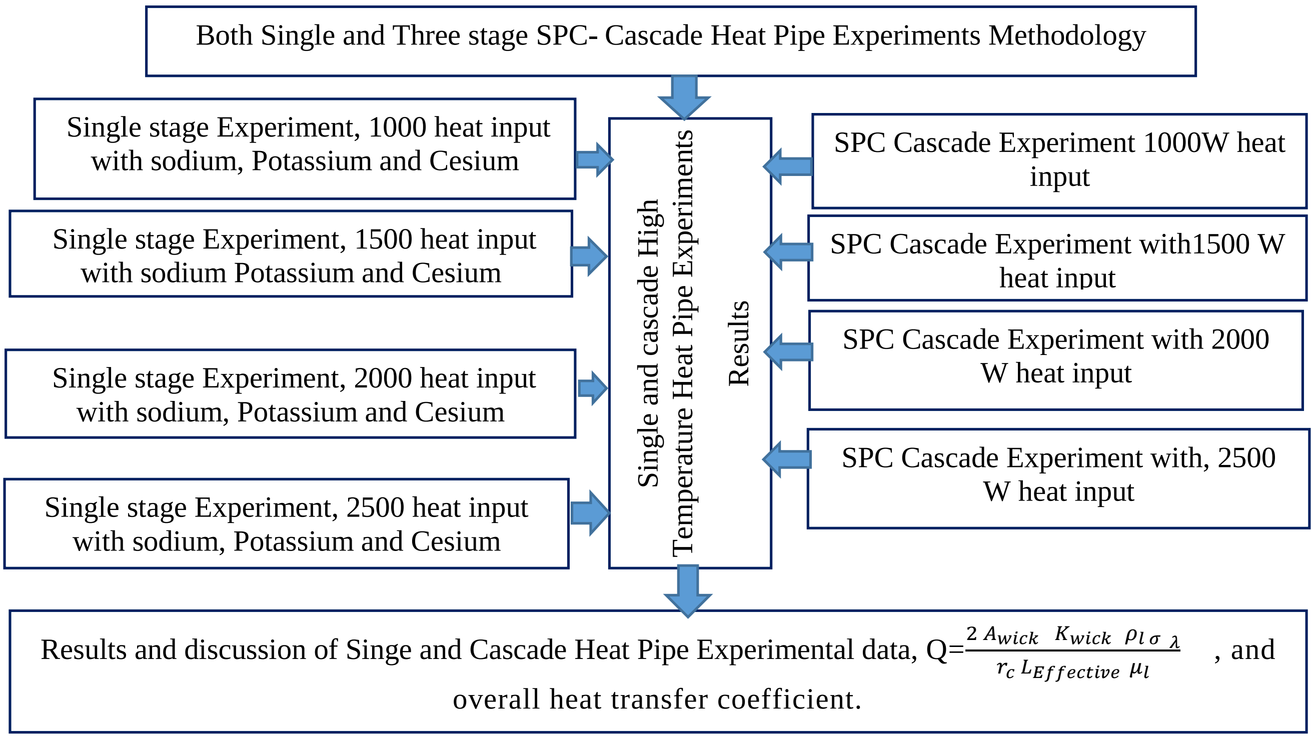

Figure 2.5 Experimental Procedure of Single and SPC- cascade heat pipe

Both single and multistage heat pipe thermal resistance and overall heat transfer coefficient the effect of heat pipe performance can be explained by calculating the variation of thermal resistance. Thermal resistance of the heat pipe can be calculated by R=$\Delta T/Q$, Where ΔT is the temperature difference between the evaporator wall. Expressions for calculating thermal resistance for different sections of the heat pipes shown in table 3. The variation of thermal resistance of the heat pipe filled with and the copper nano-particles suspension system) heat Pipe and condenser wall are presenting in Fig. 4.

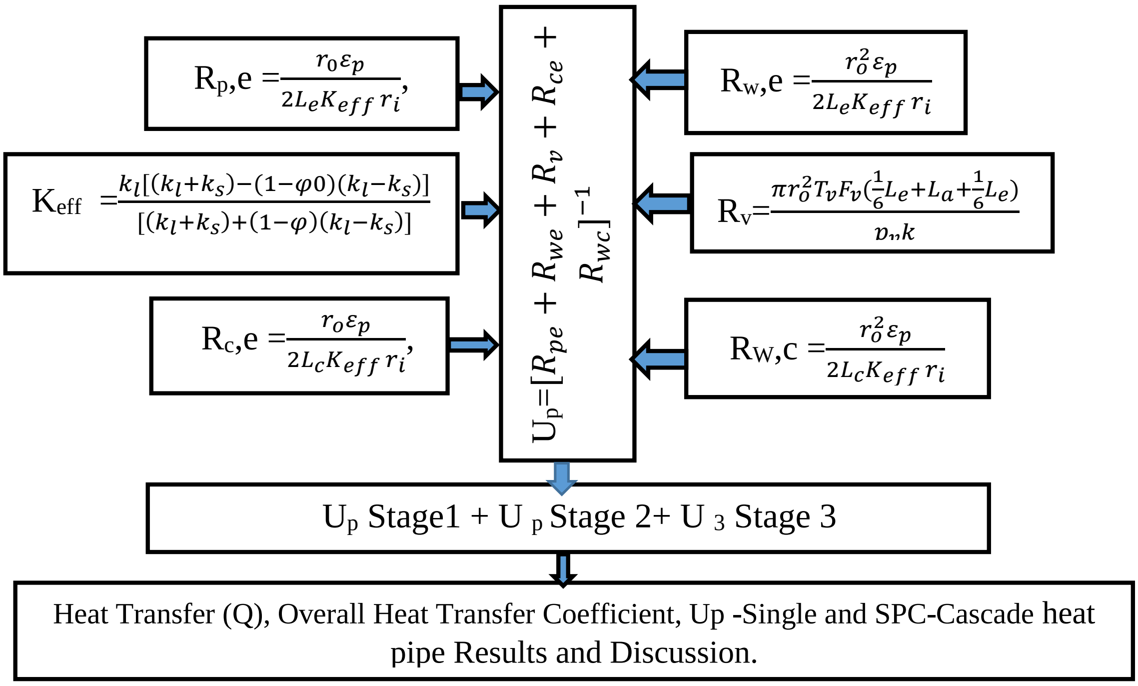

Figure 4.1. Overall, heat Transfer Coefficient calculation procedure for single and multistage (SPC-cascade

Thermal resistance of heat shows that shows heat pipe decreases with the increases of heat input. The thermal resistance of heat pipe was reduced by 32.10%. The experimental results showed that lower thermal resistance for higher heat input. Nucleation sites in the evaporator section helped to decrease thermal resistance, which extends the regime of nucleate boiling to vary high heat fluxes.

A. Error Estimation of Single and SPC -Multistage Heat Pipe

Both single and multistage experiments error estimates are very important analysis for the experimental part, and influence of results and analysis. The following main sources of experimental uncertainty were the temperature measurement, namely coolant flow rate measurement and the wattmeter. This error analysis was done and tabulated for the accuracy of flow measurement is around $\pm$2.8 % and the accuracy of the thermocouple is around $\pm$6% ^{0}C. The maximum uncertainty of the wattmeter is around $\pm$1.6., and the error analysis is followed by the method was described by Holman [].In addition to uncertainties of the heat flux and the heat transfer co efficient was predicted and tabulated as shown in Table 3 and the uncertainties calculated by the Eqs. 1, 2

$$q_c=\sqrt{\left(\frac{\partial q}{\partial Q}w_q\right)^2+\left(\frac{\partial q}{\partial D}w_D\right)^2+\left(\frac{\partial q}{\partial L_c}W_{l_c}\right)^2}- \quad (4)$$

$$h_c=\sqrt{\left(\frac{\partial h_c}{\partial q_c}w_{q_c}\right)^2+\left(\frac{\partial h_c}{\partial \Delta T}w_{\Delta T}\right)^2} \quad (5)$$

Which shows that uncertainties within a reasonable limit of 5-6%.
The symbols $w_q, w_D, W_{l_c}, w_{q_c}, w_{\Delta T}$ are the uncertainties in the heat flow rate, diameter, condenser-length condenser-heat flux and temperature drops respectively.

TABLE 4 UNCERTAINTY OF HEAT FLUX AND HEAT TRANSFER COEFFICIENT OF SINGLE STAGE AND SPC- CASCADE HEAT PIPE.

	Heat pipe with water		SPC-Cascade heat pipe	
Heat input	Uncertainty of Heat Flux single stage (%)	Uncertainty of heat transfer coefficient single stage (%)	Uncertainty of Heat Flux cascade system (%)	Uncertainty of heat transfer coefficient cascade system (%)
1000	6.12	6.34	6.23	6.55
1500	6.012	6.12	6.33	6.42
2000	5.33	5.11	6.04	6.35
2500	5.82	5.86	6.06	6.25
2750	5.92	6.03	6.25	6.31

B. *Over all Heat Transfer Coefficient of Single and SPC -multistage*

The above the procedure was used to calculate the overall heat transfer coefficient shown in Figure 2.4

$$U_p=[R_{pe}+R_{we}+R_v+R_{ce}+R_{wc}]^{-1} \quad (6)$$

Heat Transfer in the condenser section as an additional evaluation of the heat transfer performance of the heat pipe, the heat transfer coefficient at the condenser section was calculated with base fluid for single stage and multistage.

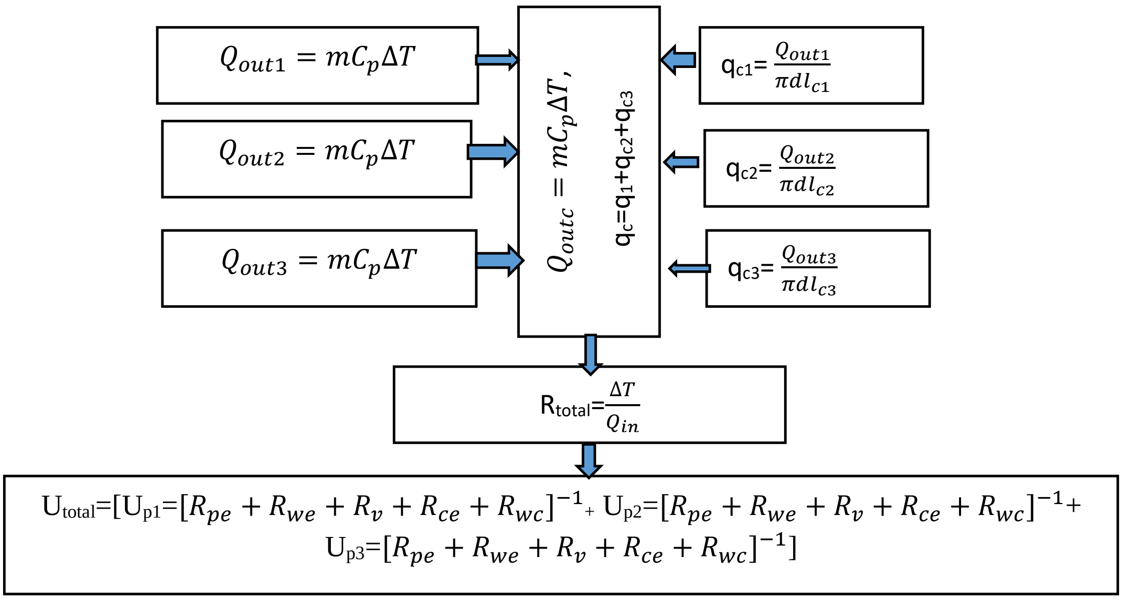

Figure 4.2 Heat Transfer, heat flux and Overall Heat Transfer Coefficient calculation procedure of SPC heat pipe

The experimental heat transfer coefficient at the condenser section of single and multi-stage can be calculated as given below

$$q_c = \frac{Q_{out}}{\pi d l_c}, \quad - \tag{7}$$

$$Q_{out} = mC_p\Delta T, \tag{8}$$

Where m is the mass of Water flow, C_p- is the specific heat of the water ΔT is the temperature difference of water flow. The same procedure used to find cascade system. Single Stage heat output is calculated by using the equation. Figure shows the condensing heat transfer coefficient enhancement due to the addition with two stages (multistage) with two different fluids. From the results, it was observed that, the heat transfer co efficient of the heat pipe changed with multistage and compared to single stage heat pipe. It is believed that the heat transfer enhancement in the evaporator and condenser section is mainly dependent on the nature of surface created by the multi stage as convection area was increased. Heat transfer coefficient in the condenser section depends on the thickness of the liquid layer and the hydrodynamic properties of the working fluid. A correlation can be established between the Nusselt number, Reynolds number and Prandtl number

$$N_u = \frac{(hC_l)}{K} = 1.12R_e^{0.8}\,p_r^{0.7} \tag{9}$$

The correlation of Eeq. 9 may be compared with the existing correlation for condensing water vapour in thermosiphon as a function of Reynolds number.

$$N_u = 5.03Re1^{/3}\,P_r^{1/3} \tag{10}$$

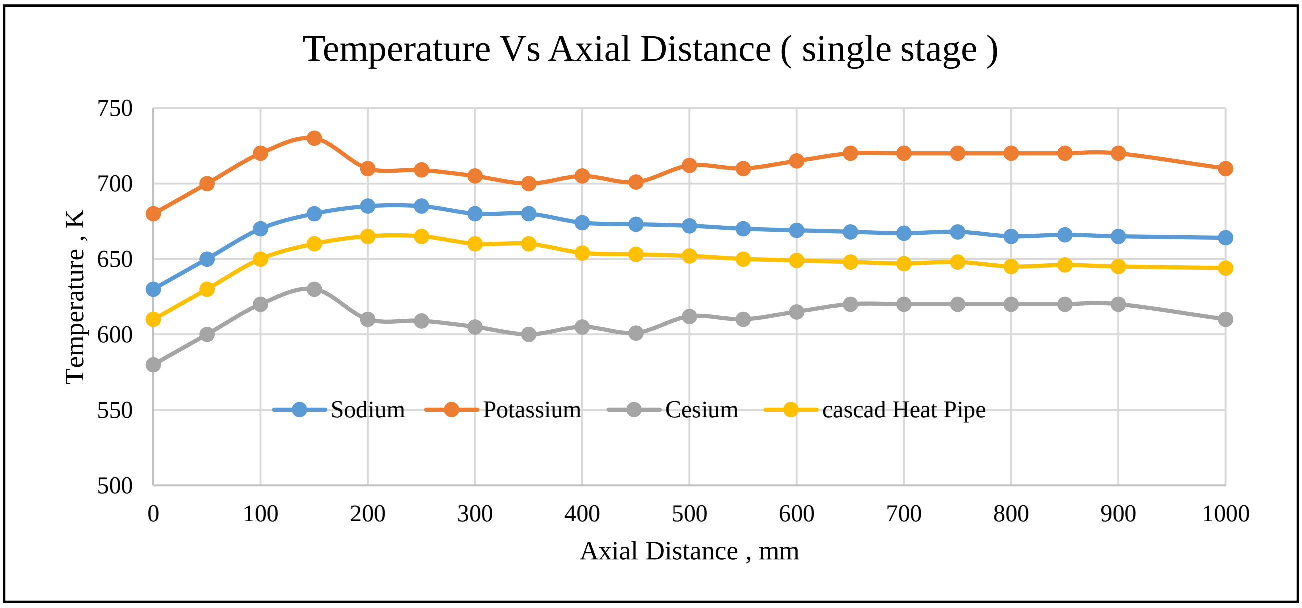

Figure 4.2 Temperature Vs Axial Distance of single and SPC-multistage heat Pipe

Figure Shows the Nusselt number variation with respect to the Reynolds number for constant Prandtl number. The trend shows an enhancement in the Nusselt number with the increase in the Prandtl number and Reynolds number, which means that the increase in Prandtl number leads to enhancement of Nusselt number. Figure shows that comparison of the experimental results of the heat pipe.

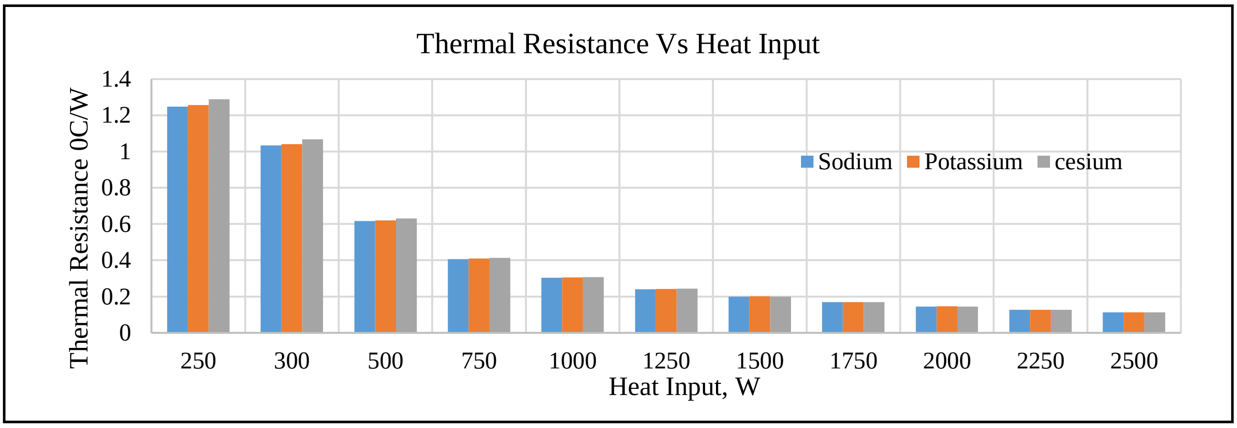

Figure 4.3 the variation of Thermal Resistance with respect to Heat Input

It can be seen the variation of resistance with heat input shown in Figure 4.3. Thermal resistance of the single stage heat pipe decreased when increase the heat input. Heat input increased from 250 to 250W.

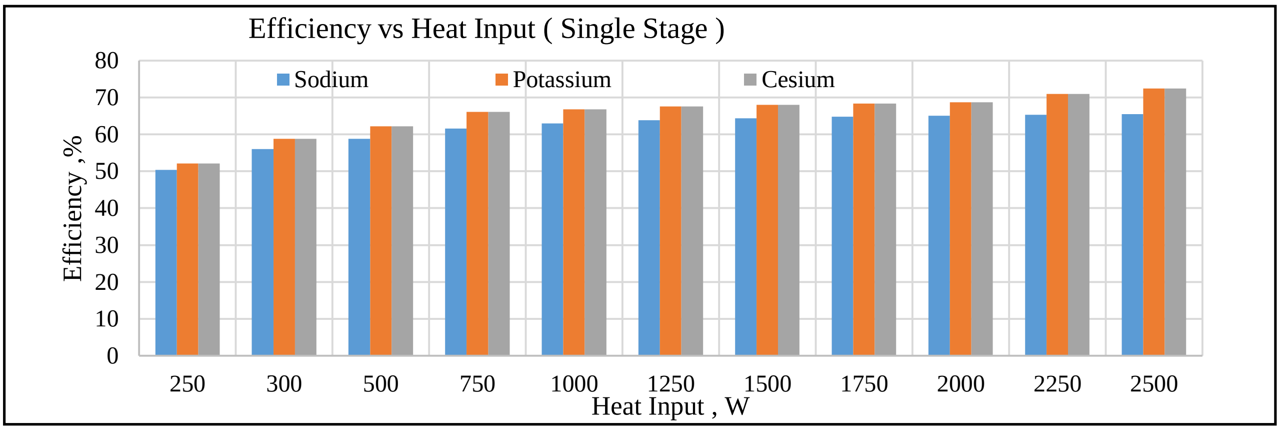

Figure 4.4 the variation of Efficiency with respect to Heat Input

It can be seen from the Figure 4.4 Variation of efficiency of SPC shows. In can be clearly indicated that,

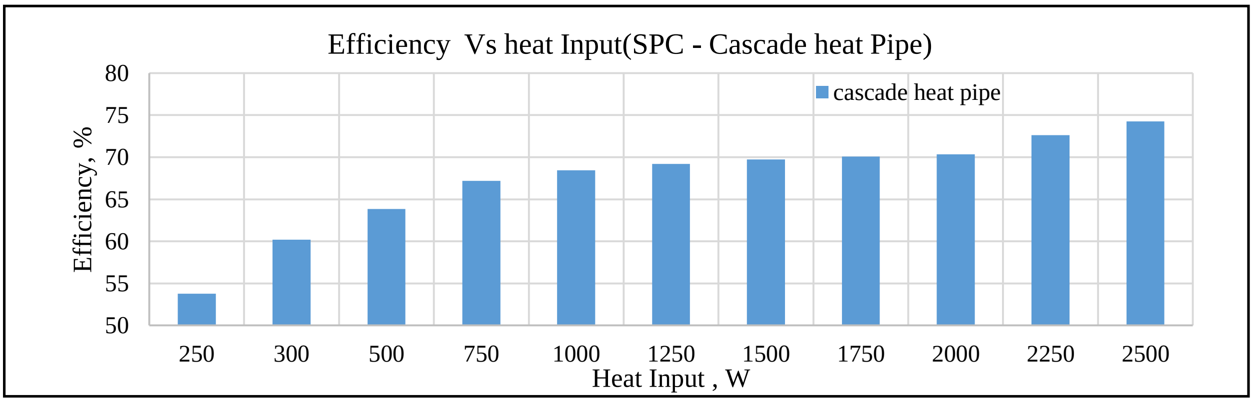

Figure 4.5 variation of Efficiency with Heat Input of SPC-Heat Pipe

Efficiency increase when temperature increases. Single stage with sodium is slightly lower compared to potassium; Cesium is slightly higher compared sodium heat pipe.

It can be seen from the Figure 4.5, Variation of efficiency of SPC shows. In can be clearly indicated that, heat transfer coefficient increase when temperature increases. Cascade heat pipe heat transfer coefficient is 18 to 19.5 % higher compared to single stage heat pipe. Experiments performed to study the heat transfer characteristics in the evaporator and condenser section of the heat pipe. The heat transfer in the condenser section depends on the Reynolds number and the Prandtl number. The both single and cascade heat pipe in side fluid velocity and condensate liquid and the hydrodynamic properties are very important role in condensing heat transfer. The variation of heat Transfer coefficient with Heat flux shown. Single and multistage heat pipe experiments were performed to study the heat transfer characteristics in the evaporator and condenser section of the heat pipe shown in Figure 4.4. Heat transfer coefficient increases when heat flux increases from 8 to 68 kW/m^2. The overall heat transfer coefficient of the system increases gradually with increase in heat flux or the saturation temperature maximum of 23.10 % and heat transfer coefficient increase with 16% compared to single stage due to decrease the thermal resistance of the heat pipe.

CONCLUSION

Based on the experimental investigation, the performance study of the heat transfer characteristics single and multistage heat pipe. Thermal resistance and efficiency of single and multistage stage was predicted for three fluids with variable heat input.

- Thermal conductivity of Sodium has slightly lower compared to Potassium and thermal conductivity and boiling point of Cesium was lower compared to sodium and Potassium.
- Merit Number of sodium was lower compared to other two fluids.
- Experimental results are obtained with sodium heat pipe efficiency was slightly lower compared to Potassium and Cesium.
- Efficiency of cascade (SPC) heat pipe was better compared to single stage and working temperature range from 600 to 750 deg, C.
- Single stage heat pipe heat transfer is 8% lower compared to cascade heat pipe due to two low boiling point fluid used in second and third stage.

Based on the experimental investigation convection area of cascade in increased and as well as heat transfer rate was increased. Based on the experiment operating temperature, range 550k to 740 K in general, Cesium/Titanium heat pipe can be more power than potassium but Potassium is a significantly better working fluid than Cesium.

Nomenclature

G	- Acceleration due to gravity,	T_{max}	- Dimensionless temperature,
∞	- Ambient	*exp*	- Experimental
Avg	- Average	*FN*	- Figure of Merit,
H	- Heat Transfer Co Efficient	*f*	- Fluid
B	- Bottom wall	*Gr*	- Grashof number,
T_m	- Bulk mean temperature	q_{pri}	- Grashof number,
B	- Co-efficient of volumetric expansion,	q_{sec}	- Heat,
		q"	- Heat flux (W/m^2)
Q_{sides}	- Convective heat loss	Q_{in}	- Heat input,W
Q_{top}	- Convective heat loss	T_{heater}	- Heater temperature, ^oC

T_{water} - Water temperature, ^oC
v - Kinematic viscosity, m^2/s

N - Number of secondary tubes arranged
Nu - Nusselt number, *hL/k* , *hd/k*
Pr - Prandtl number, *ν/α*
pri - Primary coolant
Ra - Rayleigh number,
sec - Secondary coolant
A_h - Surface area of the heater, m^2
A_1 - Surface area of the primary tank, m^2
A_2 - Surface area of the secondary tubes,
T_s - Surface temperature
ΔT - Temperature difference surface, ^oC
T - Temperature excess, (T_h- T_∞), C

Kf - Thermal conductivity of the fluid, W/m-K
α - Thermal diffusivity of the fluid, m^2/s
R_{th} - Thermal resistance, $^oC/W$
V - Voltage applied to the heater, Volts

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