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Performance Comparison of Two Combinations Cascade Heat Pipes - Cesium, Potassium, and Sodium Heat Pipe, and Sodium Cesium, Potassium Heat Pipes

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***Abstract*--- This research focuses on the construction and experimentation of a high-temperature cascade heat tubing. The performance of two combinations of Cesium, Potassium, Sodium (CPS) heat pipes and Sodium, Cesium, Potassium (SCP) cascade heat pipes was investigated and compared. Items that can be used in heat pipes and fluids have been chosen. Both single and multistage heat pipe tests were carried out using CPS and SCP, respectively. In this study, single and multistage heat pipes with variable energy inputs of 500, 1500, 2000, and 2500 W are used. A contact non-conduct temperature thermometer and system were used to calculate the first, second, and third fluid and axial temperatures. Temperature and pressure data were obtained using a temperature data logger. The results of the experiments show that a steady-state temperature was reached after 45 seconds per step. Second, the tests' results were used to determine the efficiency and measure the heat pipes' operating range. A multistage heat pipe using these salts produced temperatures ranging from 410 to 710 degrees. The cascaded heat pipe would be suitable for temperatures up to 500 degrees Celsius. A multistage heat pipe-heat exchanger increased temperature efficiency by 18.3 percent over a single-stage heat pipe-heat exchanger.**

***Keywords*--- High-temperature heat pipe, multistage, efficiency analysis, Heat Transfer Analysis**

I. INTRODUCTION

The low-temperature heat pipe is broadly used for different devices like energy storage devices, computer processers, micro-processes, electronics devices, electrical drives, solar energy storage devices, supercapacitors, and ultra-capacitors[1]. Sodium, potassium and Cesium (SCP) heat pipes focused on studying increased efficiency, favourable materials, compatibility and high heat transport characteristics at high temperatures while operating in air and water over long times[1][2]. This research aim is to select a suitable SCP multistage high-temperature heat pipe and focused on predicting the long time and high heat transfer, hence required to develop the multistage high-performance heat pipe[3]. A 316L stainless steel material tube was selected for both single and multistage stage heat pipe with a sintered porous nickel wick structure, and an integral brazed cartridge heater has successfully operated at 600 to 700 °C without signs of failure[4][5][6]. The previous research article showed a representative one-tenth segment Stirling Space Power Converter heat pipe with an Inconel 718 envelope, and a stainless steel screen wick has operated at nearly 700 °C. A hybrid (i.e., gas-fired and solar) heat pipe with a Haynes 230 envelope and a sintered porous nickel wick structure was operated for about 20,000 hours at nearly 700 °C without signs of degradation[7][8]. However, the previous heat pipe was not suitable for the heat load variation concerning the given design value[9]. Hence, this research article focused on designing a suitable cascade high-temperature heat pipe with variable heat load input. [1][10]. The following four processes are mandatory to select suitable materials for heat pipe, fluid property, and geometry parameters based on the requirement. The following design procedure are: 1) Selection of both single and multistage heat pipe materials like the container, 2) selection of Tube materials, 3) selection of wick materials for working fluid, 4) selection of suitable materials, the volume of condenser, evaporator and predict the performance limits.[11][12][13]. Subsequently, the Cascade heat pipe design process is involved; many decisions are required and must be taken and interrelated to the design and performance process due to high heat transfer in a high-temperature environment. High-temperature cascade heat pipes are typically defined as heat pipes that operate between 400 and 1100°C.

II. DESIGN METHODOLOGY OF CPS AND SCP - CASCADE HEAT PIPE

Performance studied and comparing two combinations of Cesium, Potassium, and Sodium (CPS) heat pipe, and Sodium, Cesium, Potassium (SCP) cascade heat pipes Methodology shown in figure 1.

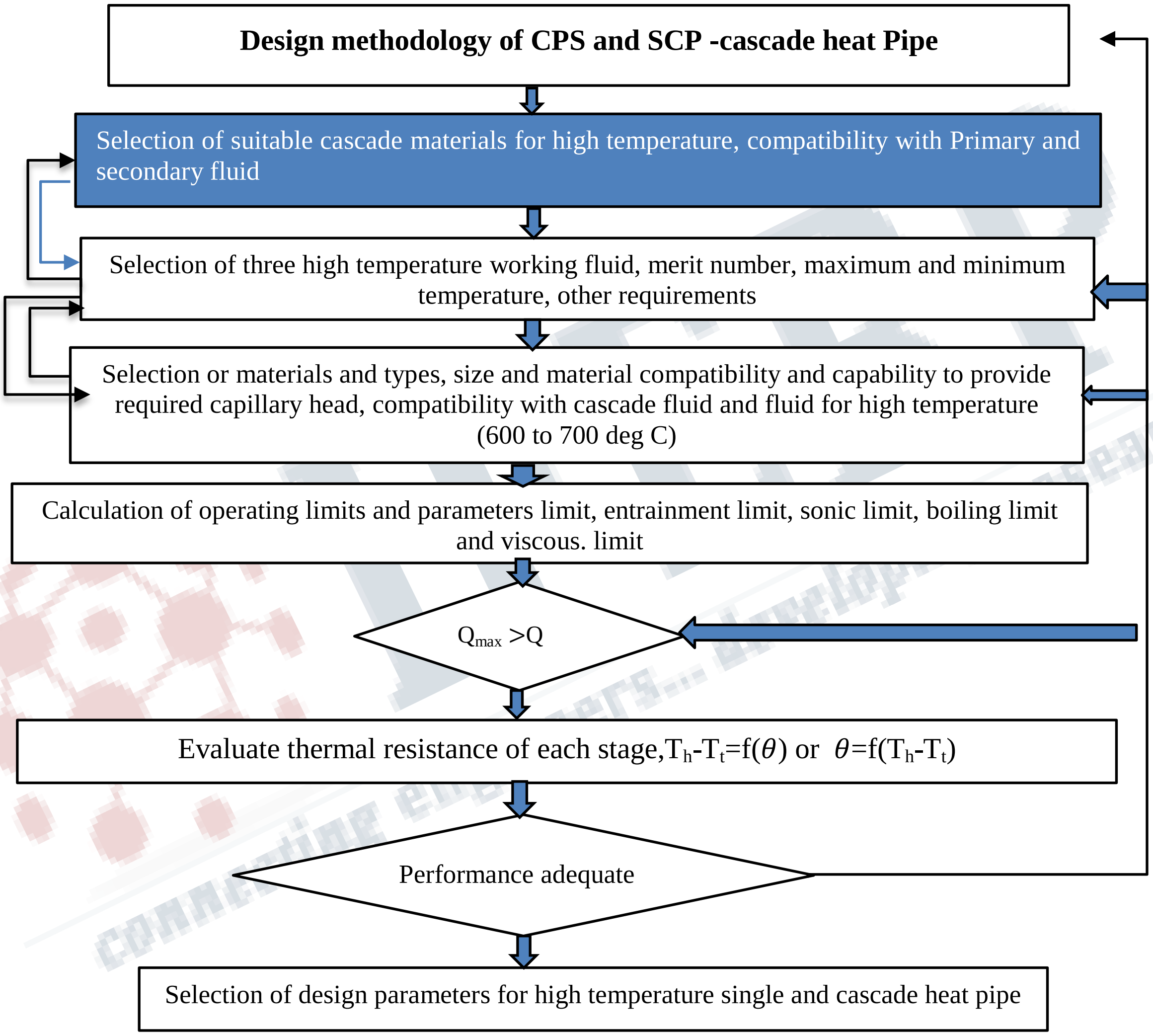

Figure 2.1 Design Procedure methodology for CPS and SCP cascade high-temperature heat pipe

However, the SCP and properties vary too much across this wide temperature range for suitable three fluids. CPS combination haet pipe operating range for each fluid is shown below Cesium 300 to 600°C (572 to 1,112°F), Potassium 400 to 1000°C (752 to 1,832°F) and Sodium 500 to 1100°C (932 to 2,012°F). High-Temperature heat was used for the following Applications: Heat Engine Receivers (Steam, Stirling, Brayton, and Rankine), Solar Thermal, Heat exchangers hypersonic wing leading edges, Waste heat recovery, Nuclear power, Thermoelectric Generators and Isothermalzing furnace elements.

The concept of design and parameter selection methods of single and cascade heat pipe is impotent for selection suitable device and procedures are shown in figure 2.1. The design procedure was followed systematically and systematically for required materials, and fluids property are shown in table 1 and 2. Heat pipe research has many intensive investigations done and resulted in rapid development and commercial production and used for different applications. The next step was to select a set of working fluid and predict the suitable operating temperature and applications. The fluid is chosen, the operating materials and wick, materials and type are chosen for high heat transfer. The best working fluid compatible with these materials is decided for given applications and experiments [14][15]. The type of wick capable of providing the required capability head is selected at the given temperature.

2.1. Design Procedure of High Temperature single and SCP- cascade heat pipe

A high-temperature heat pipe was designed and fabricated and predicted required parameters by following the systematic procedure and equations shown in Figure 2.2.

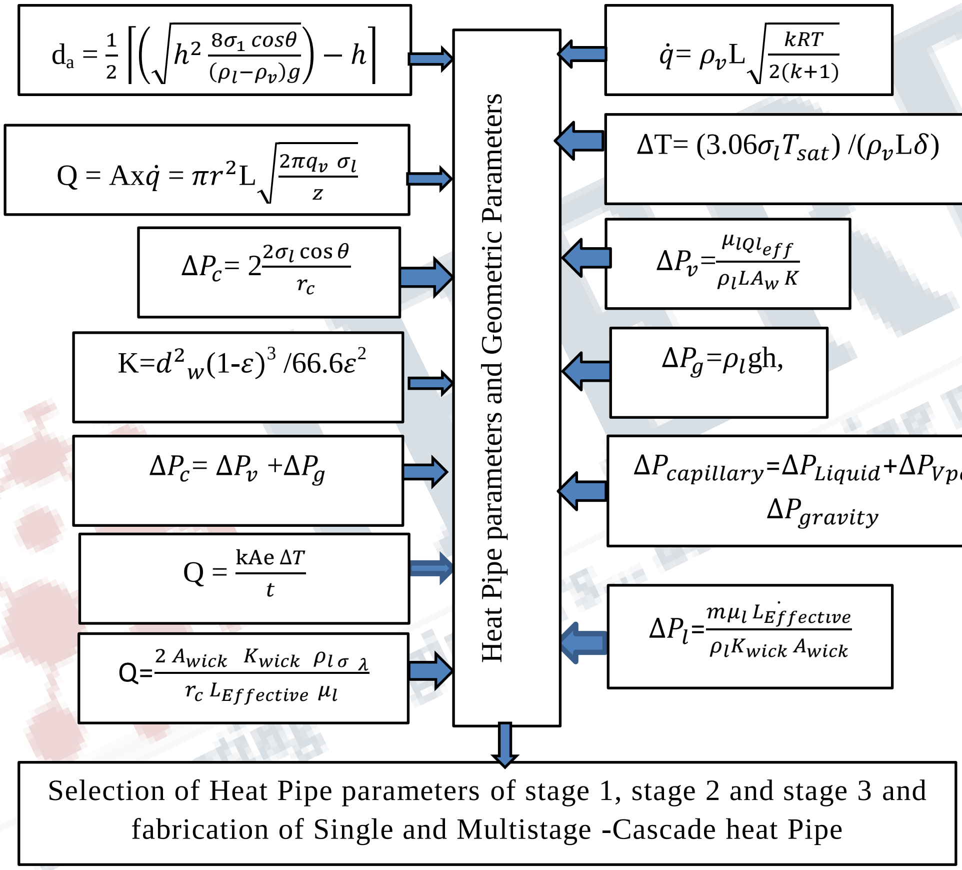

Figure 2.2 High temperature single and (SCP) cascade Heat Pipe Design Procedure

If the requirement is not met, the cycle is repeated until the requirement is satisfied. Next, the condenser and evaporator's temperature drop is predicted for the maximum allowable value[16]. The detailed design is taken up once these conditioned are satisfied. The heat pipe specification and the condenser and evaporator, where the unit is to work against the "g" force[15]. Any limitation on weight, temperature drop between evaporator and condenser will also be specified. A suitable list of working fluids is selected shown in Table 2

Single and Cascade heat pipe is based on some essential steps are elaborate; they are: The maximum diameter "d_a" 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_1 - is the surface tension of the fluid, ρ_l- and ρ_v- are the densities of the liquid and vapour. The Heat Pipe design procedure can be easily understood by the flow chart shown in Figure 2.1 and 2.2; the following parameters and detail of the specification of the 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 working fluid temperature range is specified, and the sonic limit for the fluids is determined by using the equation for maximum heat flux (Qmax). Where k is the specific heat ratio, and R is the gas constant. In case the heat flux is larger than the required heat flux, the fluid can be chosen. The maximum heat flux (Q_{max}) without entrainment is checked[17].

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

characteristic dimension-Z of the liquid and vapour interface with a value of about 0.16, it is required to predict the Q and equal to compare with Qmax or higher than the pipe's heat load to be designed than the fluids pass this limit[12]. In addition to that working limit is checked by using the Merit Number shown in Table 1. To avoid nucleation in the wick, the superheat may be obtained, and ΔT is calculated shown Figure 2.2 Where δ is a 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 fluid having a higher value of priming factor should be considered if it satisfies the other requirements. The weight and vapour pressure of the fluid dictates the container thickness and weight. A final choice of working fluid selection is based on the above parameters and other specification requirements. The type of wick is selected based on some parameters and develop the homogeneous wick and arterial wick. The capillary pressure is calculated using the 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 pressure drop for vapour flow and gravitational pressure. Predict the Vapour Pressure required for vapour flow is calculated by the equation shown in 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).

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

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

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

The wick area A_w is calculated as all quantities except A_w are known in the 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. The equation predicts heat transfer (Q) to the evaporator. 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 solid material's combined conductivities in the wick and the wick's working fluid. The maximum value of the pressure drop is calculated from the basic equation ΔP_c=sum of other pressure drops. The number of arteries is also decided using these equations. The heat pipe design requires many data about the 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. Given heat pipe, when the heat pipe is capillary limited[12]. The capillary limit and is reached when the sum of the liquid, vapour, and gravitational pressure drops is equal to the capillary pumping capability and predicted by using the equation. The merit number neglects the vapour and gravitational pressure, and the heat pipe was calculated using the 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 Min Temp., °C	Operating Max Temp., °C	Working Fluid	Envelope Materials	Comments
400	**600**	Cesium	Stainless Steel, Inconel, Haynes, Titanium	Monel, Copper, and Copper-Nickel are not compatible
500	**700**	Potassium	Stainless Steel, Inconel, Haynes	The upper limit set where Na is the better fluid. Monel and Copper are not compatible
500	**800**	NaK	Stainless Steel, Inconel, Haynes	Monel and Copper are not compatible
600	**1100**	Sodium	Stainless Steel, Inconel, Haynes	The upper limit set by Haynes 230 creep strength
1100	**1825**	Lithium	Tungsten, Niobium. Molybdenum, TZM	Lithium is not compatible with Superalloys.

Table 2 List of working Fluids boiling point, Use fuel range and Merit number for SCP- 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		

Source: *https://www.1-act.com/merit-number-and-fluid-selection.*

Based on the design procedure and method of calculations and required materials selection based on some experiments comments, The materials list based on operating low and Maximum temperature is shown in table1. The design and materials selection is made by using the design methodology. Some conflicts mainly depend on the material deterioration of one component and 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 requires 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/m^2**, **W**here σ, ρ, μ and L being the surface tension, density, viscosity and Latent heat of the fluid. The dimension of the 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. Figure 2 shows several typical heat pipe working fluids[18][19]. From the figure, it is obvious why it is chosen as the heat pipe working fluid whenever possible[15]. Its merit number is approximately equal to 10 times higher than everything else except the liquid metal is, and it means 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; to be compatible with the various fluids, more than a dozen materials are used. The above difficulty always arises in the selection of a suitable combination of material and fluid.

2.2. Experimental layout of single and SCP - cascade heat Pipe

Figure 2.3 shows the experimental setup 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. For example, helium was used in the low-temperature range of 4k.

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 flows control.

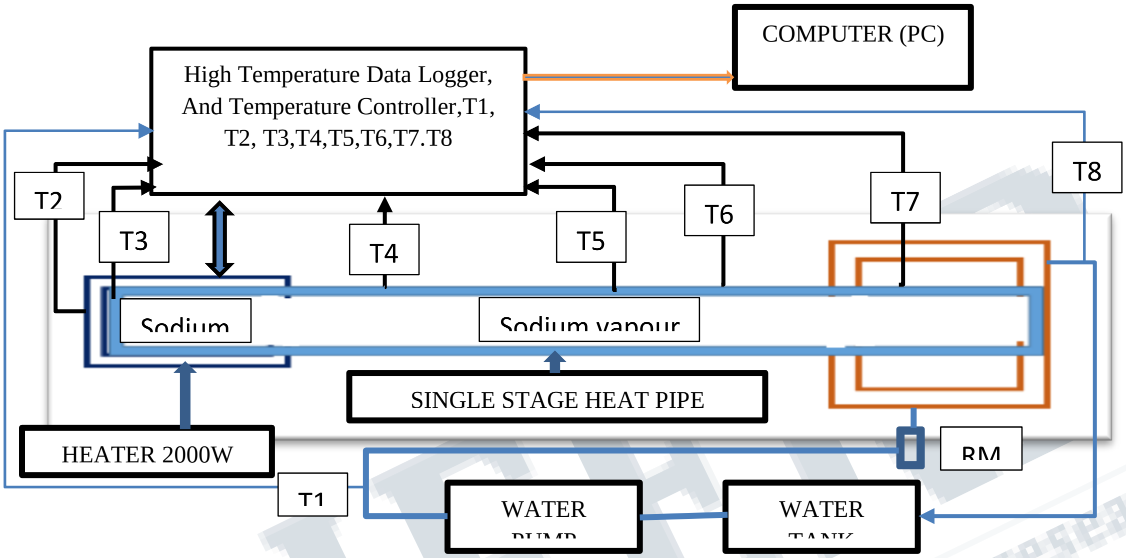

Figure 2.3 Experimental Layout of high-Temperature single-stage heat pipe setup

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 experiment setup shown in Figure 2.3. The components in the experimental setup in which there are the evaporator and condenser.

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 flows control.

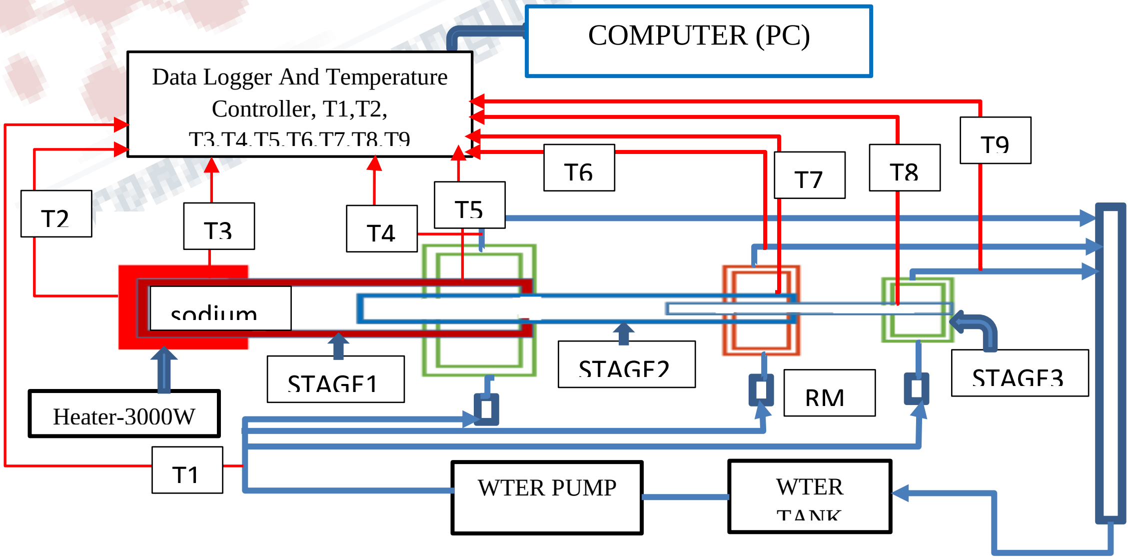

Figure 2.4 Experimental Layout of High-temperature SCP- cascade heat pipe

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

Table 3 Specification of High Temperature single and (SCP) 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

III. EXPERIMENTAL SETUP LAYOUT OF SINGLE AND SCP- CASCADE HEAT PIPE

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

The heat pipe was experiment focused on two-phase; the first was a single stage with variable heat load and a multistage heat pipe (Cascade heat pipe) with variable heat load conditions. A 1000 mm long, 30 mm diameter copper tube was used to fabricate a single-stage heat pipe, and both ends were sealed with end caps. One end cap was provided by a filling tube for charging the working fluids. The Wick section was made by A 4-layer 50/cm mesh copper screen fixed on the inner tube held in fixed positions by a guided setup. The heat pipe was evacuated using the vacuum pump, and 10^{-4} bar pressure was maintained at 120 C for about 4 hours to remove the non – condensable present in the tube. Then the heat pipe was cooled by applying ice, and the working fluid of the desired quantity (210 ml) was 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 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 40 (70x70) of flat fins 0.6 mm thickness mounted on the condenser section by bracing. The same procedure was followed, and fabricated cascade (Multistage) heat pipe and three-stage were fabricated, tested, and shown in Figure 2.3. The specification of the single and multistage heat pipe is presented in table 1. The experimental setup, Fig. 2.3, consists of a resistance heater of 1500W power output, wattmeter, and an auto transfer to provide the necessary power supply to the heaters. The national instruments (NI) based system was used to record the thermocouple readings at different heat pipe positions. Thermo-couples of K-type (10 numbers) were used to measure the temperature response at the axial distance's different position. The layout of thermocouples is presented in Fig. 3.

IV. EXPERIMENTAL PROCEDURE OF SINGLE AND SCP AND - MULTISTAGE HEAT PIPE

Single and multistage heat pipe components like evaporator, adiabatic, and condenser sections were fabricated by given length 150, 300and 150 mm, respectively, and specifications are shown in Table 3. 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) flat fins each of 1mm thickness mounted on the condenser section by bracing. The same procedure was followed and used to fabricate the cascade (Multistage) heat pipe was fabricated, tested, and shown in Figure 2.2.

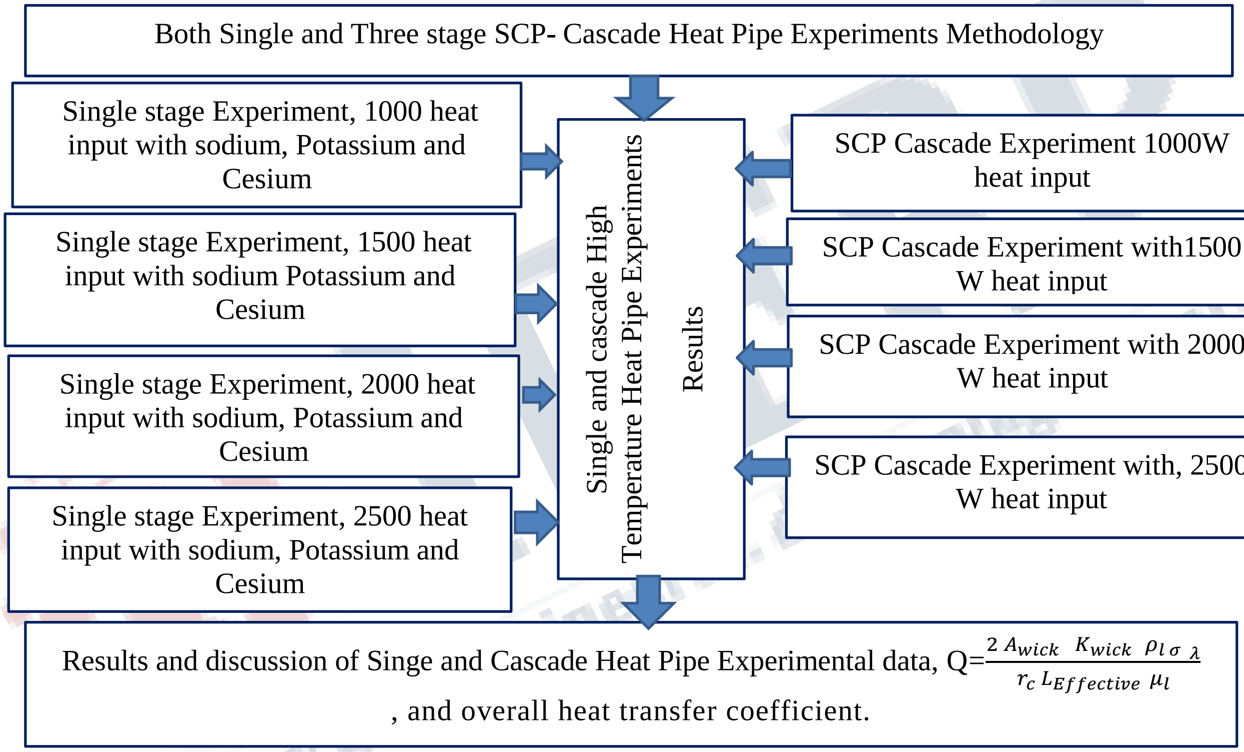

Figure 2.5 Experimental Procedure of Single and SCP- cascade heat pipe

The specification of the single and multistage heat pipe is presented in table 1. The experimental setup, Fig. 2.2, consists of a resistance heater of 1500W power output, wattmeter, and an auto transfer to provide the heaters' necessary power supply. The national instruments (NI) based system was used to record the thermocouple readings at different heat pipe positions. Thermo-couples of K-type (10 numbers) were used to measure the temperature response at the axial distance's different position. The layout of thermocouples is presented in Fig. 3.

The cooling water's inlet and outlet temperatures were measured using a two-T type thermocouple and integrated with a data logger. The mass flow rating of cooling water at a steady-state was measured by using a control valve. The heater and the adiabatic sections were insulated with 1.0 cm thick glass wool, and then the power supply was controlled by an autotransformer. The heat input is varied by using the variable transformer from 60 to 300 W. The cooling water temperature and the temperature of the heat pipe was monitored using the data acquisition system. The mass flow rate of water was measured when the heat pipe operates under a steady-state. The same procedure was used to experiment with three different fluids, and results are used for analysis. The cascade heat pipe experiment was conducted with stage 1, 2 and 3 fluid like water, ethanol and acetone.

V. RESULTS AND DISCUSSION

The significant thermal resistance parameter and the overall heat transfer coefficient affect the effect of nanoparticles on heat pipe performance by calculating the variation of thermal resistance. The thermal resistance of the heat pipe can be calculated by R=$\Delta T/Q$, Where ΔT is the temperature difference between the evaporator wall and condenser wall. Expressions for calculating thermal resistance for different sections of the heat pipe are presented in table 3. The variation of thermal resistance of the heat pipe filled with and the copper nano-particles suspension are presenting in Fig. 4.

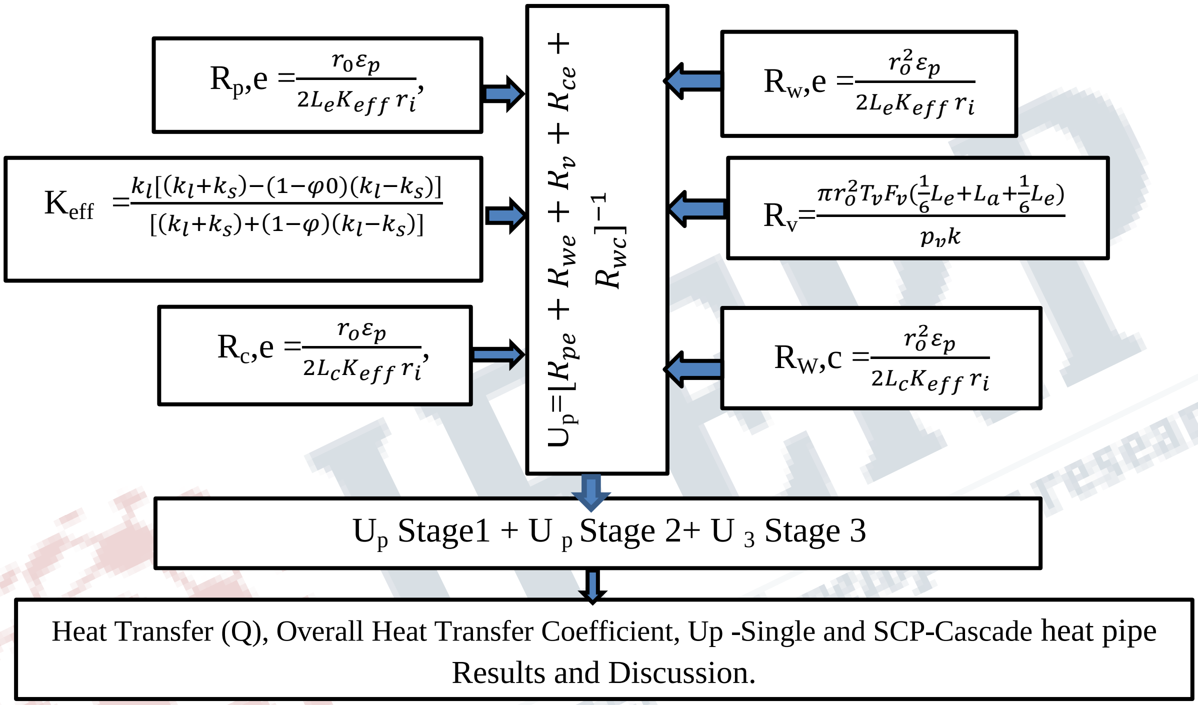

Figure 4.1. Overall heat Transfer Coefficient calculation procedure for single and multistage (SCP-cascade system) heat Pipe.

The thermal resistance trend shows that the heat pipe's thermal resistance decreases with the increases of heat the heat input. For 0.01 volume % of copper nanoparticles, the thermal resistance was reduced by 32.10%. The experimental results showed a lower thermal resistance for higher heat input by using The Nanofluid in the heat pipe. The following parameter like thermal resistance reduced due to the activation of a large number of nucleation sites in the evaporator section, which extends the regime of nucleate boiling to vary high heat fluxes

4.1. Error Estimation of Single and SCP - Multistage Heat Pipe

The error estimates are fundamental analysis for the experimental part and influence of results and analysis. The following primary experimental uncertainty sources 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$2.5 %, and the accuracy of the thermocouple is around $\pm$5% ^{0}C. The maximum uncertainty of the wattmeter is around $\pm$1.5., 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 coefficient was predicted and tabulated as shown in Table 3 and the uncertainties calculated by the Eqs. 1, 2

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

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

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 SCP and CPS- cascade heat pipe.

	Heat pipe with water		SCP-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	6.1	6.3	6.23	6.52
1500	6.01	6.12	6.33	6.4
2000	5.33	5.11	6.04	6.3
2500	5.8	5.86	6.06	6.25
2750	5.92	6.03	6.25	6.31

4.2. Overall Heat Transfer Coefficient of Single and SCP and CPS -multistage

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

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

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.

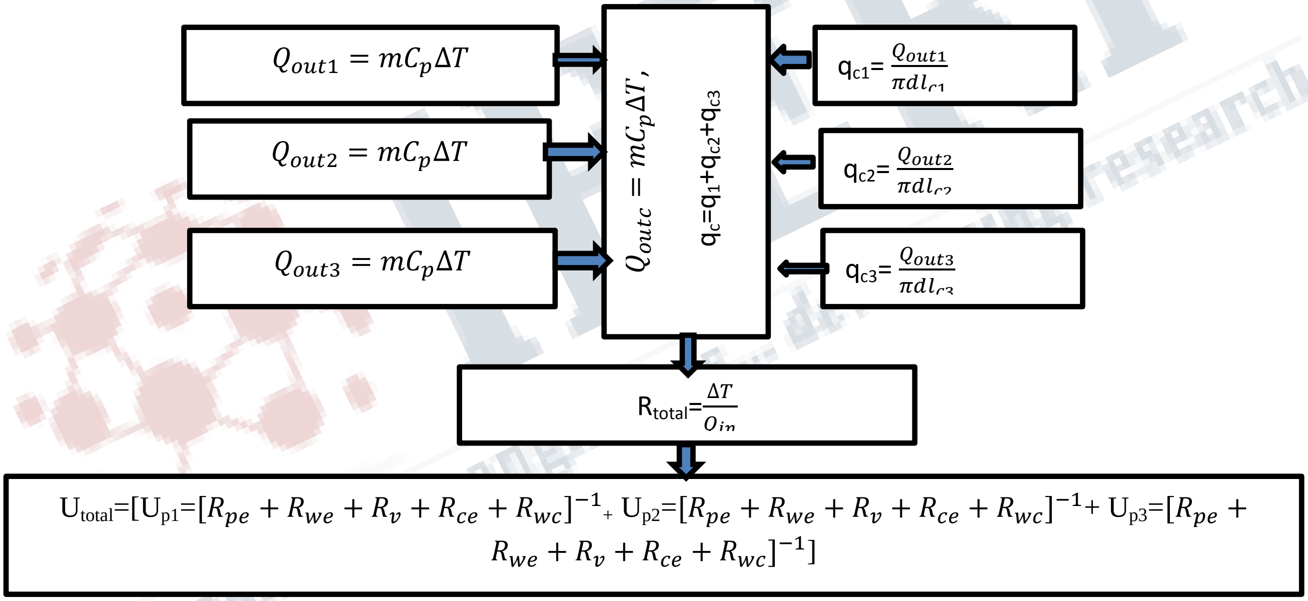

Figure 4.2 Heat Transfer, heat flux and Overall Heat Transfer Coefficient calculation procedure of SCP heat pipe

The experimental heat transfer coefficient at the condenser section of single and multistage can be calculated as given below $q_c=\frac{Q_{out}}{\pi d l_c}$, $Q_{out}=mC_p\Delta T$, 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 was used to find the cascade system. Single Stage heat output was calculated using the equation Figure shows the condensing heat transfer coefficient enhancement due to the addition with two stages (multistage) with two different fluids. The results showed that the heat transfer coefficient of the heat pipe changed with multistage and compared to the 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 the surface created by the multistage as the convection area was increased. The condenser section's heat transfer coefficient depends on the thickness of the liquid layer and the working fluid's hydrodynamic properties. A correlation can be established between the Nusselt number, Reynolds number and Prandtl number

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

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

$$N_u = 5.03\mathrm{Re1}^{/3}\,\mathrm{P_r}^{1/3} \qquad (10)$$

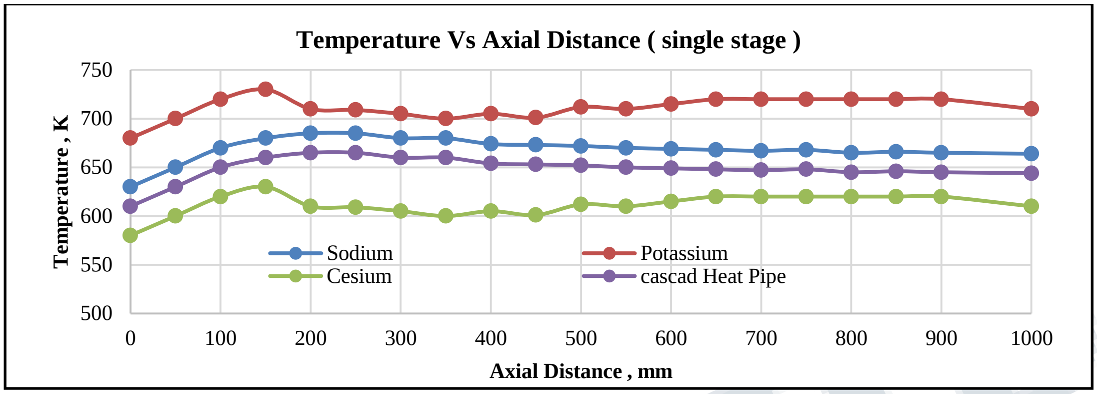

Figure 4.2 Temperature Vs Axial Distance of single and SCP-multistage heat Pipe

Figure Shows the Nusselt number variation concerning the Reynolds number for the endless 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 Prandtl number increase leads to Nusselt number enhancement. The figure shows a comparison of the experimental results of the heat pipe.

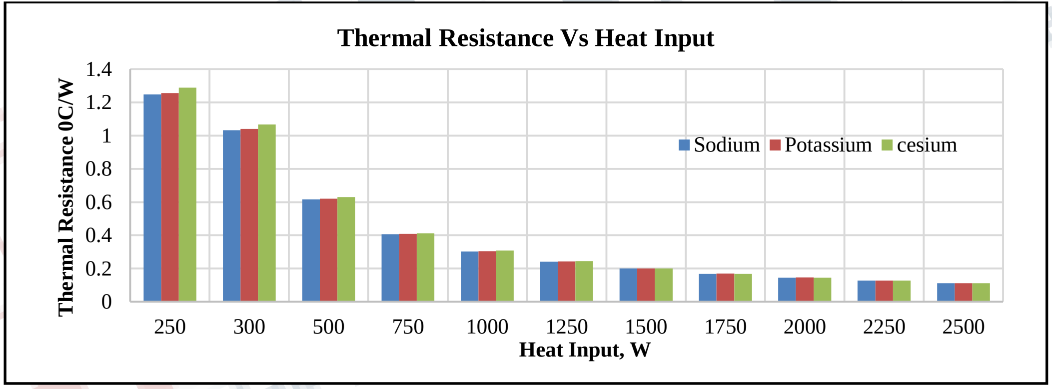

Figure 4.3 the variation of Thermal Resistance concerning Heat Input

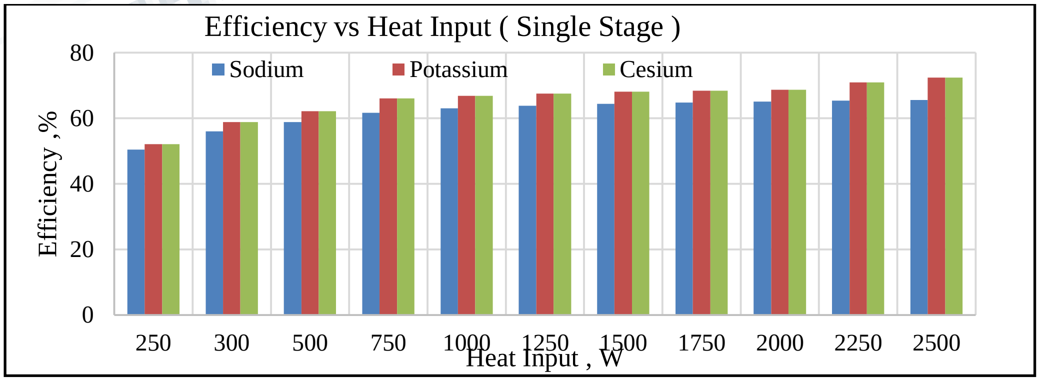

Figure 4.4 the variation of Efficiency concerning Heat Input

It can be seen the variation of resistance with heat input shown in Figure 4.2. The thermal resistance of the single-stage heat pipe decreased when increasing the heat input.

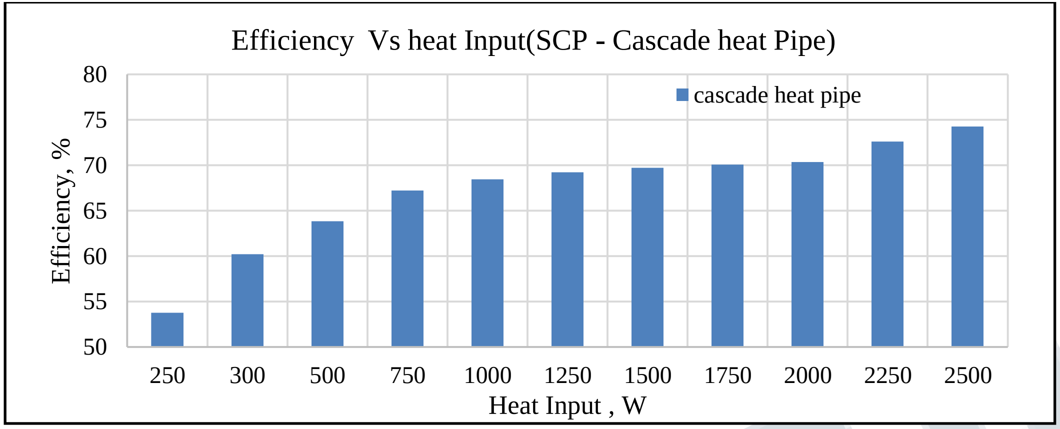

Figure 4.5 variation of Efficiency with Heat Input of SCP-Heat Pipe

It can be seen from the Figure, Variation of heat transfer coefficient with T sat (K) shows the figure 4.3. In can be indicated that, heat transfer coefficient increase when the temperature increases. Cascade heat pipe heat transfer coefficient is 18 to 19.5 % higher compared to the single-stage heat pipe. Experiments were performed, and results used 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. Both single and cascade heat pipe inside fluid velocity and condensate liquid and the hydrodynamic properties play a significant 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 evaporator's heat transfer characteristics 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 system's overall heat transfer coefficient increases gradually with an increase in heat flux or the saturation temperature maximum of 23.10 %, and the heat transfer coefficient increases by 16% compared to a single-stage due to decreased thermal resistance of the heat pipe.

VI. CONCLUSION

The experimental investigation was performed to study the heat transfer characteristics of the single and multistage heat pipe. The single and multistage stage's thermal resistance and efficiency were predicted for three fluids with variable heat input. Sodium's thermal conductivity has slightly lower than Potassium, and the thermal conductivity and boiling point of Cesium was lower than Sodium and Potassium but boiling point. The merit Number of Sodium was lower compared to the other two fluids. Experimental results are obtained with sodium heat pipe efficiency was slightly lower compared to Potassium and Cesium. The cascade (SCP) heat pipe efficiency was better than a single-stage, and working temperature range from 600 to 750 deg, C. Single-stage heat pipe heat transfer is 8% lower than cascade heat pipe due to two low boiling point fluid used in the second and third stage. Cascade's convection area increased, and the heat transfer rate was increased based on the experimental investigation. Based on the experiment operating temperature, range 550k to 740 K in general, Cesium/Titanium heat pipe can be more potent than Potassium, but Potassium is a significantly better-working fluid than Cesium.

Nomenclature

G - Acceleration due to gravity,
∞ - Ambient
Avg - Average
H - Heat Transfer Co Efficient
B - Bottom wall
T_m - Bulk mean temperature
B - Co-efficient of volumetric expansion,
Q_{sides} - Convective heat loss
Q_{top} - Convective heat loss
T_{max} - Dimensionless temperature,
exp - Experimental
FN - Figure of Merit,
f - Fluid
Gr - Grashof number,
q_{pri} - Grashof number,

q_{sec} - Heat,
q'' - Heat flux (W/m^2)
Q_{in} - Heat input,W
T_{heater} - Heater temperature, ^{o}C
T_{water} - Water temperature, ^{o}C
v - Kinematic viscosity, m^2/s
N - Number of secondary tubes arranged
Nu - Nusselt number, *hL/k* , *hd/k*
Pr - Prandtl number, *v/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, ^{o}C
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
The - Thermal resistance, ^{o}C/W
V - Voltage applied to the heater, Volts

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