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Experimental Investigation on Natural Circulation Loop with Different States of Loop Fluid at the Starting of Activation of the Circulation Loop

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***Abstract*— A Natural circulation loop is fabricated to investigate the performance of heat transfer from a heat source at the bottom to the heat sink at the top of the vertically placed natural circulation loops. The loop fluid circulates in the loop due to density differences aroused due to temperature differences at the heat source and heat sink, hence, transports heat from the heat source to the heat sink without the aid of any external agency like pumps. The heat supplied in the heat source is the driving force to circulate fluid in the loop.**

The loop is equipped with a data logger to collect the temperatures at various locations of the loop and an ultrasonic flow meter is connected to collect the instantaneous flow rates without disturbing and without touching the loop fluid flowing through the natural circulation loop.

Experiments are carried out in two different cases of steady conditions maintained in the natural circulation loop setup. In the first case, the loop fluid is allowed to reach steady state condition in the loop and then the hot water at desired temperature is supplied into the heat source. The performance of the loop is determined for different temperatures of hot water supplied into the loop and the flow circulation behavior in the loop is investigated. The Similarly, in the second case, hot water at a steady temperature is supplied into the loop and then loop fluid is filled into the loop. During loop fluid filling into the loop, the fluid is associated with some initial velocity, that will assist in fluid circulation at the starting of activation of the loop. Hence, the fluid circulation rate in the loop and efficiency of natural circulation loop increases, and heat transport from the heat source to the heat sink enhances.

Keywords*—*Natural circulation, hot end heat exchanger, cold end heat exchanger.

I. INTRODUCTION

A heat source, a heat sink and the pipes connecting them form the essential parts of a natural circulation system. Usually, the heat source is placed at the bottom or in the side pipe leg of the loop and the heat sink is located at the top end of the Natural circulation loop (NCL) to promote natural circulation. The pipes are connected to the source and sink in such a way that it forms a continuous fluid circulation path. When the loop is filled with working fluid, a natural circulation system is ready where fluid circulation can starts automatically following the activation of the heat source by supplying hot water through the heat source. With both the heat source and heat sink conditions maintained constant i.e. hot and cold fluids flowing through the heat source and heat sink are maintained constant, a steady circulation of loop fluid can be achieved, which can continue indefinitely if, the steady sate conditions of the NCL is maintained.

Natural circulation is a simple phenomenon which occurs in a fluid in presence of temperature and density gradients in a force field. The generation of density gradient is caused by temperature variations of fluid due to simultaneous heating and cooling at different parts of the loop. In a NCL the loop fluid flow is driven by thermally generated density gradient so that a pump is not required. Under the influence of gravitational force heavier fluid falls down and the lighter fluid rises up and. Under the stable operation of the loop the fluid experiences a continuous circulation through the loop.

In natural circulation systems, there is a heat source and a heat sink, with the heat source placed lower than the heat sink, both in contact with a portion of the loop fluid. As consequence of exposure to different heat fluxes, the heated part of the fluid becomes lighter and rises up in the loop, while the cooled part becomes denser and is lowered down by gravity. These combined effects establish fluid circulation in the loop.

As natural circulation loops does not need any moving mechanical parts like pump or fan, natural circulation loops are characterized by high reliability and low costs of maintenance. On the other hand, it is very important the design of the systems which use natural circulation as primary heat transfer mechanism in order to optimize the thermal performances and to avoid unwanted dynamic behaviors, such as flow instabilities or flow reversals.

Natural circulation loops find several applications in conventional engineering as well as in nuclear industries. Some of the applications are solar water heaters, electrical transformer cooling, cooling of IC engines, cooling of gas turbine blades and Geothermal energy extraction etc. Potential new fields of applications are computer-chip cooling and electronic device cooling etc. The most apparent economic advantage of natural circulation loops is the elimination of the circulating pumps. Elimination of the primary circulating pumps not only reduces capital, operating and maintenance costs but also eliminates all safety issues associated with the failure of the circulating pumps.

The objective of the present investigation is firstly, to investigate the performance of Natural Circulation Loop at various hot fluid inlet temperatures into Hot End Heat Exchanger (HEHE) when a stable loop fluid is available in the loop and secondly, to investigate the performance of NCL by supplying loop fluid into the loop when hot water is flowing steadily through the heat source.

II. EXPERIMENTAL SETUP

The experimental setup consisting of a vertically placed rectangular shaped pipe loop with two double pipe heat exchangers placed at the top and bottom ends. The bottom heat exchanger acts as heat source and the top heat exchanger acts as heat sink. They are name as HEHE and CEHE. In the pipe loop, a loop fluid is filled. The heat supplied into the HEHE is transported by the loop fluid from the heat source to the heat sink at the top end. The transportation of loop fluid takes place due to density variations due to temperature differences experienced in the heat source and heat sink. The loop is constructed with copper pipe of inner diameter of 1.2 cm at the two heat exchanger portion and acrylic pipes in the riser and down-comer portions. The loop and heat exchanger portions are properly insulated with asbestos insulation. Hence, the loop is assumed to be adiabatic. The height of the loop is 100 cm, width is 27cm and pipe inner diameter is 1.2cm.

In the experimental setup of natural circulation loop, the important devices used are Purge rotameters, a constant temperature water supply bath, an Ultrasonic flow meter, Data logger and PT100 temperature sensors. Purge rotameter provides low flow rate measurement. Purge rotameters installed in the setup are used to measure the hot water and cold water flow rates passing through the hot end heat exchanger and cold end heat exchanger respectively. The Purge rotameters used for hot water and cold water flow measurement are shown in figure 1. A constant temperature water supply bath supplies constant temperature water into the heat source of natural circulation loop.

A data-logger is installed to measure the temperatures at various locations of Natural circulation loop. The data logger is a self contained, stand alone electronic instrument that records measurements at set intervals over a period of time. Once the application is programmed into the data logger, it is placed in system, the various input signals are connected and the data logging process is started. The time interval set for recording the temperatures is 10 seconds. For recording the temperatures at various locations of the natural circulation loop, eight PT100 temperature sensors are connected to the data logger. PT100 sensors are RTD (Resistance Temperature Detector) sensors that are made from Platinum. The PT100 sensor has a electrical resistance of 100 ohms at 0°C and is common type of RTD sensor used in laboratories for measuring temperature range of -200^{0}C to 850^{0}C. The resistance temperature detector operates on the principle of the change in electrical resistance in wire as a function of temperature. The PT100 temperature sensors provide the most linear, stable, repeatable, and accurate temperature measurements.

An Ultrasonic flow meter is used to connected in the NCL to measure the instantaneous loop fluid flow rate. The measuring principle of transit-time ultrasonic flow meter is based on the influence of the flowing fluid on the traveling time of the ultrasonic signal of the instrument. The signals are transmitted through the pipe material and the transit time difference between the forward and backward signals is used to determine the flow velocity. The ultrasonic flow meter transducers are clamped on the outer pipe wall, hence do not touch the loop fluid, hence the loop fluid natural circulation will not be disturbed. The time interval set for recording the flow measurement is 10 seconds. The experimental setup with instruments connected to the Natural circulation loop is shown in the figure 2.

III. METHODOLOGY

Various instruments and flow lines are connected to the natural circulation loop setup. The experiments are carried out in two cases, which are described below.

Case 1: Deionized water is taken as the loop fluid, which is first filled into the loop and is allowed to reach standstill condition. Later, the hot water is supplied into the Hot end heat exchanger at various temperatures viz., 50, 60, 70, 80 and 90^{0}C during the experimental period.

After the loop fluid comes to standstill condition, hot water is supplied in to the HEHE at the desired temperature and a flow rate of 0.3 lpm is maintained for the hot water passing through the HEHE, similarly cold water is supplied in to the CEHE and a flow rate of 0.3 lpm is maintained. The experiment is conducted for 30 minutes, in this duration the temperature at various location of NCL are reached steady state condition.

Case 2: The hot water at the desired temperature is supplied in to the Hot end heat exchanger and a steady flow rate of 0.3 lpm is maintained to flow through the heat exchanger then the loop fluid is supplied from one side of the loop, that pipe leg acts as down-comer and from the other side of the loop, the fluid rises up, which acts as riser. Cold water is supplied in to the cold end heat exchanger and a flow rate of 0.3 lpm is maintained.

Fig. 1. Purge Rotameters for hot water and cold water flow measurement

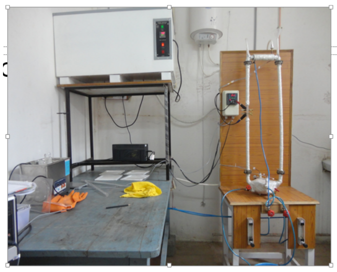

Fig. 2. Experimental Setup of Natural circulation loop

IV. RESULTS

The experiments are carried out on the natural circulation loop in two cases, which are described below.

Case 1: Deionized water is taken as the loop fluid which is first filled into the loop and is allowed to reach standstill condition. Later the hot water is supplied into the Hot end heat exchanger at desired temperature during the experimental period.

The Experimental test procedure for hot water supply at a typical temperature of 70^0C into Hot end heat exchanger is explained below.

After the loop fluid comes to standstill condition, hot water is supplied in to the HEHE at 70^0C and a flow rate of 0.3 lpm is maintained to pass through the HEHE, similarly cold water supplied in to the CEHE and a flow rate of 0.3 lpm is maintained. The experiment is conducted for 30 minuts, in this duration the temperature at various location of NCL are reached steady state condition. From the experiment, the average velocity of flow in the loop is found to be 0.02572 m/s. The temperature variation of loop fluid and secondary fluids are plotted in figure 3. The figure 4 shows the loop fluid velocity(m/s) as a function of time in seconds. Similarly, the experiments are conducted at 50, 60, 80 and 90^0C.

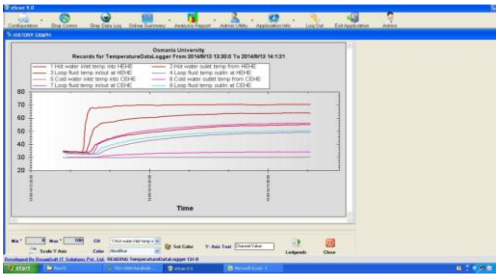

Fig. 3. Temperatures in various locations of the NCL as a function of Time for a typical hot water supply temperature of 70^0C in case 1.

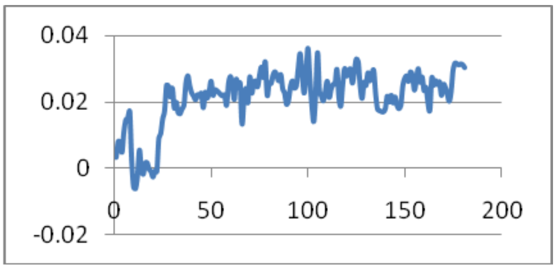

Fig. 4. Velocity(m/s) as a function of Time(s) for a typical hot water supply temperature of 70^0C in case 1.

Case 2: The hot water at the desired temperature is supplied in to the Hot end heat exchanger then the loop fluid is supplied from one side of the loop, that tube leg acts as down-comer and from the other side the fluid rises up, which acts as riser.

Effect of varying the temperature of hot fluid supplied into the hot end heat exchanger with distilled water as the loop fluid. At different temperatures (50, 60,70, 80, and 90^0C) of hot water supply, the parameters such as Flow rate, Velocity, Total flow, loop fluid temperature etc. are recorded and these observations are used to calculate loop fluid circulation rate, heat rejected by hot fluid, heat gained by loop fluid, heat rejected by loop fluid in the cold end heat exchanger, heat gained by cold fluid in CEHE and Efficiency of natural circulation loop.

The Experimental test procedure for hot water supply at a typical temperature of 70^0C into Hot end heat exchanger is explained below.

The hot water is supplied in to the HEHE at 70^0C and a steady flow rate of 0.3 lpm is maintained for the hot water, similarly cold water supplied in to the CEHE and a flow rate of 0.3 lpm is maintained. While loop fluid is filled in to the loop itself the fluid circulation is initiated and assisted by the filling fluid itself. The experiment is conducted for 30minuts, in this duration the temperatures at various locations of NCL are reached steady state condition. The average velocity observed from the experiments is 0.02984 m/s. The temperature variation of loop fluid and secondary fluids are plotted in figure 5. The figure 6 shows the loop fluid velocity(m/s) as a function of time in seconds.

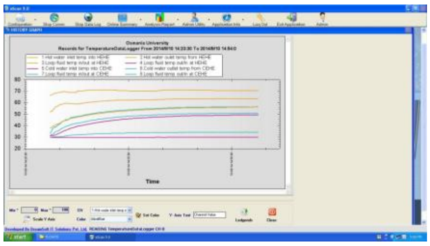

Fig. 5. Temperatures in various locations of the NCL as a function of Time for a typical hot water supply temperature of 70^0C in case 2.

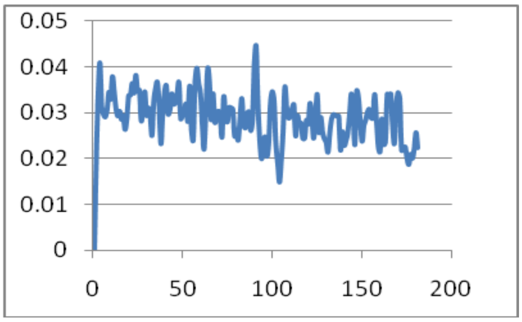

Fig. 6. Velocity(m/s) as a function of Time(s) for a typical hot water supply temperature of 70^0C in case 2.

From the experimental readings graphs are plotted and it is found that, for the same temperatures of hot water supply into the NCL, the efficiency of Natural circulation loop is better when the loop fluid is supplied into the loop while a constant temperature steady state water is passing through the heat source at the start of the activation of the Natural circulation loop. This is shown in figure 7. Similarly the experiments are conducted at other temperatures of 50, 60, 80 and 90^0C.

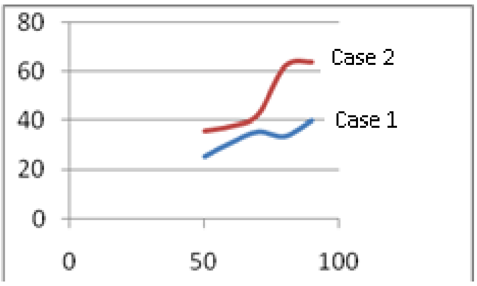

Fig. 7. Efficiency enhancement as a function of Hot water supply temperature for case1 and case2.

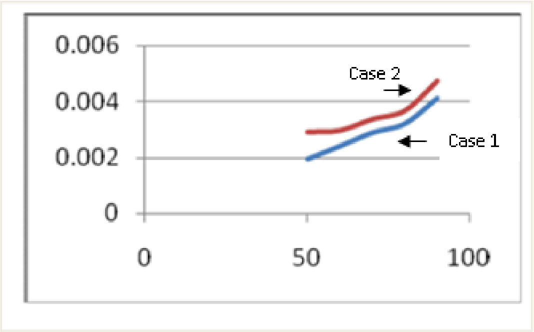

Fig.8. Flow rate (lps) enhancement in the loop as a function of hot water supply temperature (^{0}C) for case 1 and case 2.

As the temperature of hot water supply into heat source is increasing, loop fluid flow circulation in the loop is increasing which is shown in figure 8. The increase of flow rate is more in case 2 than case 1.

V. CONCLUSIONS

In the present experimental investigation, the performance of Natural Circulation Loop with distilled water as loop fluid is investigated in two cases.

In case 1, the loop fluid is first filled into the loop and allowed to reach standstill condition, and then the hot water is supplied into the heat source of NCL at various temperatures of 50, 60, 70, 80 and 90 ^{0}C.

In case 2, the hot water at the desired temperature is supplied and allowed to flow steadily through the heat source of NCL then the loop fluid is supplied from one side of the loop and loop fluid circulation is initiated during filling.

After analyzing the experimental investigation the following conclusions are drawn:

While the hot fluid entering temperature into the Hot End Heat Exchanger is increased,

1. The loop fluid circulation rate in the loop is observed to be increased.
2. The fluid in the riser temperature and down-comer temperature is increased.
3. The temperature differences and fluid circulation rate in the loop fluid is increased.
4. Fluid circulation rate in case2 is more than the fluid circulation of case1.
5. With increased flow circulation in the loop, heat transported from the heat source to sink is increased.
6. For the same hot water supply temperature into the heat source, the Efficiency of Case2 is more than the efficiency of case1. The efficiency increased in case1 from 25.59 to 39.94% and in case2 efficiency is increased from 35.66 to 63.65%.

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REFERENCES

[1] Tuckerman, Pease, B. Maiti, P.K. Das, steady state performance of single phase natural circulation loop with end heat exchanger parameters on the performance of a natural circulation loop, Int. journal of. Heat Mass Transfer 29 (2008)1-4.

[2] Seok and Choi, Heat transfer in fluid coupled indirect heat exchanger systems, ASME J. Heat Transfer (1975) 449– 503.

[3] X. Luo, X. Guan, M. Li, W. Roetzel, Dynamic behavior of one-dimensional flow multistream heat exchangers and their networks, Int. J. Heat Mass Transfer 46 (2003) 705–72.

[4] P.J. Heggs, C.L. Render, Transient response of heat exchangers with one infinite capacitance fluid, Heat Transfer Eng. 4 (2) (1983) 19–27.

[5] G. Pagliarini, G.S. Barozzi, Thermal coupling in laminar flow double-pipe heat exchangers, ASME J. Heat Transfer 113 (1991) 526–53.

[6] N.M. Rao, B. Maiti, P.K. Das, Stability behavior of a natural circulation loop with end heat exchangers, ASME J. Heat Transfer, in press.

[7] Ch. Na Ranong, W. Roetzel, Steady state and transient behavior of two heat exchangers coupled by a circulating flow stream, Int. J. Thermal Sci. 41 (2002) 1029–1043.

[8] G.Narendar,A.V.S.S Kumara Swami Gupta, A.Krishnaiah, Experimental investigation on natural circulation loop with compact heat exchanger at heat source and using nanofluid as loop fluid, (Paper No. HMTC 1300817) Proceedings of the 22th National and 11th International ISHMT-ASME Heat and Mass Transfer Conference December 28-31, 2013, IIT Kharagpur, India.

[9] G.Narendar,A.V.S.S.Kumara Swami Gupta, A.Krishnaiah, CFD analysis of natural circulation loop, International Journal of Mechanical and Automobile Engineering Volume 22 (2012) 46-52.

[10] F.E. Romie, Transient response of the counter flow heat exchanger, ASME J.Heat Transfer 106 (1984) 620–626.

[11] G.Narendar,A.V.S.S Kumara Swami Gupta, A.Krishnaiah, Investigation on natural circulation loop with compact heat exchanger as heat source and using nanofluid as loop fluid, International Journal of Systems , Algorithms & Applications, Volume 3(Issue ICRAET13, March 2013, ISSN Online: 2277-2677)pp31-34.