Variation of thermo-physical properties of thermal energy storage system with the use of Aluminum/distilled water based nanofluids through a circular pipe

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CERTIFICATION

I, Varinder Singh, declare that this thesis report entitled ***"Variation of thermo-physical properties of thermal energy storage system with the use of aluminum/distilled water based nanofluids through a circular pipe"***, submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

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ABSTRACT

The global conventional fuels in reserves are running out while the world energy consumption is increasing very fast. The scientific community agreed that thermal energy is one of the best solutions for energy supply in many parts of the world.

The experimental setup consists of water heater, thermal storage system, storage water tank and pump. The thermal storage system is loaded with steel spheres, water and aluminum/water nanofluid is used as the heat transfer fluid. During charging process the heat transfer fluid is being heated inside the heater and passes through the storage tank in order to transfer its thermal energy to the steel spheres and the water inside storage tank. In order to evaluate the system performance characteristics during charging, the effects of varying the mass flow rate, heat transfer fluid temperature, initial temperature of the storage tank during charging and processes on the rate and amount of thermal energy storage.

Moreover, several experiments are performed with water and aluminum/water nanofluid only as storage medium in order to compare the effect of steel spheres packed bed on the performance of the thermal storage system and its capacity. On the basis of experiment, it has been observed that increasing the mass flow rate results in decrease in time required to complete the charging process and increasing the heat transfer fluid temperature which results in an increase in rate and amount of thermal energy storage and hence time required to complete the charging process also increases. The steel spheres comes into thermal equilibrium in shortest time near inlet but time increases as we move further with the length of packed bed.

During the study of pressure drop characteristics, conclusion has come to know that increase in mass velocity of fluid results in pressure drop across packed bed increases. Therefore the selection of flow rate is important which shows that pressure drop is directly driving away

with mass flow rate of the fluid and at the same time Reynold number is also directly driving away with mass flow rate of the fluid.HTF mass flow rate has a considerable effect during charging. Increasing of mass velocity of fluid accelerates charging process for storage unit and cause early achieve of steady state. Nanofluids are more valuable in the energy storage and having less pressure drop through the bed during charging as compared to water.

The choice of the ratio between diameter and height of packed bed is important because the increase in this ratio (D/L) results in increase of the cross sectional area and mass flow rate. This also causes the increase in the stored energy and reduction of the pressure drop.

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CHAPTER-1: INTRODUCTION AND OBJECTIVES

1.1 Introduction

Energy is the main cause of all human actions on earth. In some past years, due to the large consumption of energy in the many different activities like transportation, Industry and household etc, demand of energy has been increased. From long time, all human requirements are satisfied by fossil fuels for energy production. But in recent times the maximum environmental problems are caused by these fossil fuels. These fuels caused massive damage to environment like Global warming etc. Being the higher demands, the prices of these fossil fuels increased every year and it will continue rising because the demands for these fossil fuels go on and at the same time fossil fuels reserves are diminishing. Therefore, additional energy sources must be introduced to order to take the position of fossil fuels. In future for energy supply, Renewable energies are likely to play the key role. As compared to fossil fuels, Renewable energies are much sustainable and do not make any harm to the environment. Renewable energies are solar energy, wind energy, tidal energy bio energy, geothermal energy etc all are comes into the category of Renewable energy. The big disadvantage of all these forms of energy is their high cost. Also some of them like solar energy, tidal energy and wind energy are nature dependent means cannot be available all the times. This is the reason why energy storage comes into picture.

1.2 Different methods for energy storage

When we have excess energy and we want o use it later then energy storage can be used. Or we can say that we can remove the disparity between the times of energy demand and energy supply.

1.2.1 Mechanical energy

1.2.1.1 a) Hydraulic storage

This is the oldest and leading method of energy storage in between all commercially methods of energy storage. In this method, two vertical reservoirs are used which are mounted at different elevations. When water moves from lower reservoir to high elevated reservoir, energy is being stored in this process. But to extract this energy, water moves back from upper reservoir to the lower one. Here the most important parameter is height and we know

Potential Energy (P.E.) = mgh

$$E = \rho vgh$$

Where v is the total volume of water in m^3, ρ is the water density in kg/m^3, g is the accerlation due to gravity in m/s^2 and h is the vertical difference between two reservoirs in meters. The main disadvantage of this type of energy storage plant is their high initial cost and long time duration to build it.

1.2.1.2 b) Compressed air storage - This is the new technique introduced for the energy storage. In this, there must be an integrated combustion turbine along with the basic components. This is the reason it also called hybrid energy storage. The air is compressed by which the combustion occur in the combustion chamber and then turbine generates the power. The 60% of the output power generated by turbine consumed by mechanical compressor to compress the air and supplies it to the combustion chamber.

1.2.2 Electrical energy

1.2.2.1 a) Batteries -In batteries, chemical energy is used to store electrical energy. There are two typesof batteries, primary and secondary. The batteries which are used only for once means

which are not charged again to use are called primary batteries. On the other hand, the batteries which are used by charging up many times again and again called secondary batteries.

1.2.2.2 b) Superconducting magnetic energy storage (SMES)-In superconducting coil, magnetic field is generated by the flow of direct current where energy can be stored. Then this superconducting coil bought to the temperature which will be lower than the superconducting critical temperature. Generally, superconducting magnetic energy stored contain power habituation system, coil, ice-cooled refrigeration. It is important to maintain here that this SMES has highest efficiency for energy storage.

1.2.3 Thermal enegry

TES systems for both heat and cold are necessary for good performance of many industrial processes. High energy storage density and high power capacity for charging and discharging are desirable properties of any storage system. TES could be the most appropriate way and method to correct the gap between the demand and supply of energy and therefore it has become a very attractive technology. It is well known that there are three methods of TES: sensible, latent and chemical heat storage

1.2.3.1 Sensible heat storage - Sensible heat storage: In this type of heat, heat capacity is means to be by raising the temperature. The amount of energy stored in the form of sensible heat can be calculated by

$$Q=mc(T_2-T_1)$$

Q is the sensible heat (kJ), c is the specific heat, m is the mass of material, T_1 is the initial temperature and T_2 is the final temperature. Water is known as one of the best materials that can be used to store thermal energy in form of sensible heat because water is cheap, abundant, high specific heat, and high density.

1.2.3.2 Latent heat storage: Latent heat is the quantity of heat engrossed or released for the period of change of the material from one phase to another phase. Generally, there are two types of latent heat, latent heat of vaporization and latent heat of fusion. The amount of thermal energy stored in form of latent heat in a material is calculated by

$$Q=m*l$$

Q is the quantity of thermal energy stored or unconfined in form of latent heat (kJ), m is the mass of the material used to accumulate thermal energy (kg), and l is the Latent heat of fusion or vaporization (kJ/kg).

Latent heat TES is mainly eye-catching due to its capability to give high energy storage density per unit mass in quasi-isothermal course. This means that in a definite purpose where the temperature range is significant, for instance in transport of susceptible temperature products, the use of PCM (Phase Change Material) becomes very helpful since it can store material at steady temperature related to the phase-transition temperature of the PCM.

1.3Thermal energy storage

Thermal energy storage (TES) has been a major research area for the last 15 years, but the information is quantitatively vast. The key devices to understand the energy preservation are the thermal energy storage (TES) systems and they agree to line up energy creation with user demand. Thermal Energy Storage use for various thermal applications, like as water heating, cooling, air-conditioning, in modern times grabbed much awareness. The effort described the use of existing assets and the best possible use of renewable sources.

Thermal Energy Storage give results in some particular areas:

• Existing power and the time hindrance between productions.

• Safety of energy supply etc.

The topic of analysis and debate has been given as follows:-

• Storage materials

• Applications

1.4 Storage materials

Packed beds characterize the best appropriate storage unit for Thermal storage system. It consists of solid material (loosely packed) in which heat carrying fluid will pass on. Because of it, thermal energy is transfer during the process. This way, the jam-packed bed stores the energy. Various studies told about different models for storage in permeable media. In this, we use the solid steel spheres for heat storage energy.

1.4.1 Metallic

Because of their heavy weights, there are not well discussed for the thermal storage material. But where weight is not the primary requirement, they are much preferable because of their following advantages:

1.4.1.1 Some important features are:-

1) High thermal conductivity.

2) High heat of fusion per unit volume.

1.5 Storage material properties

There must be some properties which are required for the better storage of thermal energy which are as follow

1.5.1 Thermo physical properties

1) High density.

2) High thermal conductivity.

3) High value of specific heat.

4) High latent heat of fusion.

1.5.2 Chemical properties

1) No chemical decomposition or phase separation.

2) Non combustible, non corrosive, and non poisonous.

1.5.3 Accessibility and cost

1) Plentiful and inexpensive

1.6 Thermal energy storage applications

1) Static storage in bioclimatic buildings.
2) Milk products, food, wine (absorbing peaks in demand), greenhouses.
3) Solar energy storage is the simplest form of thermal energy storage.
4) Thermal protection of transport, food, hotel trade, ice-cream, etc.
5) Thermal protection of electronic devices (integrated in the appliance).
6) Sanitary hot water and heating: using off-peak rate and adapting unloading curves.
7) Cooling of engines (electric and combustion).
8) Temperature continuation in rooms with computers or electrical appliances.
9) Thermal energy storage main application in medical science: transport of blood, operating tables, hot–cold therapies.

1.7 Nanofluids

Nanotechnology is the kind of technology which provides the materials with size less than 100 nm called nanomaterial. On the basis of the structure and their properties, nanomaterials are divided into four type of category [1]. Carbon based nanomaterial, metal based nanomaterials and composite. Suspend these nanoparticles into any type of conventional fluid like water, oil,

ethylene glycol to make nanofluids. The reason why nano size particles are preferred over micro size particles was well explained [2]. With use of nanoparticles over micro particles, there was a much improvement in thermo physical properties. Some important results are

Table 1.1: Difference between nanoparticles and microparticles

Properties	**Nanoparticles**	**Microparticles**
Pump Power	High	Low
Stability	Settle	Kinetically stable(long lived in suspension)
Surface/Volume ratio	1	1000 times larger than micro particles
Conductivity	Low	High
Erosion and clogging	Yes	No

Nanofluids can be used for various applications like air conditioning cooling, automotive, power plant cooling, improving diesel generator efficiency etc. because of the unique properties carried by nanofluids [3].

1.8Nanoparticles materials

Some of the following are the different types of materials having size less than 100 nm used for nanoparticles :-

1) CNT (Carbon nanotubes)
2) Metallic nanoparticles.
3) Non-metallic nanoparticles.

4) Metallic and non metallic oxides.

Most frequently used base fluids with nanoparticles.

1) Water

2) Ethylene glycol based (coolants) etc.

1.9 Importance of nanofluids

As we know that now a day sizes of heat transfer devices decreases and at the same time adequate cooling must be provided. It is difficult for the devices to operate under high operating speed, therefore temperature of devises increases to very high value which makes the devices to operate at high power [4]. Due to the poor thermal conductivity of coolant (water, oil etc.), reduced the thermal processing efficiency. Nanofluids enhanced the thermal conductivity of fluids. We can increase the heat transfer rate in thermal systems by adding very small concentrations of nanofluids and can come across the cooling needs of thermal systems. Nanoparticle size plays a vital role in enhancement of thermal conductivity as enhancement in thermal conductivity increased by 40% by particle size below 50 nm [5]. So for lighter size with slow velocity heat exchanger, nanofluids enhanced the thermal conductivity. Due to large surface area to volume ratio of nanofluids, heat transfer rate increased. There was an increase in heat transfer rate by using continues heat exchange between nanoparticles and base fluid through convection mechanism [6]. When collision between particles occurs due to Brownian motion which depends on viscosity of base fluid, temperature and nanoparticle size, heat transfer takes place. Decrease in particle size indicates to large motion and convection heat transfer become dominant [7]. The resulting nanofluids having many benefits and some important of them are as follow:

1) **Enhancement in heat conduction -** Base fluids have lower thermal conductivities than nanofluids because of some factors. Between the base fluids and the solid particles, heat transfer increases due to the increase in ratio of surface area to volume. Due their very small size, the other most important advantage is their high mobility.
2) **Clogging elimination -**Nanoparticles are self-possessed of thousands of atoms with diameter of about 1 ~ 100 nm and are sound detached in nanofluids, just to avoid the problem of clogging. For higher endorse the heat transfer, it can be used in micro channels where heat transfer is increased by increasing thermal conductivity and effective heat transfer area.
3) **Lesser press drop and fall in pump power -**To improve the thermal conductivity, nanoparticles have established high effectiveness due to its huge precise surface area. It is likely that a lot smaller concentration of nanoparticles is required to attain comparable enhancement in bigger particle suspension. A smaller amount of material is required so that increase in viscosity as well as pump power will be smaller.
4) **Erosion reduction** -Being very small in size, nanoparticles does not carry so much momentum and hence the impact of kinetic energy on the surfaces of solid is also small. Therefore components erosion, like pumps, pipelines and heat exchangers, will reduce to a great extent. Also in liquid phases, nanoparticles discrete and reduce wear and friction.

1.10 Nanofluids applications

1) Used in biomedical applications.
2) Used as coolant in radiators.
3) Used for cooling of devices such as microchips in computers
4) Used in a fuel.
5) Used in industrialized cooling applications.

6) Used as heat transfer fluid in the jam-packed bed system.

7) Used in detergent

CHAPTER-2: LITERATURE REVIEW

2.1 Nanofluid: Importance and application

2.1.1 Importance of nanofluid

As we know that now a day sizes of heat transfer devices decreases and at the same time adequate cooling must be provided. It is difficult for the devices to operate under high operating speed, therefore temperature of devices increases to very high value which makes the devices to operate at high power [1]. Due to the poor thermal conductivity of coolant (water, oil etc.), reduced the thermal processing efficiency. Nanofluids enhanced the thermal conductivity of fluids. We can increase the heat transfer rate in thermal systems by adding very small concentrations of nanofluids and can come across the cooling needs of thermal systems. Nanoparticle size plays a vital role in enhancement of thermal conductivity as enhancement in thermal conductivity increased by 40% by particle size below 50 nm [2]. So for lighter size with slow velocity heat exchanger, nanofluids enhanced the thermal conductivity. Due to large surface area to volume ratio of nanofluids, heat transfer rate increased. There was an increase in heat transfer rate by using continues heat exchange between nanoparticles and base fluid through convection mechanism [3]. When collision between particles occurs due to Brownian motion which depends on viscosity of base fluid, temperature and nanoparticle size, heat transfer takes place. Decrease in particle size indicates to large motion and convection heat transfer become dominant [4].

2.1.2 Applications of nanofluid

For efficient heat dissipation, nanofluids can be used over a wide range of application. The various applications of nanofluids are as follow:

2.1.2.1 Nanofluid as coolant - For smaller size and better positioning of the radiators, the use of nanofluids as coolant is preferred. Due to the higher efficiency, engines could be operated at higher temperatures allowing for more power. In a study [5],showed that radiator area can be reduced by 10% by using nanofluids. By this 5% fuel can be saved by reducing the air drag.

a) In medical stream: Large amount of heat (2000-3000W/cm2) produced by high intensity x-rays which should be feasible by nanofluids technology.

b) Vehicles cooling: Nanofluids are used as engine oil, coolant, lubricant, gear oil, and, transmission fluid [6]

c) Transformer cooling: For reducing transformer size and weight, nanofluid technology is preferable in power generation industry. This technology used either to increase in the performance of existing transformer or reduce the size of new transformers for same power transmitted.

d) Microelectronics cooling: Using gold nanofluids as working fluid results in significant reduction around 37% in thermal resistance.

e) Cooling in defense equipments: Number of many military systems and devices, such as high powered military electronics, radars, military vehicle components, and lasers, require very high-heat-flux cooling. Also to military vehicles like jet, submarine etc, nanofluids provide the advance cooling.

2.1.2.2 Nanofluid in fuel - With addition of aqueous aluminum nanofluid to diesel fuel, results in more total combustion heat at the rate of fewer amounts of smoke and nitrous oxide in exhaust emission. It happens because of high oxidation activity of pure Al which permits to increase the decomposition of hydrogen from water during combustion process.

2.1.2.3 Nanofluid in brake fluids - When the brake fluid reaches its boiling point during braking process, vapor lock is created which delay the hydraulic system from dispersing heat results in brake failure. Nanofluids improve the characteristics and optimize the performance.

2.1.2.4 Industrial cooling applications - Great energy savings and resulting emission reductions by apply nanofluids for industrial cooling. They showed that nanofluids have the potential to save about 300 million kWh of energy for replacement of cooling and heating water for industries. [8,10] Using nanofluids in electric power industries, about 3000-9000 million kWh of energy per year could be saved which is equivalent to the annual energy consumption of about 50,000-150,000 households. In compact heat exchangers, cooling enhancement by 8-30% using nanofluids. The nanofluids were found on nanofins situated on the heater surface and augment the heat flux. It was observed that specific heat capacity of nanofluids was enhanced by 50%. So in thermal energy storage applications compared to cooling applications, nanofluids have better efficiency.

2.1.2.5 Solar devices - The efficiency direct absorption solar collectors is limited by the absorption properties of the working fluid. Also utilizing nanofluids as the absorption mechanism, efficiency improves up to 5% in solar thermal collectors [7].From experimental results, initial quick increase in efficiency with volume fraction, afterwards efficiency comes into level but volume fraction continues to increase [8]. Nanofluid based solar collector has longer payback period. Also it has 3% higher levels of pollution and around 9% lower embodied energy than a conventional collector [9].Experimentally the enhancement of heat transfer on car radiator with CuO and Fe_2O_3 nanofluids at constant flow rate of 10 L/min for different concentrations. Theoretical relations and calculations were used to compare with given data. Results showed that at constant temperature, as the Reynolds number of air increased the overall heat transfer

coefficient increased but the overall heat transfer coefficient decreased as the temperature increased at same concentration and Reynolds number. Heat transfer coefficient with Al_2O_3 water nanofluid on automobile radiator at constant flow rate of 2-5 L/min at different concentrations (0.1, 0.3, 0.5, 0.7, 1.0% vol.) and temperature range was 37^0C - 49^0C [10]. From results, it cleared that with increase in concentration of nanoparticle, outlet temperature of coolant decreased. At same concentration, with increase in flow rate of coolant, outlet temperature of coolant increased. At 0.7% vol. concentration enhancement become 35% because Nussle number increased as the Reynolds number increased. The effect of water and ethylene glycol as coolant on the performance of heat transfer coefficient of car radiator [11]. With 2% concentration of Cu nanoparticle, enhancement in heat transfer coefficient was 3.8% atair Reynolds number 6000 and coolant Reynolds number 5000. The effect of adding nanofluids that there was around 19% reductions in frontal area and at the same time power increased by 13%. Oleic acid was used as a surfactant for stability of nanoparticles at different temperature range (100C-800C) for more than 80 days [12]. They also exposed that with increase in concentration of nanoparticle, viscosity also increased. At 800C and 0.035concentration of Al_2O_3, maximum enhancement was around 11.25%.

2.2References

[1] S.K.Das, N. Putra, P. Thiesen and W. Roetzel., "Temperature dependence of thermal conductivity enhancement for nanofluids", -transactions of ASME. Journal of Heat Transfer Vol. 125 pp 567-574.

[2] Eastman JA, Choi SUS, Li S, Applied Phys Letter (2001) 78:718-720.

[3] V. Karthik, S. Sahoo, S.K. Pabi, S. Ghosh, International Journal of Thermal Sciences (2012) 1-9.

[4] Seok Pil Jang and Stephen U. S. Choi, "Role of Brownian motion in the enhanced thermal conductivity of nanofluids" Applied Physics Letter volume 84, 4316 (2004).

[5]Leong K.Y., Saidur R., Kazi S.N., Mamun A.H.,“ Performance investigation of an automotive car radiator operated with nanofluid based coolants (nanofluid as a coolant in a radiator)”, Applied Thermal Engineering 30(2010) 2685-2692.

[6] Peyghambarzadeh S.M., Hashemabadi S.H., Hoseini S.M., Seifi Jamnani M., “Improving the cooling performance of automobile radiator with Al2O3/water nanofluid”, Applied Thermal Engineering 31 (2011) 1833-1838.

[7] Natarajan & R Sathish.,(2009), Role of nanofluids in solar water heater, International Journal of Advanced Manufacturing Technology.

[8] T P Otanicar, P E Phelan, R S Prasher, G Rosengarten, & R A Taylor,(2010),Nanofluid – based direct absorption solar collector, Journal of renewable and sustainable energy, 2.

[9] T P Otanicar & J S Golden., (2009), Comparative Environmental and Economic Analysis of Conventional and Nanofluid Solar Hot Water Technologies, Environ. Sci. Techno., 43(15), pp 6082–6087.

[10] Peyghambarzadeh S.M., Hashema badi S.H., Hoseini S.M., Seifi Jamnani M., “Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators”, International Communications in Heat and Mass Transfer 38 (2011) 1283–1290.

[11 Murshed S.M.S, Leong K.C,Yang C.," Enhanced thermal conductivity of Ti02 water based nanofiuids", International Journal of Thermal Sciences 44 (2005) 367-373.

[12] Dey TK, Kole Madhusree, “Thermal conductivity and viscosity of Al2O3 nanofluid based on car engine coolant”, J. Phys. D: Appl. Phys. 43 (2010) 315501.

[13] Varinder Singh, Sumeet Sharma, Dr. D.Gangacharyulu, “Variation of CuO distilled water based nanofluid properties through Circular Pipe”, Volume 3 Special Issue, ISSN 2349-4476, pp 414-420.

[14] Varinder Singh, Sumeet Sharma, Dr. D. Gangacharyulu, Nanofluids: “Importance and Application”, CETCME 2015.

[15] Varinder Singh, Sumeet Sharma, Dr. D. Gangacharyulu, “Variations of Thermo-Physical Properties with CuO Distilled Based Nanofluids through a Circular Pipe”, PSIMT 2015, pp 331-336.

2.3 Literature review for thermal storage and thermo-physical properties

With increase in demand of energy, use of various non-conventional resources of energy has become popular but till now, not much effort has been made to store thermal energy. In case of solar energy system, the use of thermal energy storage reservoir is becoming popular. In this paper efforts are made to improve thermal performance of such systems is presented. Murshed et al. [1] had led a combined experimental and theoretical study on the effective thermal condubbctivity and viscosity of nanofluids. The viscosity and thermal conductivity of nanofluids were measured and found to be considerably higher than the values of the base fluids. Both the viscosity and thermal conductivity of nanofluids increased as the nanoparticle volume fraction increased. The thermal conductivity of nanofluids was perceived to be strongly dependent on temperature. Shuichi et al. [2] had performed experimental study to examine heat transfer performance of aqueous suspensions of nanoparticles, that is, Al_2O_3, CuO etc. They found that the heat transfer increases by hanging the nanoparticles in base fluid and become more effective

with increase in particle volume fraction. Also the presence of particles produces adverse effects on viscosity and pressure loss which also increased with the particle volume fraction. The augmentation of the above properties occurred due to the particles accumulation. Laura et al. [3] has given the information about stability, viscosity and thermal conductivity of water-based nanofluids containing TiO_2 nanoparticles. With increase in mass concentration and temperature, thermal conductivity of TiO_2-water nanofluids was increased. The performance of viscosity was calculated by means of a Rheometer in the temperature range between 283K and 343 K as a function of concentration and temperature. Yurong et al. [4] had measured flow rate and heat transfer characteristics of aqueousTiO_2nanofluids flowing through a straight vertical pipe under both the laminar and turbulent flow conditions. Thermal conductivity has been increased by adding nanoparticles into the base liquid and it will be augmented by increasing concentration or decreasing particle size. D Zhu et al. [5] investigate from the study, viscosity of nanofluid first decreased with increase in shear rate and then a constant approach is attained at a shear rate more than 100 s^{-1}.The results also showed that for a given Reynolds number the pressure drop of the nanofluid flows was almost same to that of the base liquid flows. Rashidi et al. [6] determined heat transfer coefficient of CNT nanofluid in laminar flow regime and there was noticeable increment in the convective heat transfer coefficient of nanofluids. This increment was depends on the CNT concentration and flow condition. Yulong et al. [7] had done experimental study on heat transfer performance of aqueous suspensions of multi-walled carbon nanotubes flowing through a horizontal tube. From study, it was found that the enhancement of convective heat transfer coefficient depends on the flow conditions (Re), CNT concentration and the pH value. Namburu et al. [8] had investigated that SiO_2 nanofluids with ethylene glycol/water exhibit non-Newtonian behavior at lower temperature and Newtonian behavior at higher temperature because

curves between viscosity and shear rate was horizontal straight lines for temperatures more than -10°C Zeinali et al. [9] had investigated with convective heat transfer characteristics of Al_2O_3/water nanofluid inside a circular tube at constant wall temperature. With increase in concentration of nanoparticles in nanofluid, the heat transfer coefficient is increased and it was much higher than the estimated of single phase heat transfer correlation used with nanofluid properties. Yanuar et al. [10] has investigated experimentally the flow and convective heat transfer characteristics of water-based nanofluids flowing through a spiral pipe. The ratio of pitch to diameter of spiral pipe is 7.0 and mean hydraulic diameter of 30 mm and length of spiral tube(test section) is 1600 mm. The convective heat transfer coefficient and relative viscosity of nanofluids increased with an increase in concentration of nanoparticles. Meyer et al. [11] had done experiment to determine the convective heat transfer of multi-walled carbon nanotubes flowing through a straight horizontal tube for a Reynolds number range of 1000–8000, which included the transitional flow regime. Naraki et al. [12] experimentally proved that in a car radiator, the overall heat transfer coefficient of CuO/water nanofluids, under the laminar flow regime ($100 < Re < 1000$. The result showed that the overall heat transfer coefficient with nanofluid was more than the base fluid. D S Kim et al.[13] studied that to calculate the pressure drop and the convective heat transfer coefficient, all the physical properties of the Al_2O_3/water nanofluids, i.e. density, specific heat capacity, thermal conductivity, and dynamic viscosity were needed. Heyhat et al. [14] had done experiment to examine the study of heat transfer coefficient and friction factor of the nanofluids under the constant wall temperature and laminar flow condition flowing in a horizontal tube on fully developed region under. Nanofluids are mixture of nanoparticles and the base fluids. Nanoparticles tend to cumulate with the time elapsed, due to their high zeta potential. Due to this agglomeration, not only the settlement of nanoparticles is a

problem but also thermal conductivity of nanofluids decreases [16,28]. Nanofluids are generally prepared by most economic method for large scale by two step method. First with the help of inert gas condensation or other suitable techniques, nanoparticles or nanotubes are produced as dry powder and the nanosized powder dispersed into base fluid. But nanoparticles have the propensity to aggregate because of its high surface area which is the main disadvantage of this method. Ultrasonic sonication high-shear mixing and ball milling are the techniques used to reduce the particle aggregation and also for the improvement of nanofluids dispersion, surfactants are used. [17,18,19,20]. The stability of nanofluids is obtained by suspending 25–45 nm nanopowder in water with different surfactants. It has been found that for CuO water based nanofluid, good stability was obtained for 1% mass SHMP and instability might had been related with the average size of particles. [22,29]. With the use of suitable surfactant, nanofluids in all the experiments have been stabilized. The results showed that the overall heat transfer coefficient increases with addition of nanoparticles. Overall heat transfer coefficient decreases with increase in nanofluid inlet temperature and increase with increase in volumetric flow rate. The maximum value can predicted for the overall heat transfer coefficient was 94.11 W/m^2 K and the error was around 2% [23,25,26]. The specific heat capacity of nanofluid is affected by the particle size and particle-liquid interface. There are discussion on measurement value and prediction value of thermal equilibrium model [15]. The experiment performed for density measurements on three different nanofluids. For ZnO nanofluid, maximum deviation between experimental values and theoretical value was about 8%. With increase in volume concentration, deviation was also increased. Also with increase on temperature of nanofluid, density too increased [21].The results under laminar flow conditions shows considerable enhancement of convective heat transfer with

the use of nanofluids. With increase in Reynolds number, as well as with increase in particle concentration, this enhancement in convective heat transfer increases [24,27].

2.4 Gaps in literature survey

A lot of research has been done on the nanofluids and their thermo physical properties but the research in the field of thermal storage is lagging behind. From my literature survey, there are some important points which needed some alertness.

1. Study of the utilization of other heat transfer fluids having superior thermal conductivity that of water.

2. Study of thermal losses after thermal storage in both cases and evaluate it against energy storage using water for a period of time.

3. Exploration of new different materials having higher thermal conductivity.

4. Calculate the pressure drop distinctiveness through the filled bed (used as storage) using unlike fluids.

5. Calculate the parameters which effects on the pressure drop and thermal energy storage when energy is stored in jam-packed bed with unlike storage medium.

2.5 References

1. S.M.S. Murshed, K.C. Leong, C. Yang, Investigations of thermal conductivity and viscosity of nanofluids, International Journal of Thermal Sciences, 47 (2008) 560–568.

2. S Torii, Turbulent Heat Transfer Behavior of Nanofluid in a Circular Tube Heated under Constant Heat Flux, Hindawi Publishing Corporation, Advances in Mechanical Engineering, Volume 2010, Article ID 917612, 7 pages, doi: 10.1155/2010/917612.

3. L Fedele, L Colla, S Bobbo, Viscosity and thermal conductivity measurements of water based nanofluids containing titanium oxide nanoparticles, international journal of refrigeration, 35 (2012) 1359.

4. H Yurong, J Yi, C Haisheng, D Yulong, C Daqiang, L Huilin, Heat transfer and flow behavior of aqueous suspensions of TiO2 nanoparticles (nanofluids) flowing upward through a vertical pipe, International Journal of Heat and Mass Transfer 50 (2007) 2272–2281.

5. S Wu, D Zhu, X Li, H Li, J Lei., Thermal energy storage behavior of Al2O3–H2O nanofluids, Thermochim Acta, 483 (2009) 73–80.

6. F. Rashidi, N. Mosavari Nezamabad, Experimental Investigation of Convective Heat Transfer Coefficient of CNTs Nanofluid under Constant Heat Flux , Proceedings of the World Congress on Engineering, London, U.K. Vol. III WCE (2011).

7. D Yulong, A Hajar, W Dongsheng, W.A Richard, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), International Journal of Heat and Mass Transfer, 49 (2006) 240–250.

8. PK Namburu, DK Das, KM Tanguturi, RS Vajjha., Numerical study of turbulent flow and heat transfer characteristics of nanofluids considering variable properties, International Journal of Thermal Science, 48 (2009) 290–302.

9. S. Z Heris, M. N Esfahany, S. G Etemad, Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube International Journal of Heat and Fluid Flow, 28 (2007) 203–210.

10. Yanuar, N. Putra, Gunawan & M. Baqi, Flow and of convective heat transfer characteristic of spiral pipe for nanofluids, 7(3) (2011) IJRRAS_7_3_03.

11. J.P. Meyer, T.J. Mckrell, K. Grote, The influence of multi-walled carbon nanotubes on single-phase heat transfer and pressure drop characteristics in the transitional flow regime of smooth tubes, International Journal of Heat and Mass Transfer, 58 (2013) 597–609.

12. M. Naraki, S.M. Peyghambarzadeh, S.H. Hashemabadi, Y. Vermahmoudi, Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator, International Journal of Thermal Sciences, 66 (2013) 82-90.

13. G.H Ko, K Heo, K Lee, D S Kim, C Kim, Y Sohn, M Choi, An experimental study on the pressure drop of nanofluids containing carbon nanotubes in a horizontal tube, International Journal of Heat and Mass Transfer, 50 (2007) 4749–4753.

14. M.M. Heyhat, F. Kowsary, A.M. Rashidi, M.H. Momenpour, A. Amrollahi, Experimental investigation of laminar convective heat transfer and pressure drop of water-based Al2O3 nanofluids in fully developed flow regime, Experimental Thermal and Fluid Science 44 (2013) 483–489.

15. L Zhou, B Wang, X.F Peng, X.Z Du, and Y.P Yang, On the Specific Heat Capacity of CuO Nanofluid, Hindawi Publishing Corporation, Advances in Mechanical Engineering, Volume 2010, Article ID 172085, 4 pages, DOI: 10.1155/2010/172085.

16. W Yu and H Xie, A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications, Hindawi Publishing Corporation Journal of Nanomaterials Volume 2012, Article ID 435873, 17 pages doi:10.1155/2012/435873.

17. S.K. Das, S.U.S. Choi, W.H. Yu, T. Pradeep, nanofluid: Science and Technology, John Wiley & Sons Inc., 2007.

18. W Yu, D France, J. L Routbort, and S. U. S Choi, Review and Comparison of Nanofluid Thermal Conductivity and Heat Transfer Enhancements, Heat Transfer Engineering, 29(5) (2008) 432-460.

19. J. M Romano, J. C Parker, and Q. B Ford, Application Opportunities for Nanoparticles Made from the Condensation of Physical Vapors, Adv. Pm. Part., (1997) 12-13.

20. Y Li, J Zhou, S Tung, E Schneider, S Xi, A review on development of nanofluid preparation and characterization, Powder Technology, 196 (2009) 89–101.

21. R. S Vajjha, D. K Das and B. M Mahagaonkar, Petroleum Science and Technology, Density Measurement of Different Nanofluids and Their Comparison with Theory, 27 (2009) 612–624.

22. M Drzazga, M Lemanowicz, G Dzido, A Gierczycki, P.C Jako, Preparation of metal oxide water nanofluids Inz. Ap. Chem. 51(5) (2012) 213-215.

23. M. Naraki, S.M. Peyghambarzadeh, S.H. Hashemabadi, Y. Vermahmoudi, Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator, International Journal of Thermal Sciences, 66 (2013) 82-90.

24. W Dongsheng, D Yulong, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow condition, International journal of heat and mass transfer 47 (2004) 5181-5188.

25. X.Q Wang, A.S Mujumdar, Heat transfer characteristics of nanofluids: a review, International Journal of Thermal Science, 46 (1) (2007) 1–19.

26. J. Huang, X. Wang, Q. Long, X. Wen, Y. Zhou, and L. Li, Influence of pH on the stability characteristics of nanofluids, Proceedings of the Symposium on Photonics and optoelectronics (SOPO ’09) 2009.

27. C Choi, HS Yoo, JM Oh., Preparation and heat transfer properties of nanoparticles in transformer oil dispersions as advanced energy-efficient coolants, Current Applied Physics (2008) 710–712.

28. L Qiang and X Yimin, Convective heat transfer and flow characteristics of Cu-water nanofluid, Science in China, (Series E) 45(4) (2002).

29. K.B. Anoop, T. Sundararajan, Sarit K. Das, Effect of particle size on the convective heat transfer in nanofluid in the developing region, International Journal of Heat and Mass Transfer 52 (2009) 2189–2195.

30. Yanuar, N. Putra, Gunawan & M. Baqi, Flow and of convective heat transfer characteristic of spiral pipe for nanofluids, 7(3) (2011) IJRRAS_7_3_03.

31. Varinder Singh, Sumeet Sharma, Dr. D.Gangacharyulu, Variation of CuO distilled water based nanofluid properties through Circular Pipe, Volume 3 Special Issue, ISSN 2349-4476, pp 414-420.

32. Varinder Singh, Sumeet Sharma, Dr. D. Gangacharyulu, Nanofluids: Importance and Application, CETCME 2015.

33. Varinder Singh, Sumeet Sharma, Dr. D. Gangacharyulu, Variations of Thermo-Physical Properties with CuO Distilled Based Nanofluids through a Circular Pipe, PSIMT 2015, pp 331-336.

CHAPTER-3: EXPERIMENTAL SET-UP

In this chapter, the experimental work has been done for calculating "Variation of thermo-physical properties of thermal energy storage system with the use of aluminum /distilled water based nanofluids through circular pipe" has been discussed. All these experiments were performed at chemical engineering lab of Chemical department of Thapar University. The detailed description of all the set up is discussed below.

3.1 Layout of experimental set-up

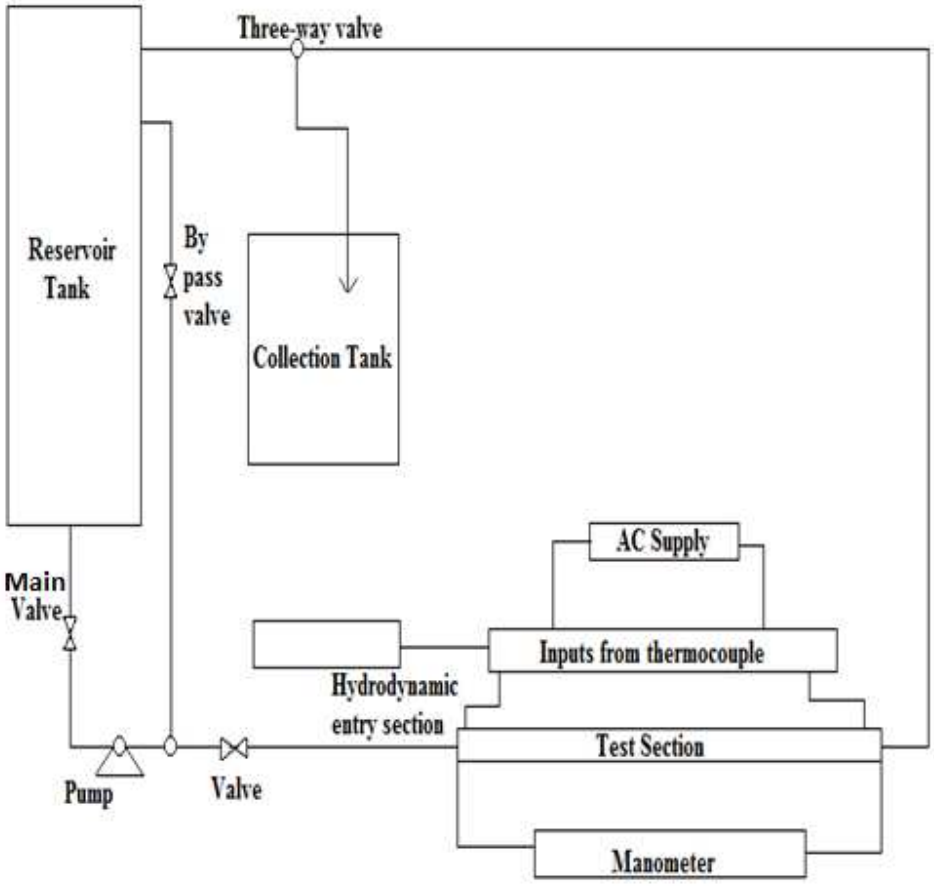

Figure 3.1: Layout of experimental set-up

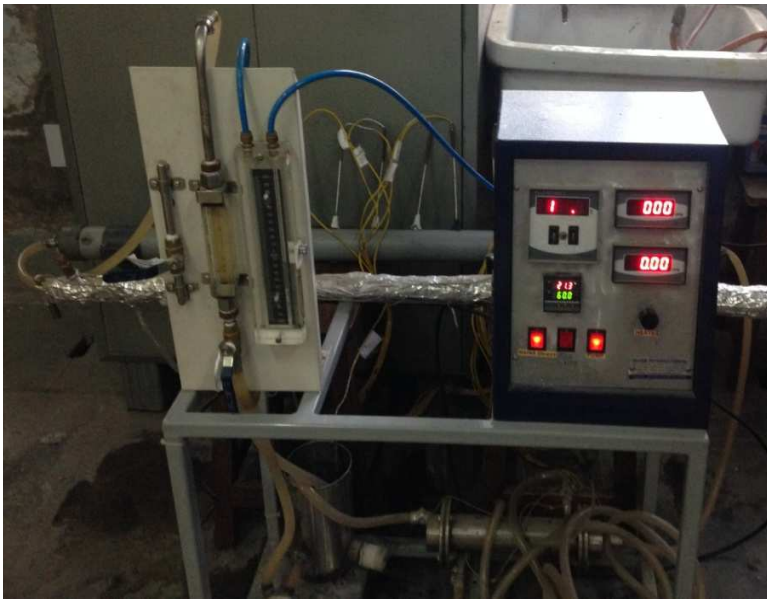

Figure 3.2: Experimental set-up

3.2 Utilities required:

Table 3.1: Description of various equipments used in experimental setup

Equipment	**Description**
Test section	PVC pipe of diameter 12.7cm and 1.5m length, embedded with 8 thermocouple
Hot water storage tank	fibre insulation
U-tube manometer	Measuring pressure drop across the test section
Temperature sensor/ thermocouples	RTD PT-100 type
Hot water circulation	Magnetic drive pump
Water flow measurement	Rotameter (celebration has been done)
Control panel	Digital controller with on/off switch

- Water supply of 8litre/min
- Electricity 3 phase, 220V, 50Hz
- Floor area 2.5m×0.8m

3.3 Test Section

The test section (thermal storage system) is a hollow pipe made of PVC with outer diameter 12.7 mm, inner diameter 9.5mm and length 1.5 meter in which 8 temperature sensors were inserted, 6 sensors on surface, 1 sensor at inlet and 1 sensor at outlet and manometer to measure the pressure difference across the test section. This hollow packing was filled with steel spheres with diameter of 3.92mm. An AC power supply was used to provide heat. A thick thermal insulating layer has put around the heater along the test section.

3.3.1 Layout of test section

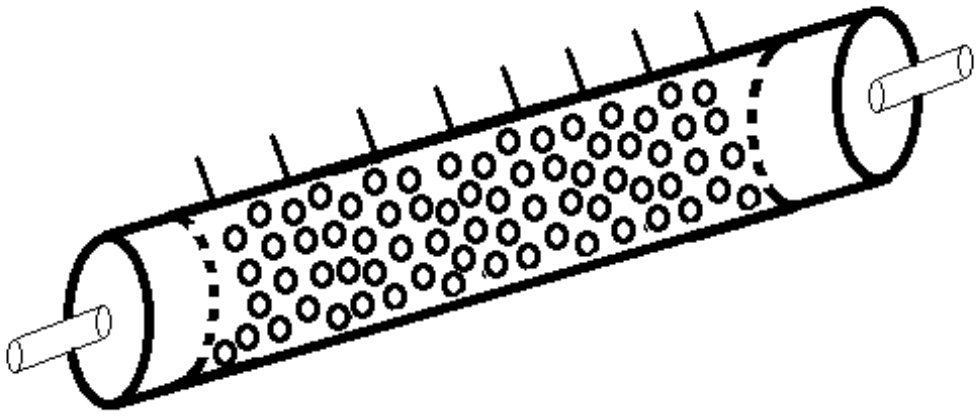

Figure 3.3: Layout of test section

During the charging cycle, thermal energy is being absorbed and stored by the balls which were placed inside the main storage tank. This occurs between steel balls and hot fluid because of the heat transfer process.

Table 3.2: Thermal properties of steel balls

Specific heat capacity	0.480 kj/kg °C (30- 70 °C)
Density	8314 kg/m^3

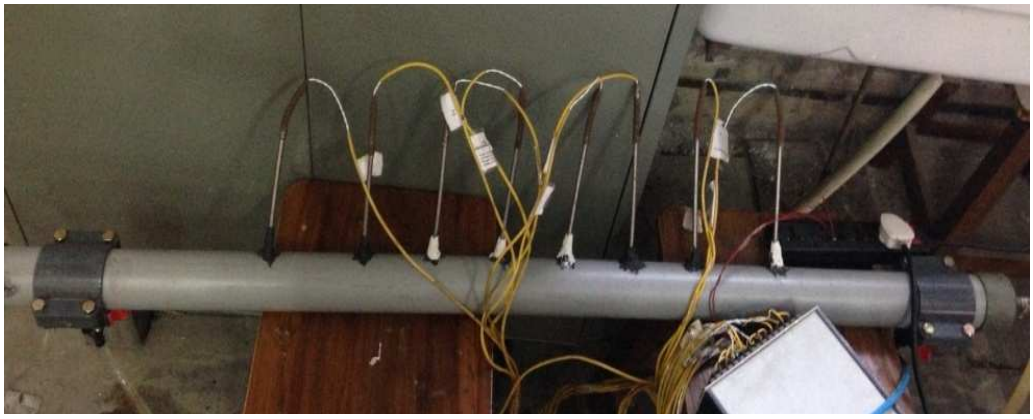

Figure 3.4: Test section

3.4 Hot water reservoir

The hot water storage tank circular in shape with 250J heater is mounted inside it to heat the fluid. The capacity of this storage tank is 6 liter. The main dimensions of this storage tank are given in table 3.3.

Table 3.3: Dimensions of storage tank (in cm)

Inner diameter	27
Outer diameter	27.8
Height	16.5

Figure 3.5: hot water storage tank

3.5 Pump

The pump used in this experiment has no moving parts. Also, it has dependable operation with simple structure and good sealing. The maximum temperature under pump can operate is 90 due to its polypropylene material.

Table 3.4: Pump specification

Model	PMP-15
Voltage	AC 220 V,50HZ
Power	50W
Maximum flow	900LPH
Speed	2800 RPM
Maximum head	2.5 Mtrs.

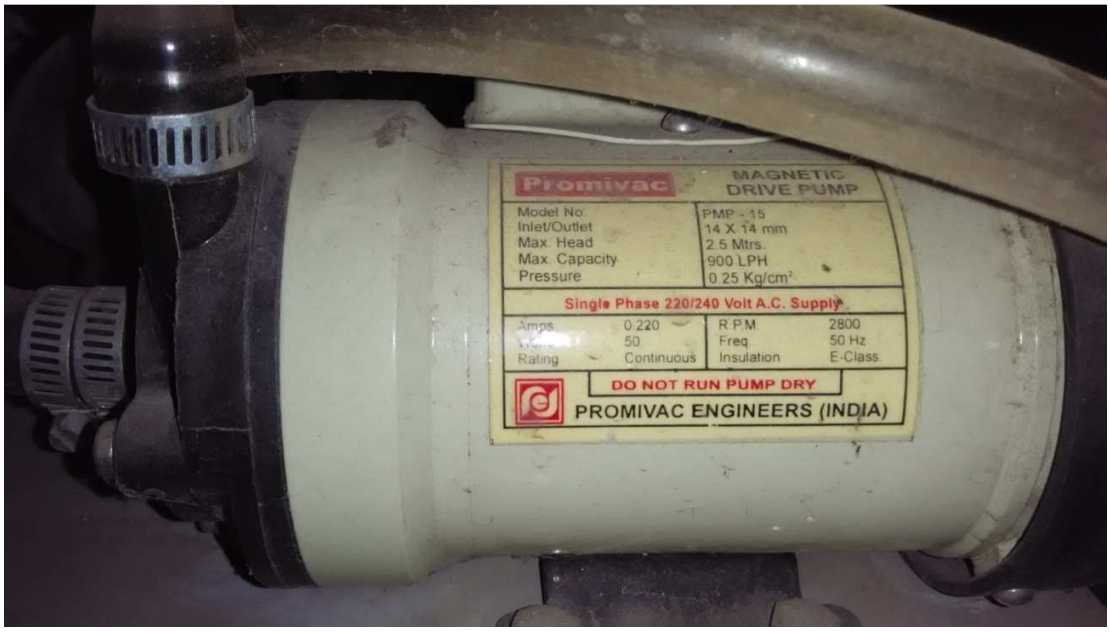

Figure 3.6: Pump

3.6 Manometer

Figure 3.7: Manometer

Differential U-tube manometer was used for the measurement of pressure drop across the test section. One end of the manometer tube was connected to the inlet of the test section whereas the

other end was connected to the outlet. The pressure drop is calculated by measuring the difference between the heights of liquid column. The working fluid in manometer was water.

3.7 Rotameter

The device used to measure the volumetric flow rate of the fluid is rotameter. It works on the principal of variable area. To control the flow according to the requirement, a control valve is used. The range of the rotameter is 0-2.5 LPM. The collaboration of rotameter was done before taking the readings from the experimental set-up.

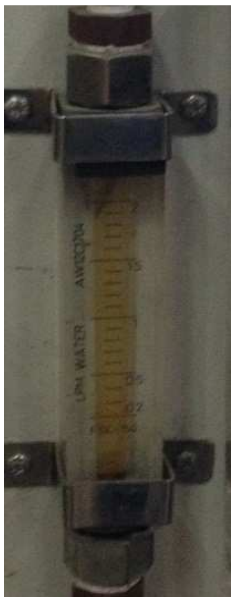

Figure 3.8: Rotameter

3.8 RTD PT-100

RTDs PT-100was used for measuring the temperature at different locations of packed bed with steel balls. Six RTDs (TC2, TC3, TC4, TC5, TC6, and TC7) were located across the length of the test section and two RTDs (TC1 and TC2) were located at inlet and outlet of test section for the measuring the inlet and outlet temperatures of aluminum/water based nanofluid.

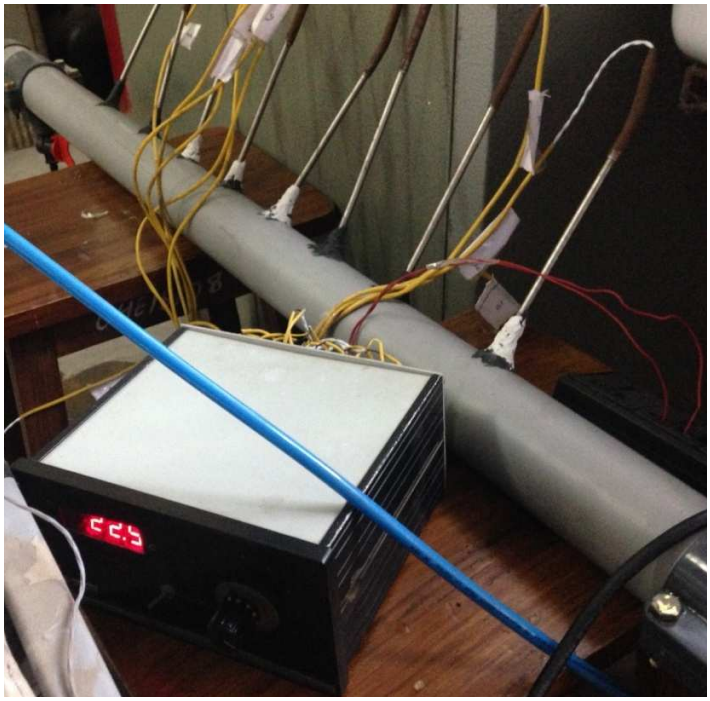

Figure 3.9: Thermocouples

For the preparation of nanofluids, following equipment was used:

3.9 Ultra sonicator

Figure 3.10: Ultra sonicator

For various purposes, sound energy is used to agitate the particles in a aluminum/water based nanofluid. This process is known as sonication and done in ultrasonic bath which is called as sonicator. By breaking intermolecular interaction, sonication is also used for speed up the dissolution. Sonication is more useful when the magnetic stirring was not much effective for given sample. For nanoparticles which were not evenly dispersing in liquids, sonication is most preferable.

3.10 KD2 Pro

To calculate the thermal properties like thermal conductivity, viscosity, density etc of fluid, KD2 Pro device is used. This device consists of sensors and controllers which were inserted into aluminum/water based nanofluid medium. To measure the volumetric specific heat capacity and diffusivity, double needle sensor is used while on the other hand, single needle sensors are used to measure resistivity and thermal conductivity.

Figure 3.11: KD2 pro

3.11 Viscometer

Resistance to the adjacent layer of fluid's flow is known as viscosity. A Brookfield Rheometer shown in Fig.3.12 was used for measuring viscosity in which spindle is driven by calibrated

spring. The spring deflection shows the viscous drag of fluid against spindle. The measuring range of Brookfield Rheometer is determined by the size and shape of the spindle, the rotational speed of the spindle, full scale torque of the calibrated spring and the container in which spindle is rotating.

Figure 3.12: Viscometer

3.12 Gravity bottle

Figure 3.13: Pycnometer

To calculate the density of any fluid, pycnometer or specific gravity bottle is used. Specific gravity is a dimensionless term which is defined as density of the substance to the density of reference material. First weighed the empty bottle, now filled this bottle with the fluid whose specific gravity has to be found and then again weighed. Calculate the difference between weights and divide it by weight of equivalent volume of water gives the specific gravity of that fluid. As we know density of water is 9810 kg/m^3 at room temperature of 28^oC.

Figure 3.14: Gravity bottle

The main parameters taken into consideration for the density measurement experiment using gravity bottle were temperature, density and mass of nanoparticles. With the change in these parameters, results in overall variation of density with temperature.

CHAPTER-4: EXPERIMENTAL WORK

To investigate "Variation of thermo-physical properties of thermal energy storage system with the use of aluminum/distilled water based nanofluids through a circular pipe**",** First is to prepare nanofluids by taking distilled water as the base fluid and aluminum nanoparticles. With the help of different equipments, we were determined the thermal properties like viscosity, density, thermal conductivity, specific heat. All these parameters were found at different temperatures and at different concentrations.

4.1 Experimental procedure

An experimental set up was designed to carry out experiment at different inlet temperatures and mass flow rates of the working fluid. Double distilled water was used as the working fluid. Following procedure was follow to carry out the experiments.

1. Working fluid was heated by using an electric heater to raise its temperature up to the desired value. A PID controller was used to maintain the temperature of working fluid at constant value.
2. The pump was switched on and rotameter was adjusted to the required flow rate.
3. During charging, working fluid exchange the heat with steel spheres and temperature of steel spheres was recorded with the help of thermocouples after an interval of 1 minute till the steel balls has reached thermal equilibrium.
4. During discharging, steel balls were at higher temperatures and working fluid was heated by passing it through steel balls.
5. At given flow rate, the pressure drop was measured by using manometer.
6. Similar procedure was followed to carry out the experiments at different mass flow rates and with nanofluids at different concentrations.

4.2 Methodology

To perform the experiments on testing with aluminum /water nanofluids, the methodology was used given below:

1. 20 nm averaged sized aluminum nanoparticless used for experiment.
2. To perform the different experiments, aluminum/distilled water based nanofluids of different concentrations 0.1%, 0.2% and 0.5% were prepared by mixing the 0.317gm, 0.783gm and 1.572gm of nanoparticles in 50ml of distilled water respectively. To make these nanofluids more stable, 0.1% of surfactant was directly added to all three different concentrations for 50ml of distilled water. Ultra-sonicator was used for almost 3 hours for sonication process which increases its dispersion stability. Every time for the experiments, new nanofluids were prepared.
3. KD2 pro instrument was used for measuring thermal conductivity and Pycnometer was used for measuring density of aluminum/water nanofluids.
4. The viscosity of nanofluid was measured by Brookfield Viscometer.
5. Now after calculating all the above properties, the aluminum/water based nanofluids was passed through the test section of thermal storage system at defined flow rates and concentrations to perform further experiments.

4.3 Experimental calculations

4.3.1. Porosity

Ratio of the volume of water in gap between the steel spheres in the packed bed (storagesystem) to the total geometrical volume of packed bed is called the void fraction of a packed bed. It is generally known by the term porosity. In simple way, we can define porosity as the ratio of existing volume for flow to the total volume.

Volume of steel spheres =$\frac{4}{3}\pi r^3 \times n$

n = no of steel sphere

Geometrical bed volume=$\pi r^2 \times l_{bed}$

Volume of fluid in voids = Geometrical bed volume – volume of spherical balls

Void fraction (ε)= $\frac{V_{fluid}}{V_{bed}}$

4.3.2. Thermal energy stored by the steel spheres:-

4.3.2.1 Sensible heat stored by steel spheres

$$Q = m_b c_b \Delta T$$

$$m_w = v_w \times \rho_w \times n$$

Where -

m_b= Mass of steel sphere, kg

c_b= Specific heat capacity of balls, J/kg-^{0}C

ΔT =Temperature difference before and after charging, ^{0}C

T_1= Initial temperature, ^{0}C

T_2 = Final temperature, ^{0}C

ρ_b= Density of steel sphere, Kg/m^3

v_b= Volume of steel sphere, m^3

n = No of steel spheres

4.3.3 Thermal energy storage by water in the voids between the steel spheres:

$$Q = m_w c_w \Delta T$$

$$m_w = v_w \times \rho_w$$

Where -

m_w= Mass of water, kg

ρ_w =Density of water, kg/m^3

v_w = Volume of water in water, m^3

c_w= Specific heat of water, J/kg-^{0}C

Total storage energy = steel sphere + thermal energy storage by water in the voids between the steel sphere.

4.3.4. Pressure drop across the bed

1. Main valve must be keep closed and bypass valve should be opened. After that start the pump.

2. To measure the pressure drop, join the manometer to the packed-bed and to let the fluid flow through bed and open the main valve.

3. Wait till steady condition was reached.

4. With the help of manometer and rotameter, calculate pressure drop and flow rate.

5. Both main valve and throttling the bypass valve were opened according to increase the flow rate and after that repeat the points (3) and (4).

4.4 Calculations:-

Flow rate: Q= LPH, Joule

Pressure drop of manometric fluid = $\Delta H_{m,}$ cm

Bed porosity = ε

Sphericity =ϕ_s= 1

Cross sectional area of the bed =$\frac{\pi}{4}d^2$, m^2

Volume of bed =$\frac{\pi}{4} d^2 \times L$, m^3

Diameter of the steel sphere = 0.0396m

Mass flow rate = $\dot{m}$, kg/sec

Mass velocity, G=$\frac{\dot{m}}{area\ of\ bed}$, kg/m^2 sec

Reynold number, Re = $\frac{D \times G}{\mu}$

$\Delta P = \Delta H_w \times \rho \times g$, N/m^2

$\Delta H_w = \frac{\rho_m - \rho}{\rho \times \Delta H_m}$, m

$\rho_m$andρ are density of manometric fluid and density of fluid .

CHAPTER-5: RESULTS AND DISCUSSION

5.1 Properties variation of nanofluids

In this section, variations of temperature with the thermo-physical properties like density, viscosity, thermal conductivity was discussed.

5.1.1 Temperature versus density

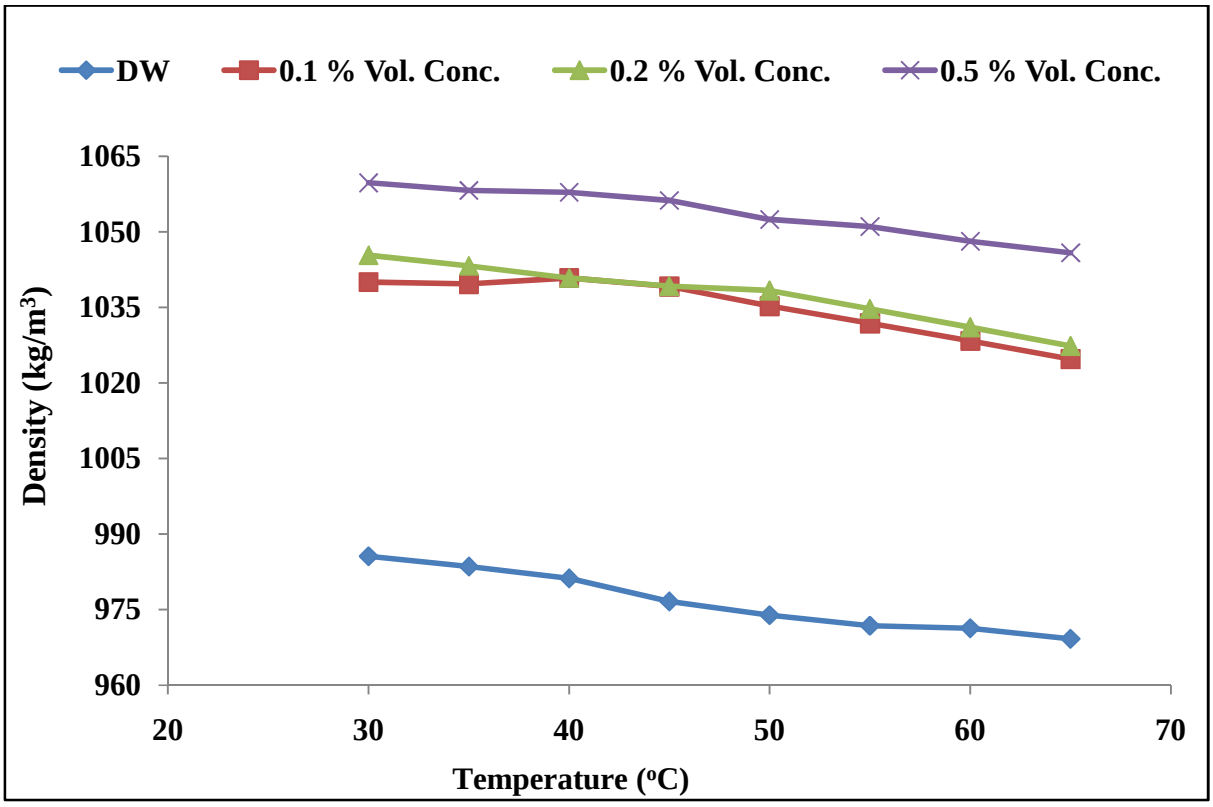

Figure 5.1: variation of temperature versus density

With increase in concentration of nanoparticles from 0.1 vol. % to 0.50 vol. % by keeping the same temperature of 40°C, density of aluminum/water based nanofluids increases from 0.98 % to 1.78 % compared to base fluid i.e. distilled water. Density of distilled water and aluminum/water

based nanofluids decreases with the increase in temperature. Density decreased by 2.49 % for distilled water, 2.17 % for 0.1 vol. % concentration, 1.97 % for 0.25 vol. % concentration, and 0.76 % for 0.50 vol.% concentration with increase in temperature from 20°C to 80°C.Since the density of nanoparticle is more than the base fluid and also with increase in concentration, the amount of nanoparticle in base fluid increased which leads to increase in density with concentration. Increased density of nanofluids results in more pressure drop, more pumping power required.

5.1.2 Temperature versus viscosity

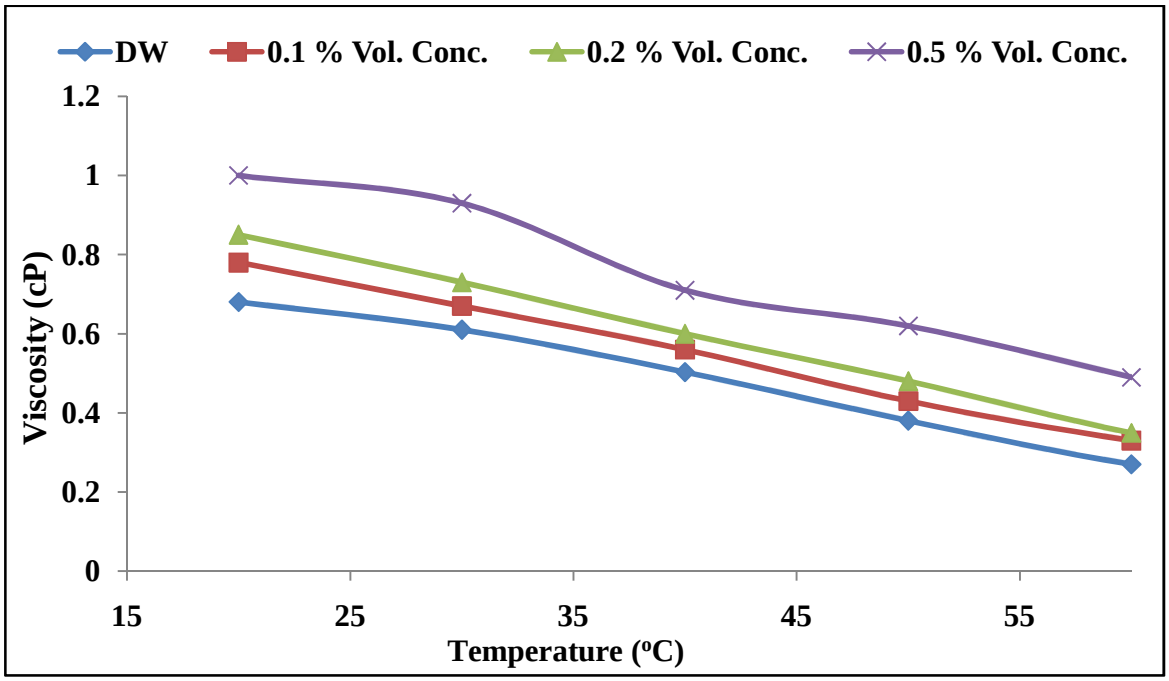

Figure 5.2: variation of temperature versus viscosity

At same temperature, viscosity of nanofluid increases as the concentration increases but with increase in temperature, viscosity decreases for same concentration. From the Fig. 5.2, with the increase in the concentration of nanoparticles from 0.1 vol. % to 0.5 vol. % at temperature of

20°C, viscosity of aluminum/water based nanofluids increases from 5.0% to 34.48% compared to base fluid i.e. distilled water. Also viscosity of aluminum/water based nanofluids decreases with increase in temperature. Viscosity decreased by 68.42% for distilled water, 65% for 0.1 vol. % concentrations, 68% for 0.25 vol. % concentration and 65.57% for 0.50 vol. % concentrations for the temperature range of 20°C to 80°C. Viscosity increases on addition of nanoparticles hence as a result, more pumping power is required.

5.1.3 Temperature versus thermal conductivity

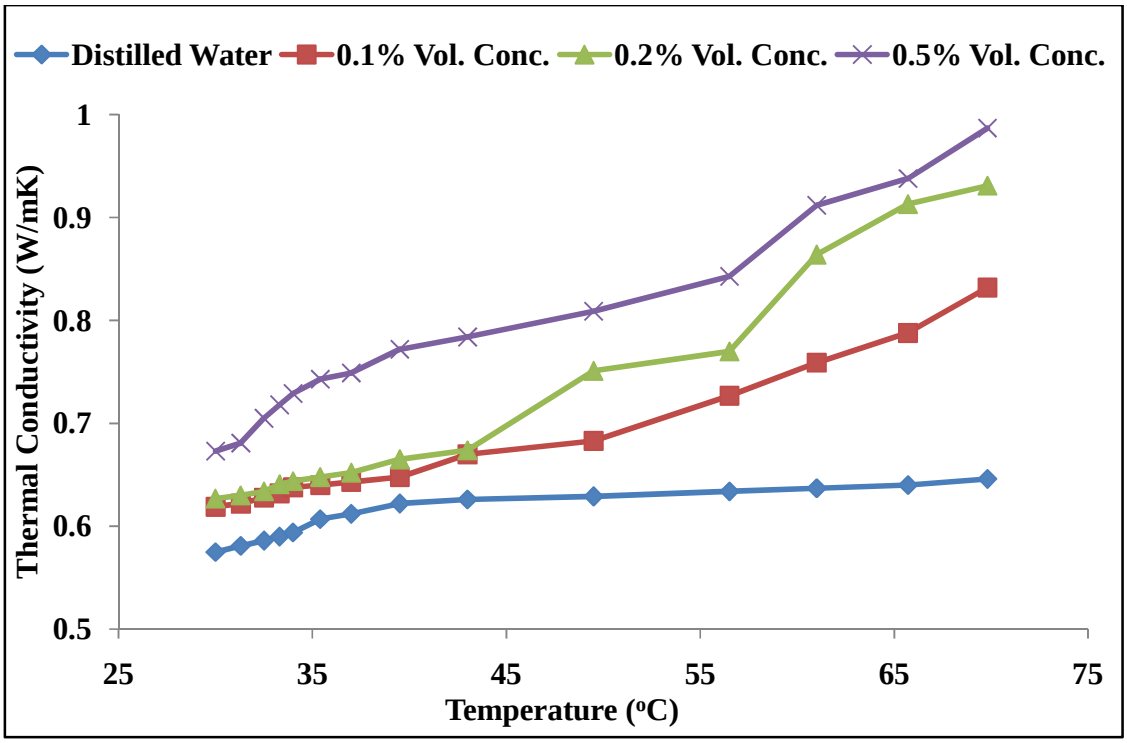

Figure 5.3: variation of temperature versus thermal conductivity

It can be seen from the Fig 5.3 that for aluminum/water based nanofluids, thermal conductivity increases from 0.62 to 0.65 with increase in concentration of nanoparticles to 0.1% vol. at 40°C and at the same time thermal conductivity increased with increase in temperature. Thermal

conductivity increased by 8.3% for distilled water, 13.94% for 0.1 vol. % concentration, 19.03% for 0.25 vol. % concentration, and 21.12% for 0.50 vol. % concentration for the temperature range of 20°C to 80°C. This is because aluminum nanoparticles have more thermal conductivity than the base fluid. Increased thermal conductivity results in lesser time requirements for the system to reach thermal equilibrium.

5.2 Temperature variation of test section

In this section, variation of temperatures with flow rate, concentration was discussed during both charging and discharging process.

5.2.1 During charging:

In charging, with the effects of flow rate and concentration on temperature, the effect at different locations on packed-bed with temperature was studied.

5.2.1.1 Effect of flow rate

For flow rate of aluminum/water based nanofluid at 1 LPM, temperature sharply rises up to 50^0C within the time period of 8-10 minutes. But after 50^0C, it takes around 10-12 minutes to reach up to around 65^0C. As we increases the flow rate from 1LPM to 1.5 LPM and then to 2 LPM, the temperature rise after 10 minutes were 6^0C and 4^0C respectively.

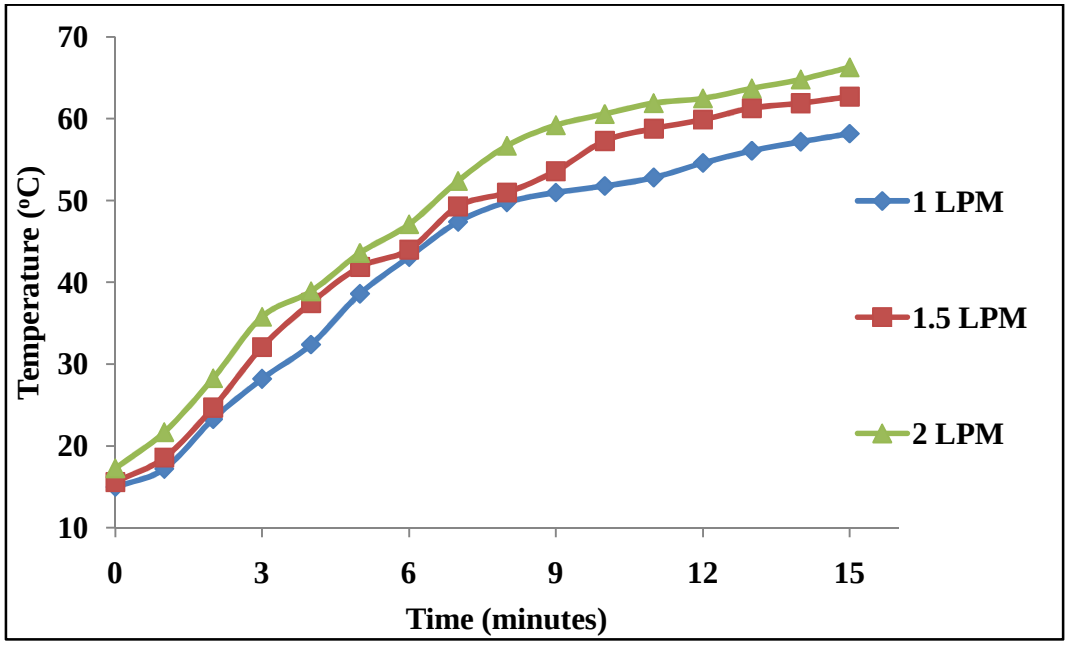

Figure 5.4: Temperature versus time for different flow rates during charging

5.2.1.2. Effect of concentration

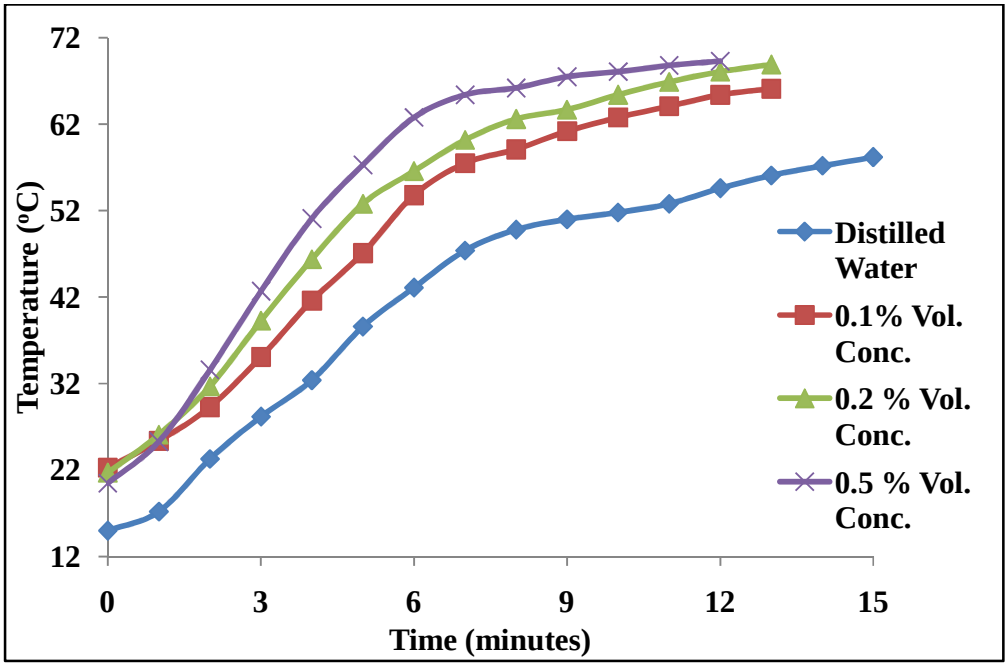

Figure 5.5: Temperature versus time at different concentrations of nanoparticle during charging

For the concentration of 0.1% of vol., temperature reaches up to 55^0C within the time period of 6-7 minutes. But after that it takes around 10 minutes more to achieve the temperature rise of 10^0C. As we increase the concentration from 0.1% vol. to 0.5% vol. , the temperature rise was around 7^0C from 57^oC to 64^0C for the time period of 8 minutes. With increase in flow rate as well as concentration of nanoparticles, thermal equilibrium establish in lesser times. As a result, low pumping power requirement goes up due to increase in pressure drop.

5.2.1.3. Effect at different points along length of pipe

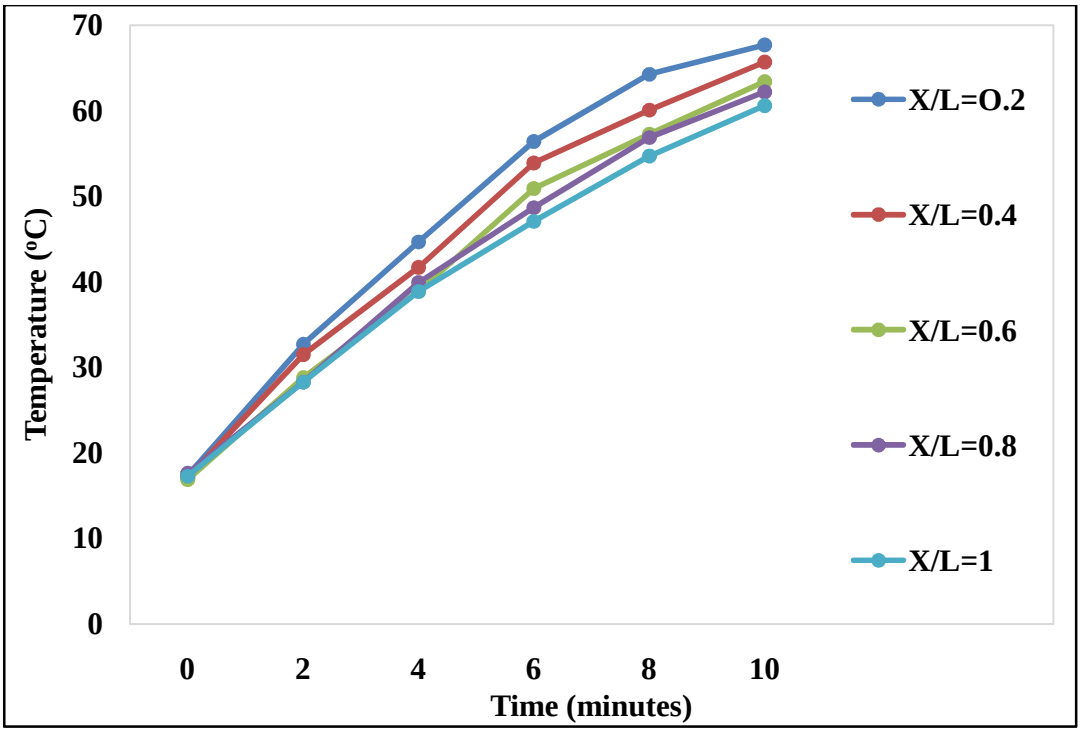

Figure 5.6: Temperature versus time along the length of test section

This graph shows the variation of temperature at different locations of pipe with time. For all considering points on pipe, temperature reaches its maximum value within 10 minutes. There

was a continuous sharp rise in temperature with time till it reaches its maximum value but after that rate of temperature rise decreases.

5.2.2 During discharging

5.2.2.1. Effect of flow rate

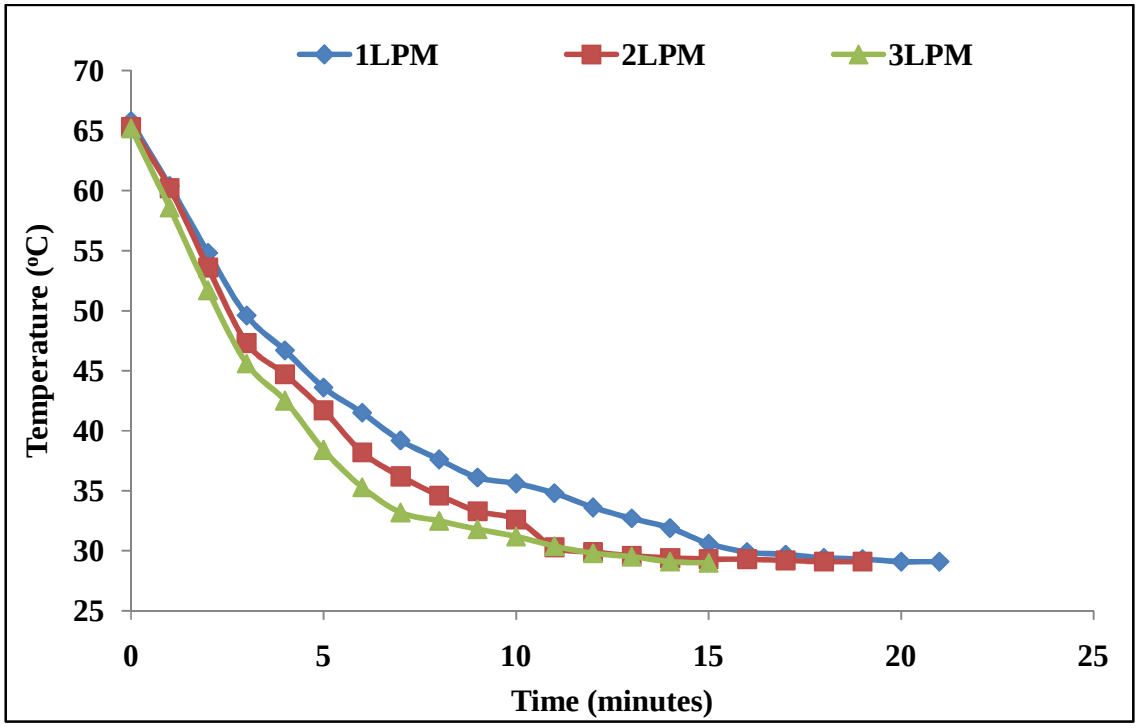

Figure 5.7: Temperature versus time for different flow rates during discharging

From the fig.5.7, temperature goes on decreasing with time for flow rate of 2LPM. Or just within the time zone of 10 minutes, the temperature of steel balls comes down from 65^0C to 33^0C. But after 10 minutes, the decrement in temperature is almost negligible as for time interval of 8 minutes from 10 to 18 minutes, temperature falls down from 33^0C to 29^0C.Also we can observe from the graph that as we increase the flow rate from 1LPM to 3LPM, the time taken to reach the temperature from 65^0C to 29^0C is reduced from 22 minutes to 15 minutes.

5.2.2.2. Effect of concentration

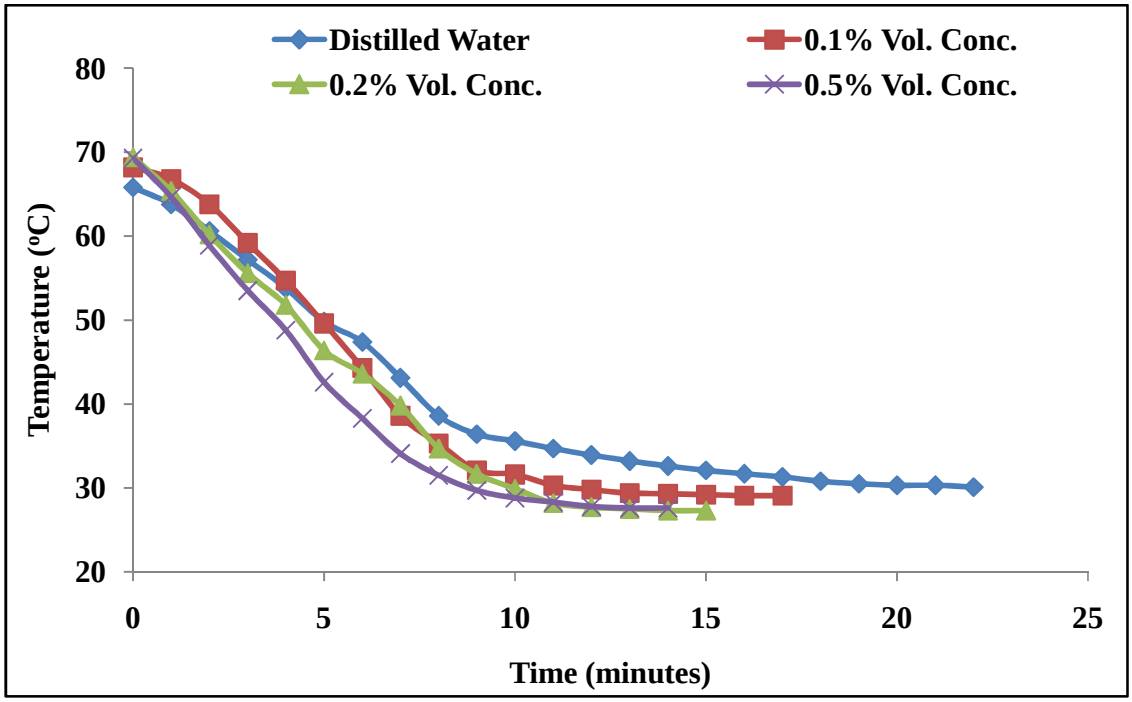

Figure 5.8: Temperature versus time for different concentration during discharging

As seen in the fig. 5.8, 22 minutes has been taken to reduce the temperature of steel balls from 65^0C to 30^0C for distilled water. But as we increase the concentration from 0.1% to 0.2% and then to 0.5%, time taken to fall down the steel balls temperature to a minimum value is reduced from 17 to 15 to 14 minutes respectively.

5.3 Pressure drop and friction factor effect

5.3.1 Pressure drop versus flow rate

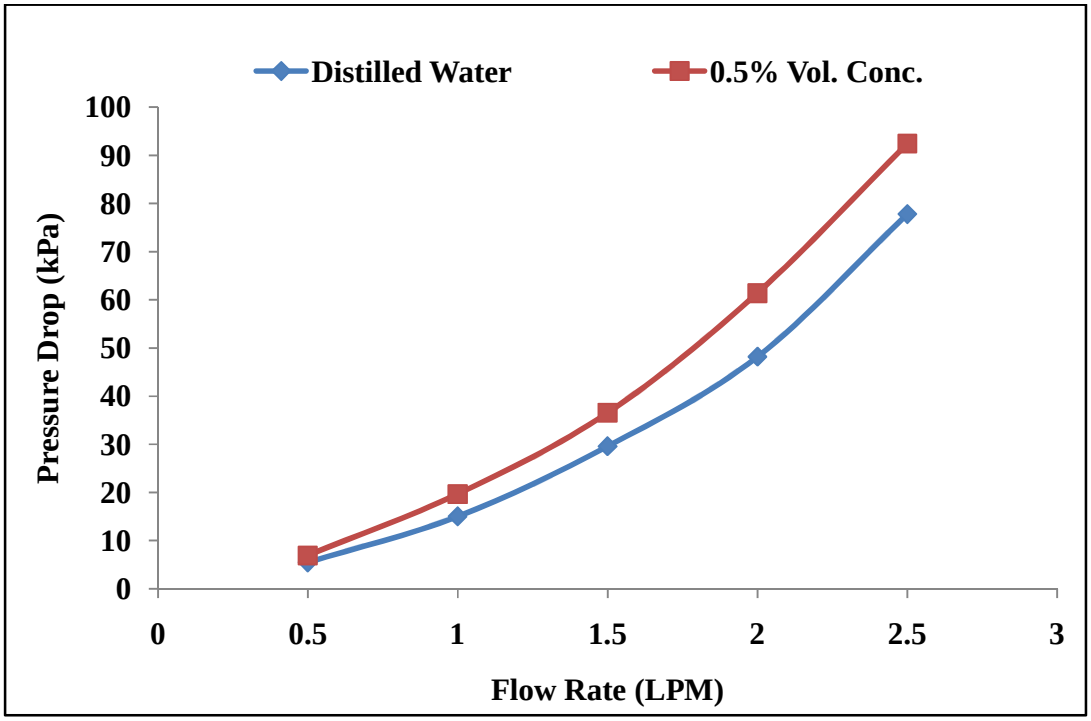

Figure 5.9: variation of pressure drop versus flow rate

Fig. 5.9 shows that pressure drop increases with the increase in flow rate. In this graph, the selection of mass flow rate is very important because as we seen in the graph, with increase in mass flow rate from 0.5 to 2.5, there is around 91% increment in pressure drop for distilled water and it will be 92.4% for the 0.5% Vol. concentration of nanofluids.

5.3.2. Friction factor versus flow rate

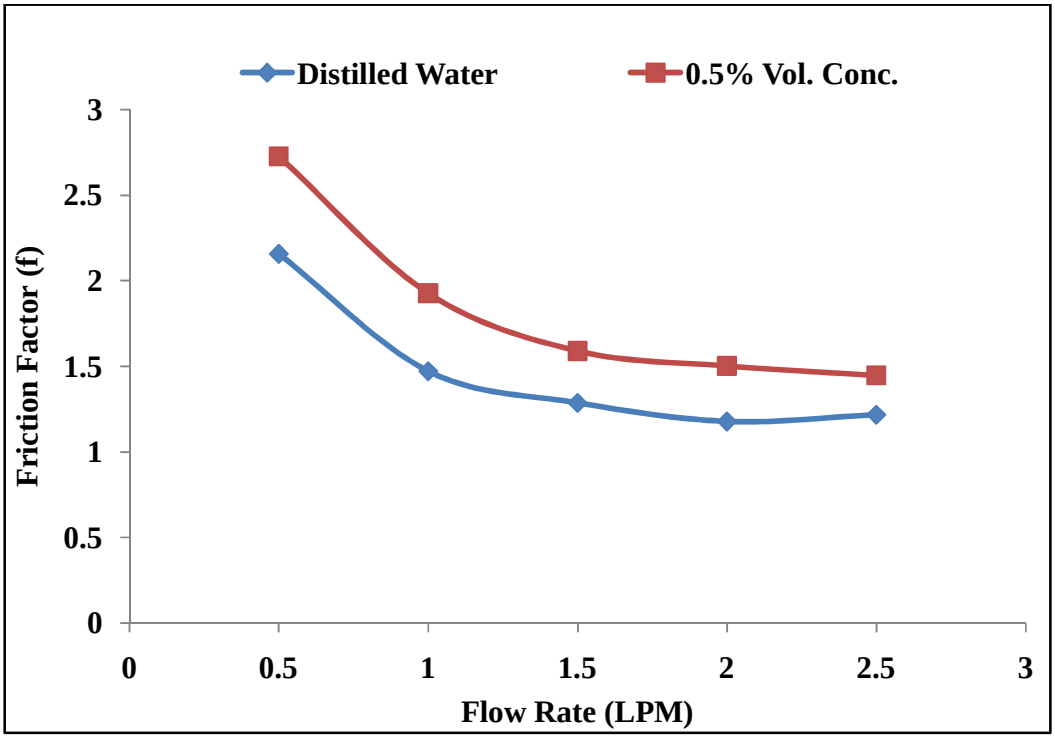

Figure 5.10: variation of friction factor versus flow rate

As seen from the fig. 5.10, by adding concentration of nanofluids, friction factor increases as compared to distilled fluid for the defined flow rate. Also with increase in flow rate from 0.5 to 2.5 LPM, 43.5% decrease in the friction factor for distilled water and 46.8% decrement in the case of the nanofluids with 0.5 % vol. concentration.

CHAPTER-6: CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this chapter, the result obtained from the experimental performance of thermo-physical properties of aluminum/water nanofluids of thermal storage has been summarizes.

1. Aluminum/water based nanofluid mass flow rate has a considerable effect on charging. With Increase in mass velocity of fluid effect the charging process by accelerate for storage unit and provide pressure drop. Through packed-bed, nanofluids store more energy than water for the charging process with the less pressure drop.
2. But pressure drop of packed-bed increase with increase in mass velocity. So the selection of mass flow rate plays an important role.
3. The increase in the ratio of diameter to length results in increment of mass flow rate as well as cross sectional area. Hence storage energy increases and pressure drop decreases. The specific heat capacity of nanofluids below the 0.08% concentration is very low and for the concentration above 0.1%, nanoparticles are settling down and make it unstable.
4. Aluminum/water based nanofluid for the 0.1% concentration takes a smaller amount of charging time as compare to distilled water to reach at equilibrium state because nanofluids has higher thermal conductivity at higher temperatures.
5. Near the inlet of test section, temperature of steel spheres comes into equilibrium in lesser time but as we move forward, it increases along the length of packed bed.

6.2 FUTURE SCOPE

There are a number of areas which required further research that can be done to progress the kind of flow through packed beds. The first area of research to establish the inaccuracies present by trying different size and shapes of spheres (storage medium). The most noticeable thing to see

that how packed-bed of non-spherical shapes behaves. The second area of research is that how the other fluids, base fluids as well as nanoluids (other than aluminum/water nanofluid) behave over packed-bed of energy storage. Also, one can think about changing the sizes of steel balls, packed bed or also can try with the different shapes which can also give exclusive results of energy storage. A last but important area of study would be to test various bed dimensions at a constant inlet velocity.

ANNEXURE

Table A1: Experimental data of thermal conductivity of distilled water at different temperatures

Distilled water	
Temperature (^{o}C)	Thermal conductivity(W/mK)
30	0.575
31.3	0.581
32.5	0.586
33.3	0.59
34	0.594
35.4	0.607
37	0.612
39.5	0.622
43	0.626
49.5	0.629
56.5	0.634
61	0.637
65.7	0.64
69.8	0.646

Table A2: Experimental data of thermal conductivity of aluminum/water at different temperatures and different concentration.

CONCENTRATION 0.1%	
Temperature(^{0}C)	Thermal conductivity(W/mK)
30	0.619
31.3	0.622
32.5	0.628
33.3	0.632
34	0.638
35.4	0.64
37	0.643
39.5	0.648
43	0.67
49.5	0.683
56.5	0.727
61	0.759
65.7	0.788
69.8	0.832

CONCENTRATION 0.2%	
Temperature(^{0}C)	Thermal conductivity(W/mK)
30	0.627
31.3	0.63
32.5	0.634
33.3	0.641
34	0.644
35.4	0.648
37	0.652
39.5	0.665
43	0.674
49.5	0.751
56.5	0.77
61	0.864
65.7	0.913
69.8	0.931

CONCENTRATION 0.5%	
Temperature(^{0}C)	Thermal conductivity(W/mK)
30	0.673
31.3	0.681
32.5	0.705
33.3	0.718
34	0.729
35.4	0.743
37	0.749
39.5	0.772
43	0.784
49.5	0.809
56.5	0.843
61	0.912
65.7	0.938
69.8	0.987

Table A3: Experimental data of density of distilled water at different temperatures

Temperature(^{0}C)	DW
30	985.6
35	983.5
40	981.2
45	976.6
50	973.9
55	971.8
60	971.3
65	969.2

Table A4: Experimental data of density of aluminum/water nanofluid at different temperatures and different concentration

CONCENTRATION 0.1%	
Temperature(^{0}C)	Density
30	1040
35	1039.6
40	1040.8
45	1039.1
50	1035.2
55	1031.8
60	1028.3
65	1024.7

CONCENTRATION 0.2%	
Temperature(^{0}C)	Density
30	1045.3
35	1043.2
40	1040.8
45	1039.2
50	1038.3
55	1034.7
60	1031
65	1027.3

CONCENTRATION 0.5%	
Temperature(^{0}C)	Density
30	1059.7
35	1058.2
40	1057.8
45	1056.2
50	1052.4
55	1051
60	1048.1
65	1045.8

Table A5: Table A3: Experimental data of viscosity of distilled water at different temperatures

Distilled water	
Temperature(^{0}C)	Viscosity:
20	1
30	0.93
40	0.71
50	0.62
60	0.49
70	0.35

Table A6: Experimental data of viscosity of aluminum/water nanofluid at different temperatures

CONCENTRATION 0.1%	
Temperature(^{0}C)	Viscosity
20	0.85
30	0.73
40	0.6
50	0.48
60	0.35
70	0.26

CONCENTRATION 0.2%	
Temperature(^{0}C)	Viscosity
20	0.78
30	0.67
40	0.56
50	0.43
60	0.33
70	0.258

CONCENTRATION 0.5%	
Temperature(^{0}C)	Viscosity
20	0.68
30	0.61
40	0.503
50	0.38
60	0.27
70	0.2

Table A7: Experimental data of charging time v/s temperature with water and aluminum/water nanofluid

1 LPM				
Time (Mins)	Temperature(^{0}C)			
	Water	Nanofluid		
		0.10%	0.20%	0.50%
0	15	22.3	21.7	20.5
1	17.2	25.4	26.1	25.3
2	23.3	29.3	31.7	33.6
3	28.2	35.1	39.3	42.7
4	32.4	41.6	46.4	51.1
5	38.6	47.1	52.8	57.3
6	43.1	53.8	56.6	62.8
7	47.4	57.5	60.2	65.4
8	49.8	59.1	62.6	66.2
9	51	61.2	63.7	67.5
10	51.8	62.8	65.4	68.1
11	52.8	64.1	66.9	68.8
12	54.6	65.4	68.1	69.3
13	56.1	66.1	68.9	
14	57.2	66.8	69.4	
15	58.2	67.2		
16	59.5	67.9		
17	60.6	68.2		
18	61.7			
19	62.8			
20	63.8			
21	64.9			
22	65.8			

Table A8: Experimental data of discharging time v/s temp with water and aluminum/water nanofluid at different flow rates

0.5% volume concentration			
Time (Mins)	Temperature(^{0}C)		
	1LPM	2LPM	3LPM
0	65.8	65.3	65.2
1	60.4	60.2	58.6
2	54.8	53.6	51.7
3	49.6	47.3	45.6
4	46.7	44.7	42.5
5	43.6	41.7	38.4
6	41.5	38.2	35.3
7	39.2	36.2	33.2
8	37.6	34.6	32.5
9	36.1	33.3	31.8
10	35.6	32.6	31.2
11	34.8	30.3	30.4
12	33.6	29.9	29.8
13	32.7	29.6	29.5
14	31.9	29.4	29.1
15	30.6	29.3	29
16	29.9	29.3	
17	29.7	29.2	
18	29.4	29.1	
19	29.3	29.1	
20	29.1		
21	29.1		

Table A9: Experimental data of variation of temperature v/s time at different section of packed bed with water and aluminum/water nanofluid along the length x/l

X/L=O.2	
Time	Temperature(^{0}C)
0	17.4
2	32.7
4	44.7
6	56.4
8	64.3
10	67.7

X/L=O.4	
Time	Temperature(^{0}C)
0	17.1
2	31.5
4	41.7
6	53.9
8	60.1
10	65.7
12	68.9

X/L=O.6	
Time	Temperature(^{0}C)
0	16.9
2	28.8
4	38.9
6	50.9
8	57.3
10	63.4
12	65.7
14	67.8

X/L=O.8	
Time	Temperature(^{0}C)
0	17.6
2	28.3
4	39.9
6	48.7
8	56.9
10	62.2
12	64.1
14	66.5

Table A10: Experimental data of variation of pressure drop for distilled water and aluminum/water nanofluids at 0.5% concentration and different flow rates

Distilled Water	
Flow rate(LPM)	Pressure drop (kPa)
0.5	5.513
1	15.052
1.5	29.617
2	48.208
2.5	77.825

CONCENTRATION 0.5%	
Flow rate(LPM)	Pressure drop (kPa)
0.5	6.97
1	19.698
1.5	36.567
2	61.436
2.5	92.456

Table A11: Experimental data of variation of friction factor for distilled water and aluminum/water nanofluids at 0.5% concentration and different flow rates

Distilled Water	
Flow rate(LPM)	Friction factor
0.5	2.157185978
1	1.472427142
1.5	1.287650949
2	1.17895907
2.5	1.218088146

CONCENTRATION 0.5%	
Flow rate(LPM)	Friction factor
0.5	2.727297
1	1.926911
1.5	1.589814
2	1.502459
2.5	1.447087

Table A12: Experimental data of discharging time v/s temperature with water and aluminum/water nanofluid at different concentration for 1LPM

1LPM	
Time (Mins)	Temperature(^{0}C)
	Distilled Water
0	65.8
1	63.8
2	60.6
3	57.2
4	53.8
5	49.8
6	47.4
7	43.1
8	38.6
9	36.4
10	35.6
11	34.7
12	33.9
13	33.2
14	32.6
15	32.1
16	31.7
17	31.3
18	30.8
19	30.5
20	30.3
21	30.3
22	30.1

1LPM	
Time (Mins)	Temperature(^{0}C)
	Concentration 0.1%
0	68.2
1	66.8
2	63.8
3	59.2
4	54.7
5	49.6
6	44.3
7	38.6
8	35.3
9	32.1
10	31.6
11	30.3
12	29.8
13	29.4
14	29.3
15	29.2
16	29.1
17	29.1

1LPM	
Time (Mins)	Temperature(^{0}C)
	Concentration 0.2%
0	69.4
1	65.4
2	60.2
3	55.6
4	51.8
5	46.4
6	43.6
7	39.8
8	34.7
9	31.7
10	29.9
11	28.2
12	27.7
13	27.5
14	27.3
15	27.3

1LPM	
Time (Mins)	Temperature(^{0}C)
	Concentration 0.5%
0	69.3
1	64.7
2	58.9
3	53.5
4	48.8
5	42.6
6	38.3
7	34.1
8	31.5
9	29.7
10	28.8
11	28.3
12	27.8
13	27.6
14	27.6