The application of heat pipe for designing uniform temperature batch reactor

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Abstract:

In the experimental investigation carried out, the performance of a two-phase closed thermo-siphon (heat pipe) with water as the working fluid for thermal control batch reactor was studied. And the effect of some operation variables such as time, input heat power, filling ratio and materials on the reactor temperature were studied. The experiments performed in the filling range of 30%-80% and input heat power between 200- 1200 watt and the temperature uniform in the reactor, heating time and Optimal filling ratio were studied. The results obtained in this research project were the consistency of the temperature inside the reactor and the optimal filling ratio. Also, the results of this experiment are useful in design, optimization of heat pipe and control of reactor temperature.

Key words: Thermo-siphon, Heat Pipe, Filling Ratio, Input heat power

1. Introduction

Heat transfer is one of the basic subjects for discussion in industries and the heat pipe is one of the best pieces of apparatus for transferring heat [1]. The initial formulation of the heat pipe concept can be traced to the patents of A.M.Perkins and J.Perkins in 1892 [2]. The concept of a passive two-phase heat transfer device capable of transferring large quantities of heat with minimal temperature drop was first introduced by Gaugler in 1942 [3], when Grover and his colleagues at Los Alamos National Laboratories published the results of an independent investigation and first applied the term heat pipe [4]. Since then many applications have been found in various industries such as chemical and petrochemical, power generating, metallurgical, ceramics and cement, electronic, mechanical, transportation and aeronautical industries [4].

To reform the chemical reactor, key equipment in industrial processes with the heat pipe technology will not only be beneficial to energy optimization of the reactor itself. More importantly, it is useful for chemical reaction to raise the output and yield, thus bringing the industrial production equipment level onto a new step [5].

2. Theory

A heat pipe is a simple piece of equipment with no inlet or outlet that transfers heat rapidly between two points. One of the most important characteristics of heat pipes is their high heat conductivity. Due to the application of latent heat, the ability of the equipment to transfer heat is highly promoted as it can transfer a huge amount of heat energy along with very little difference in temperature.

Due to capillary forces, the working fluid is led back to evaporation section through porous wick to accomplish the process cycle [6, 7].

Heat pipes have shown the ability to cover a wide range of temperature in heat transfer processes. Therefore, they have been used to an appreciable extent for various applications [9] such as: ventilation systems, condensers, heat exchangers [10], transistors, laptops, mobile sets [11-13], electronic devices [14, 15], medical [16, 17], reactors [6], aerospace technology [3, 7, 9] and so on.

Heat pipes in the these applications, utilize Sake (as) adjust (control) temperature, heating and cooling Generate (Produce), temperature control and temperature Uniform.

3. Equipment design and experiments:

The equipment used in conducting the experiments is shown in fig 1 and includes variable parts:

1. Thermo-siphons
2. Reactor Vessel
3. Electric Heater
4. Data Logger
5. Computer
6. Thermocouples
7. Ampere meter
8. Voltmeter
9. Rheostat
10. Support bars

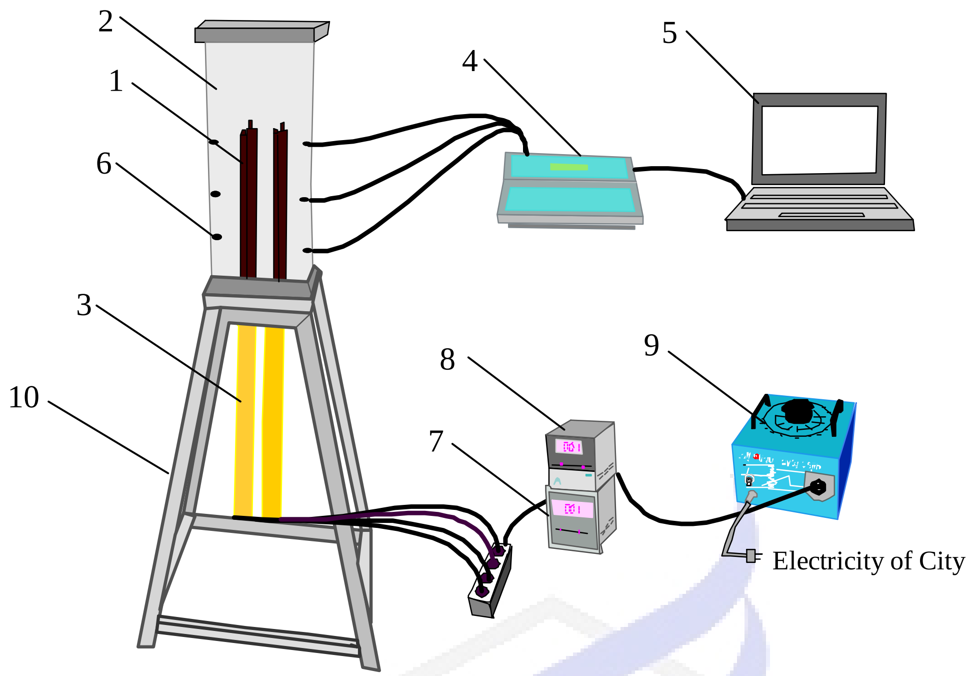

Fig.1. Experimental Apparatus

There are four thermo-siphons in this equipment, having no wick, in which the working fluid returns to evaporation section due to gravity. Thus, these pipes must be installed vertically. In this regard the condensation and evaporation sections are being located in lower and upper side of the pipe, respectively. The body and its caps are made of cupper and the working fluid is water with respect to its compatibility with cupper. The physical specifications of the aforementioned thermo-siphons are: ID= 20mm, OD= 22mm, L= 900mm. The length of the condenser section in thermo-siphons, in the evaporator section, and in the adiabatic section is 50cm, 30cm and 10cm, respectively. Heat arrives in the evaporator section via electric heater. The evaporator and adiabatic section exactly (Totally) isolate by asbestos-mica in order to prevent the wastage of heat resulting from radiation and convection heat transfer.

The main section of the system in which the experiment is to be done is the vessel of experimentation (reactor), holding the fluid that is being tested. A kind of reactor vessel made of plexy-glass. The reactor vessel is made of double-glazing plexy-glass in order to save heat. The image of the reactor along with the thermo-siphon is shown in figure 2.

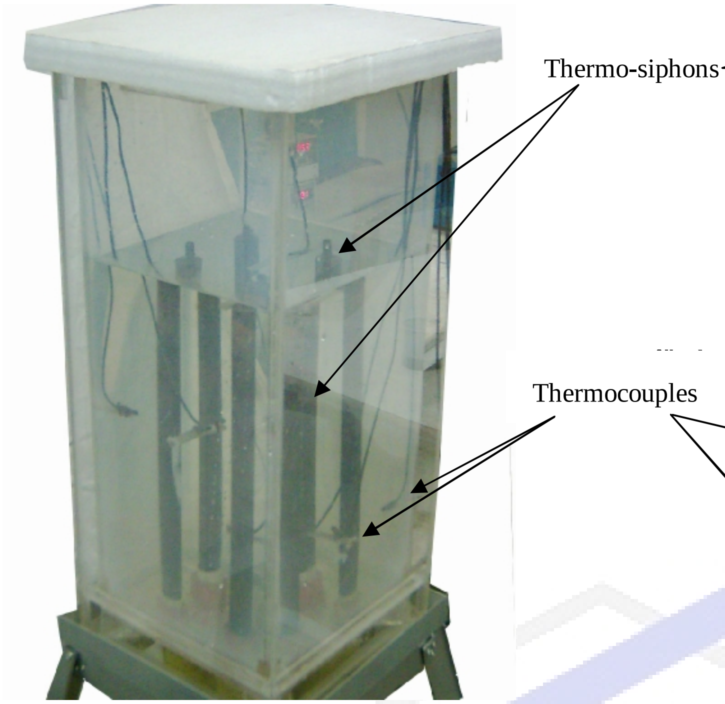

Fig.2. Experimental reactor

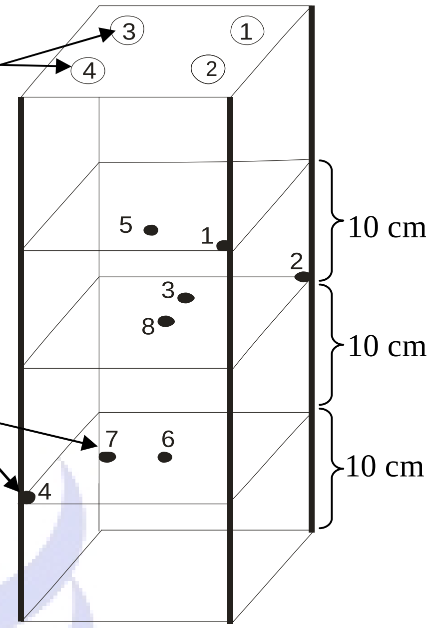

Fig.3. Sensor's location in the reactor

In order to measure the temperature of the different points in the reactor, a heat sensor is used. The temperatures can be seen by data Logger and computer. Sensor's location in the reactor is shown in fig 3.

The available reactor has been made for endothermic reactions, so the condenser section of the thermo-siphons is inside the reactor and the evaporator section pass through bed slots of reactor, and situate at outside the reactor. The reactor has been strongly fixed in place by support, and it can be closed by a motion and insulation door completely.

To perform experimental experiments, several operational variables have been studied:

a) (Permanent) controlled effects:

Working fluid: Distilled water

Condenser length: 30 cm

Evaporator length: 50 cm

Inside and outside diameters: 20, 22 mm

Aspect ratio: 25

Kind of pipe: cupper

b) Variable factors (effects):

Time: 0-120 min

Input heat power: 100-1200 W

Filling ratio (F.R.): 30%, 50%, 60%

Sensors: number of 1- 8

Material inside reactor: water, molasses, dough

1) Considering the uniform distribution of temperature inside the reactor:

In this section, we assumed the power and F.R. to be constant. The effect of the increase of temperature has been studied with the passage of time.

By connecting the electrical current, and warming the elements, the heat pipes start working.

The water inside the reactor gradually warms up because of the absorption of heat from thermo-siphons' condenser, and the temperature profile form around the pipe.

Most of the reactions performed inside the reactor are able to progress with a specified temperature. However, we should prepare the optimal temperature throughout the reactor so that until the reaction with the highest performance can be done. Usually the reactors warm by heaters that are installed around the body of the reactors. In doing so, the execution of heat will cause the occurrence of more reactions inside the body of the reactor, and the performance will be low in the middle of it. Utilize the heat pipes in different place of reactor to cause until distributing heat uniform to component in side the reactor and prepare the suitable condition for performing the reaction.

2) Considering the effect of input heat power on the reactor temperature:

In this step of the experiment on the one of sensor sample in constant F.R., considering effect of increase the input power on the temperature with time. The input heat power to heater can be regulated with a rheostat. Sometimes we need to prepare the special temperature inside the reactor at a specified time and/or at a certain time we should achieve the target temperature. Also, in some cases, we need to be careful so that reactor temperature does not exceed the limit at the time of the experiment is being carried out. Additionally, the temperature of the reactor should not become less than the minimum. In order to carry out the above-mentioned steps successfully, we used to regulation of the input heat power.

3) Considering the effect of changing the F.R. on the reactor temperature:

In this step of the experiment we would like to consider the effect of the increase of F.R. on temperature with the passage of time for one sensor sample in constant power.

One of the heat pipe parameters is filling ratio of working fluid that was changed to become optimum for effective performance of pipe. In this experiment with changing the volume of working fluid, can be regulate value of F.R. with perform this experiments, we can found the best F.R. for heat pipe effective efficiency.

4) Considering the effect of the increase of the fluid viscosity on the consistency of temperature inside the reactor:

In this step, the power and F.R. have been constant and the effect of the increase of temperature with the passage of time for the every one sensors sample with fluid more than water viscosity inside the reactor has been studied.

The procedure and apparatus operation is similar to the first step, except that the load of fluid in the reactor was changed. Since the viscosity of water is low, condition of isothermal prepare simpler inside the reactor. However, in this step, fluid with higher viscosity than the first step has been utilized so that the effect of uniform temperature on materials that have higher viscosity can be taken into consideration.

Ultimately, we will be able to generalize this result to other fluids. The utilized fluid in this step is molasses.

5) Considering the effect of input power value on reactor temperature with high viscose fluid:

In this section of experiments on one of the sensors in constant F.R., effect of increase the input power on the temperature with time at variation of power gradually from 200 to 1200 watt has been considered.

The operation and performance of the apparatus are similar to the second step. The only difference is that this time from fluid with more viscose than water was used. Now we can generalize the results of this step to other fluids.

4. Results and discussion:

1) The results of the first step of the experiment: Considering the uniform distribution of temperature inside the reactor

While power and F.R. are constants, the temperature of sensors increases with time gradually. The results are shown by figures 4 and 5 which indicate the difference between the temperatures that is being discussed and the first temperature.

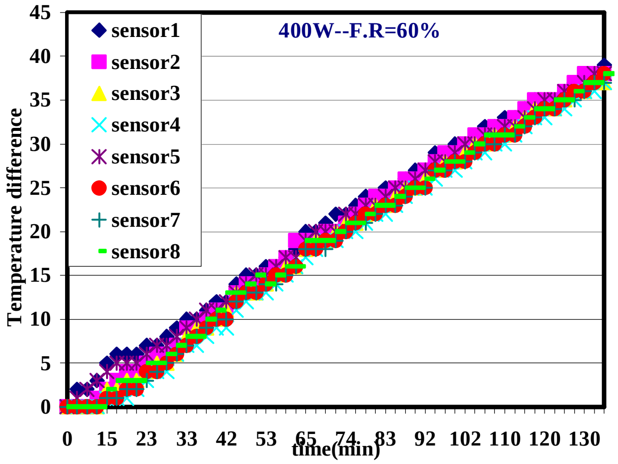

Fig.4. Temperature difference for eight sensors at power of 400W and filling ratio of 60%

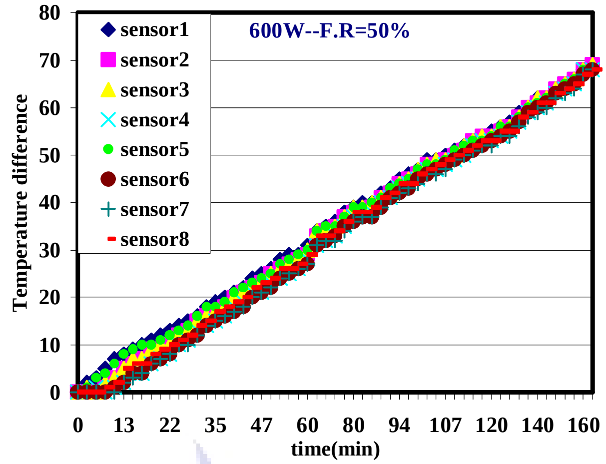

Fig.5 Temperature difference for eight sensors at power of 600W and filling ratio of 50%

With this result we found which sensor temperature is the highest and which one sooner becomes warmer than other sensor. Of course, the different is slight.

Because of lower density (SPGR) for hot fluid, turbulence in the top of condenser and the vapor inside pipe going up, the upper levels become warmer first.

Also, we have seen with increasing the temperature of sensor, temperature of corner and center of reactor go up quiet sooner than other places inside the reactor. As a result, we can write the following sequence:

7< 6< 4< 3< 8< 2< 5< 1

to show better uniform temperature inside the reactor, diagrams of temperature at sensors have drawn been by figures 6 and 7. This result shows that sensors' temperature is approximately a straight line that shows uniform temperature inside the reactor.

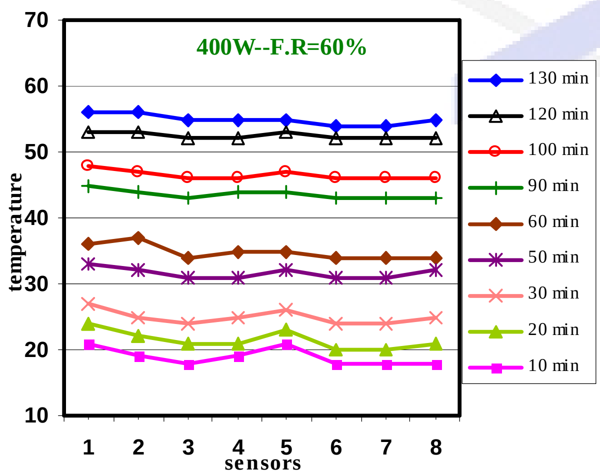

Fig.6. Temperature of sensors at different times at the power of 400W and filling ratio of 60%

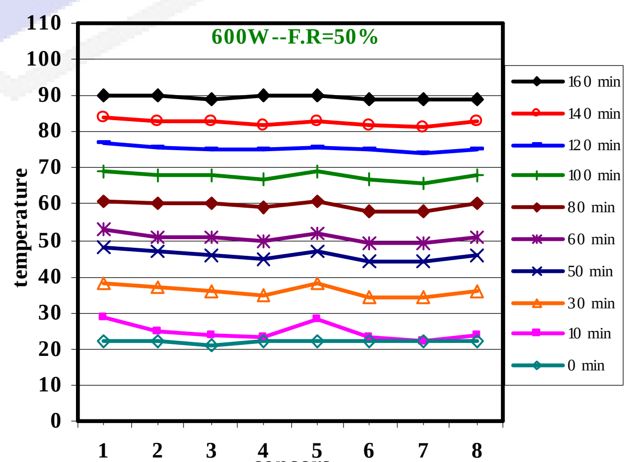

Fig.7. Temperature of sensors at different times at the power of 600W and filling ratio of 50%

2) The results of the second step of the experiment: Considering the effect of input heat power on reactor temperature

For one of the specified sensors in constant F.R., the temperature of different places of the reactor increase with the increase of input heat power with the passage of time.

This Result is represented by figures 8, 9:

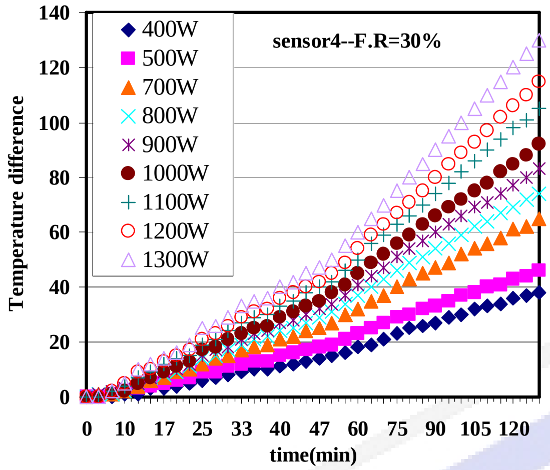

Fig.8. Temperature difference for different power at a filling ratio of 30% and sensor 4

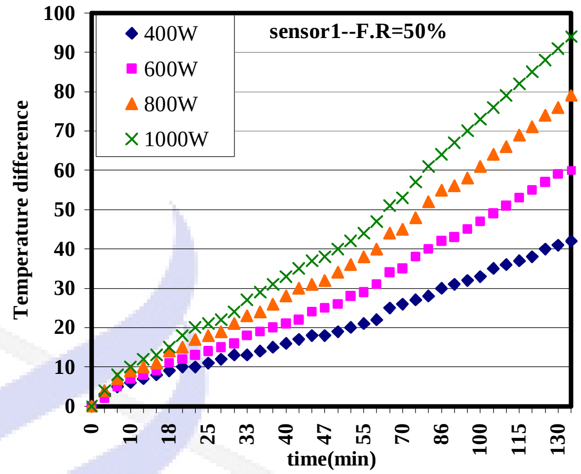

Fig.9. Temperature difference for different power at a filling ratio of 50% and sensor 1

Therefore by increasing the power within a length of time and the value of heat and temperature of difference places in the reactor go up. The more the input power, the less time is needed to reach a specified temperature. This point has been indicated by figure 10 and 11.

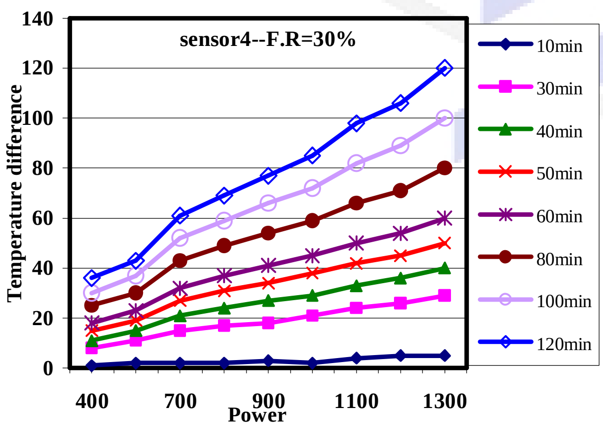

Fig.10. Temperature difference versus different power at filling ratio of 30% and sensor 4

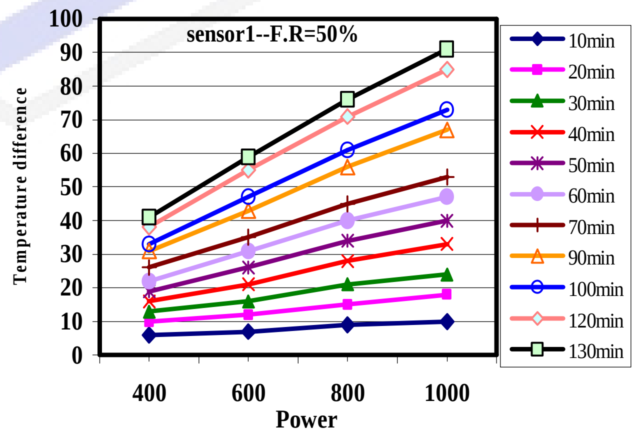

Fig.11. Temperature difference versus different power at filling ratio of 50% and sensor 1

3) The result of the third step of the experiment: Considering the effect of changing the F.R. on the reactor temperature

For a specified sensor with a constant power, the increase of temperature is different for different F.R.s, (fig. 12, 13).

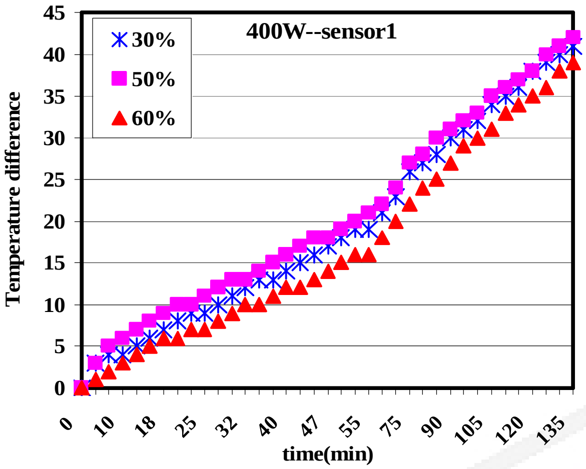

Fig.12. Temperature difference for different filling ratio at power of 400W and sensor 1

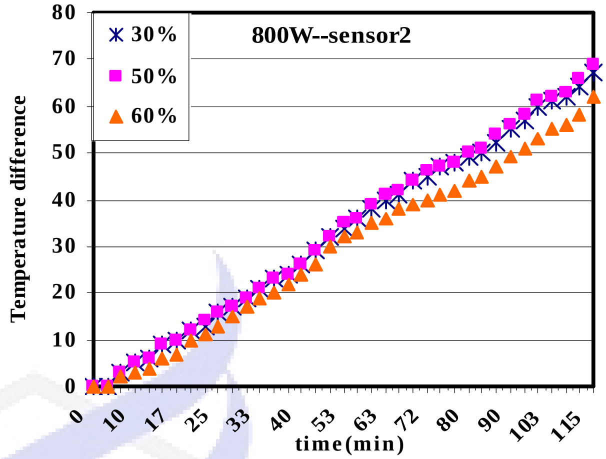

Fig.13. Temperature difference for different filling ratio at power of 800W and sensor 2

Consequently, one can find the best F.R. by paying careful attention to the diagrams, so that the temperature of sensors in that F.R. has been highest temperature along the time. The above figures show that the optimum F.R. is %50, because it demonstrates the highest temperature for different powers and sensors.

The plots (fig. 14, 15) below explain the above results:

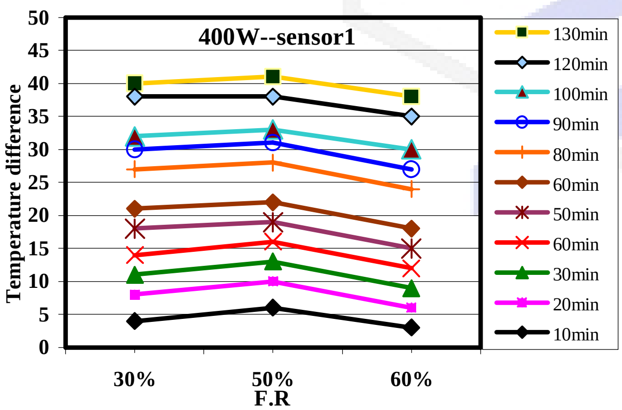

Fig.14. Temperature difference versus different filling ratio at power of 400W and sensor 1

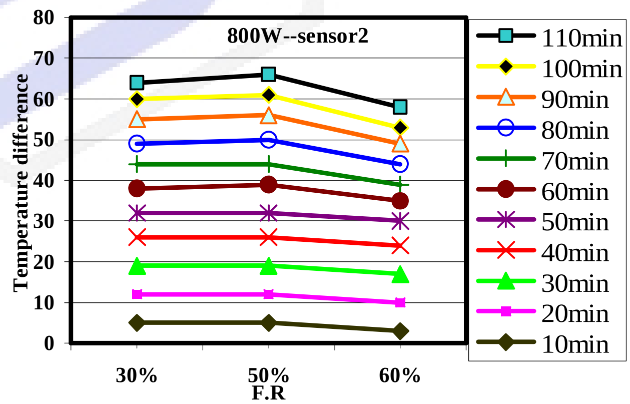

Fig.15. Temperature difference versus different filling ratio at power of 800W and sensor 2

According to the diagrams, we can write the following:

60% < 30% < 50%

4) The result of the fourth step of the experiments: Considering the uniform temperature inside the reactor with viscose fluid

Like to the first step at constant power and F.R. both, temperature of sensor increase gradually with time, And fluid with high viscosity applied.

Tests are done for the optimum F.R. (50%) and molasses. And the sensors 1 and 5 which are outside the molasses have been removed.

The Results shown by figure 16, 17:

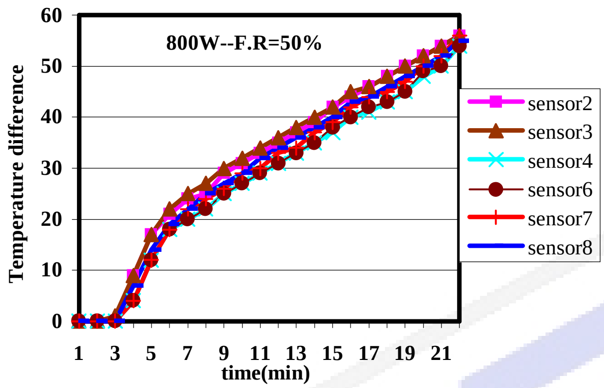

Fig.16. Temperature difference for different sensors at power of 800W and filling ratio of 50% for molasses

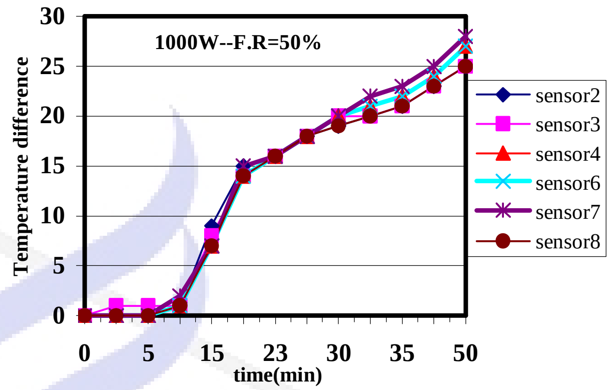

Fig.17. Temperature difference for different sensors at power of 1000W and filling ratio of 50% for molasses

Hence, for viscose fluid could have consequence that temperature of sensors on top of condenser more than other place and relation of increasing the temperature of sensors in molasses following this:

7, 6, 4 < 3, 8, 2 < 5, 1

For to seeing the isothermal inside the reactor, the temperature plots versus sensors number draw which indicate that the sensor temperature is nearly a straight line and temperature inside the reactor is almost uniform at different times.

Figures 18 & 19 represent the above concept:

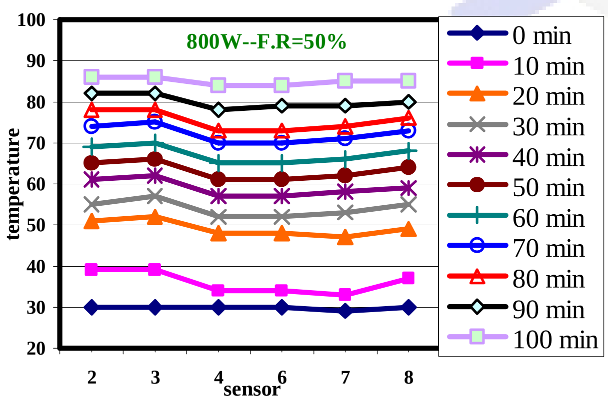

Fig.18. Temperature of sensors at different time at power of 800W and filling ratio of 50% for molasses

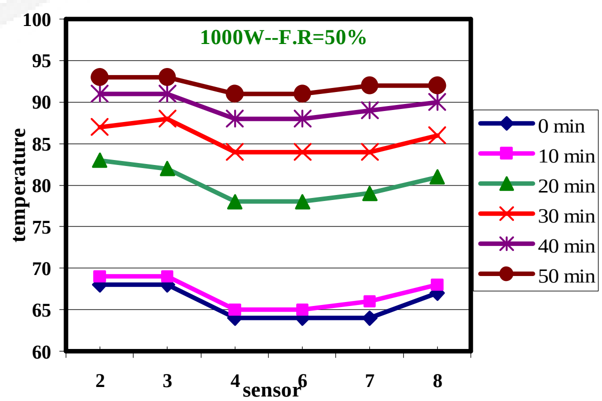

Fig.19. Temperature of sensors at different time at power of 1000W and filling ratio of 50% for molasses

Difference of temperature between different places inside the reactor decrease at high temperature and the uniformity of temperature is much better seen because the viscosity will decrease at high temperatures, and both hot and cold fluids are mixed easily.

5) The result of the fifth step of the experiment: Considering the effect of input power value on reactor temperature with high viscose fluid

For specified sensor and constant F.R., temperature of different places of the reactor with increase the input power to system going up with time, the result shown by figures 20 & 21:

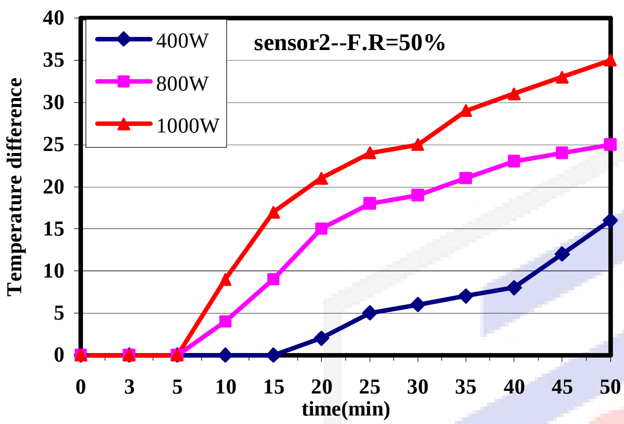

Fig.20. Temperature difference for different powers at filling ratio of 50% and sensor 2 for molasses

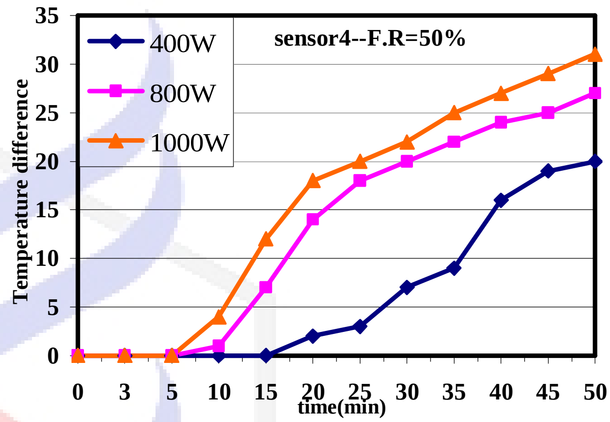

Fig.21. Temperature difference for different powers at filling ratio of 50% and sensor 4 for molasses

The results obtained for molasses show that the more the input power become, the less time it will take to reach a specific temperature. Furthermore the best possible power can be chosen according to the conditions of the reaction, so that a desired temperature can be reached within a specific period of time. Figures 22 & 23 show the difference of temperature versus power:

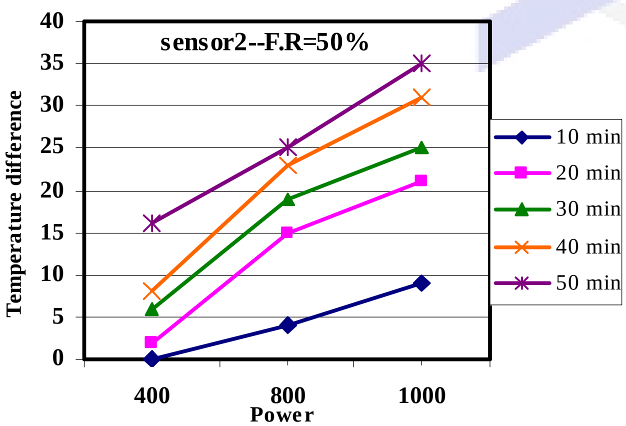

Fig.22. Temperature difference versus different power at filling ratio of 50% and sensor 2 for molasses

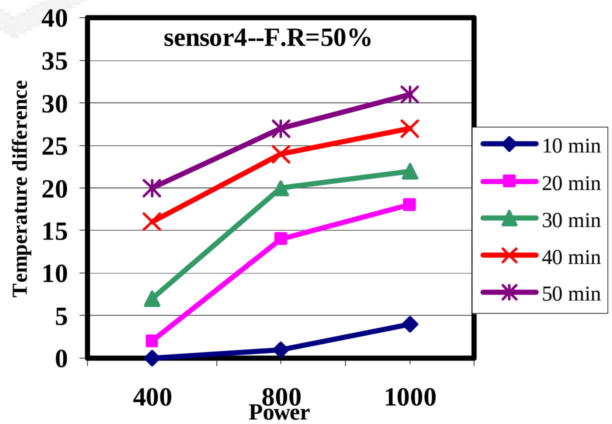

Fig.23. Temperature difference versus different power at filling ratio of 50% and sensor 4 for molasses

5. Conclusion:

In the research, carried out the effects of some operation variables on the control of batch reactor temperature with heat pipes were studied and the following results were obtained:

A. Because of the lower density (SPGR) of hot fluid, turbulence at the top of the condenser and the vapor going up inside the pipe, first warm the upper levels. Also, the temperature of the parts in the corners of the reactor becomes warmer than the other parts at the same level. Therefore, we can write the following: 7< 6< 4< 3< 8< 2< 5< 1

B. The temperature of the sensor in different places of the reactor is almost constant at certain times, which is demonstrative of the uniformity of temperature and isothermal in the reactor.

C. As the temperature increases at input power and F.R. constants, the uniformity of temperature becomes optional.

D. For one specific sensor, the temperature of the different places of the reactor increase as the input heat power increases after the passage of time. The more the input heat power becomes the less time will be needed to reach a specific temperature.

E. At certain times, the higher powers add to more temperature. Therefore, it is better to select the best power with respect to the reaction condition to reach an appropriate temperature.

F. For a variety of powers and sensors, a filling ratio of 50% shows the highest temperature. (Aspect ratio= 25)

G. Also, for viscose fluid, at constant power and F.R., the temperature of the sensor increases gradually with time and the temperature of sensors on top of the condenser is more than other places. Thus, relation of increase of the temperature of the sensors in molasses has been shown as: 7, 6, 4 < 3, 8, 2 < 5, 1

H. Regarding the viscose fluid, the temperature of sensors at a specified time inside the reactor is almost constant, and shows isothermal and uniform temperature at different places in the reactor. The difference of temperature between different places inside the reactor with molasses decrease at high temperature and uniformly of temperature appear better, because the viscosity will decrease at high temperature and both hot and cold fluids mix easily.

I. As for the viscose fluid, on the specified sensor in constant F.R., with the passage of time, the temperature of different points of the reactor increases as the input power, at specified periods of time, increases in temperature. This way the best power can be selected considering the reaction conditions so that the desirable temperature is gained.

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