An experimental investigation to cool exemplar lithium-ion cell using oscillating heat pipe using blends of methanol- diethyl ether

Kartik Drolia[1], S L Bhandarkar[1], Mohammad Arshad1, Amit Pal[2], Naveen Kumar Garg[3]
[1]Automobile Technology, Pusa Institute of Technology, Pusa, New Delhi 110 012, India
[2]Department of Mechanical Engineering, Delhi Technological University, Bawana Road, Delhi-110042, India
[3]Department of Automobile Engineering, G B Pant Institute of Technology, Okhla, New Delhi-110020, India

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Abstract: Today's world has made electric vehicles an imminent need for the hour. Energy performance means that in contrast with internal combustion engine powered vehicles electric vehicles are more energy-efficient. Lithium-ion batteries have been constantly growing in their energy density (gravity energy density) and the cell price per kWh has fallen. Batteries with lithium molecule are seen as appealing to vehicles. Its temperature control system plays an extremely important role in its longevity and performance. Numerous studies of the oscillating heat pipe (OHP) have been performed in order to sustain battery cells under the perfect temperature variation by utilizing various boundaries such as filling proportions, working liquids, pipe diameter, and material of the heat pipe. This work explores the reduction in the operating temperature of such batteries by means of the OHP and the use of methanol- diethylether blends as working material in various mixing ratio(MR) proportions (1:0.25, 1:0.75 and 1:1) to obtain the best performance. The results were also compared with only methanol as working fluid.

1. Introduction

Fossil fuel has been a significant contributor in India's gross domestic product (GDP); playing an important role to step up its wealth. However, its consumption found to be much higher than its production rate. India generates even lower than 1.5% of what it is consuming with little preserve, such huge consumption and requirement of the country has been fulfilled by imports. According to different studies, India imports more than 50% of its requirement. And in coming years, the trend is more likely to continue. With the rapid growth in population, the utilization is probably going to incremental. Consequently, it is really essential to adopt a comprehensive policy to preserve it for future generation. As well as, it necessitates to initiate exploration and development of the clean and renewable source of energy [1].Various researches have been conducted in this field and it was noticed that the productionofelectricityby non-traditional sourceslikenuclearpowerandhydroelectric has been ongradualrise. At the same time, more investments are being made on the study of use of batteries in the EVs.Unfortunately, not much heed is paid to battery thermal management (BTM) due to poor understanding of its thermal behaviour [2]. Even a thermal management system was developed for pouch batteries having two plates and to read its thermal behaviour, the battery was discharged at 1, 2, 3, and 4C with respective temperature of 10°C, 15°C and 20°C with water cooling system [3].

Numerous cooling techniques like traditional air-cooling [4,5] liquid cooling [6], refrigerant direct cooling [7-9] and heat pipes [12-13] have been used in last few years to increase the thermal dissipation of batteries used in EVs. But only heat pipe technology has several advantages over other above-mentioned systems including cost effectivity, light weight and higher heat dissipation efficiency.

Recently, a heat pipe BTMS was designed and it was noticed that temperature variation can be regulated under 50℃, if the heat is generated at power input of below 50W. Thus, the desired difference in temperature can only be attained if the heat is generated below 30W and it is inevitable to refer to a heat pipe without the distribution of temperature. With the additional terms included in an electrochemical thermal model, argues against calorimetric measurement on 15.7Ah Li-Mn 204/ carbon pouch type power cell. The heat is either generated in reversible or irreversible process in lithium ion batteries. Rao et al. [16] also investigated PCM/OHP combined BTMS and found it more favourable than OHP cooling system. Qu et al. [17] used a special flexible oscillating heat pipe for electric/hybrid vehicles. The evaporator section-maintained temperature under 50℃ at 121W of input.

Smith et al. [18] in their work designed a battery management system with oscillating heat pipe positioned close to cells and to investigate its performance, the water and ethanol were mixed in different amount of 40%, 50%, 60%; in ratio of 1:1, 1:2 respectively. And when input was 56W, the filling rate reached 30%. The average battery temperature was maintained under 47°C with uniformity and the difference was 1-2C. A BTMS was also tested with wet cooling system on 4 Ah and 8 Ah battery module, the system worked stable in unsteady discharge condition and increased the cell heat transfer efficiency in a very short time under 30°C [19].The system suggested involvement of components like cooling plates that sponges heat from every coloured (polychromatic) cell, a remote heat pipe circuit that transports heat till 0.3m and a liquid plate that scatters heat from the pipe into environment. With coolant (water) temperature 25°C and cell temperature 55°C, around 440W of heat was dispersed by BTMS per module. As well as +5°C of temperature was maintained between the coloured cells. During high discharge rate, natural convection was not adequate for battery cooling. In such situations, battery system based on micro heat pipe array proved to be really useful. As it not only helped in controlling the rise in temperature but also in maintaining the temperature uniformity and its thermal performance found to be best under changing conditions. An experiment on oscillating heat pipe (OHP) was conducted and to read its characteristics eleven working fluids with filling ratio of 50% with different input of heat varying from 20 to 110W was tested. Various fluids were used in an experiment like methanol water, ethanol water etc. The physico properties of the working fluids had large influence on working of OHP. Different fluids in OHP were used in the past investigations to get better results like methanol-water, ethanol-water etc.

In the present study, an exemplar lithium ion battery cooling system was designed and fabricated. The system was filled using different mixing ratios (1:0.25, 1:0.75 and 1:1) of methanol–diethylether as working substance and their important properties at different temperature range, and the effects were also studied.

2.Materials and Methodology

In figure 1 the schematic diagram of oscillating pipe of an exemplar battery cooling system has been shown. Figure 2 shows the actual

Corresponding Author,
E-mail address: gargnk1973@gmail.com

experimental set up. The oscillating pipe was built of copper capillary tube having length of 0.19m having an inner diameter of 0.0025 m and outer diameter 0.0045m. No. of coils were optimized to 4. The main reasons behind opting the copper pipe was due to its higher heat conductivity nature, ease of machinability, easy availability, durability and cost effectiveness. Methanol and diethylether of purity 99.5% were selected as working fluids and were procured prom reputed chemical supplier in New Delhi. These working fluids were blended together in different mixing ratio proportions of 1:0.25, 1:0.75, and 1:1. The blending ratios were restricted because of the comparatively lower boiling point of the diethylether. Below the minimum mingling ratio the significant effect couldn't be observed and dominance of methanol was observed. The upper limit was selected to side-step any vapour lock in the system at higher temperatures. It has been an efficient heat transfer group as there was no need of any external power source to initiate the process and better heat transfer properties.

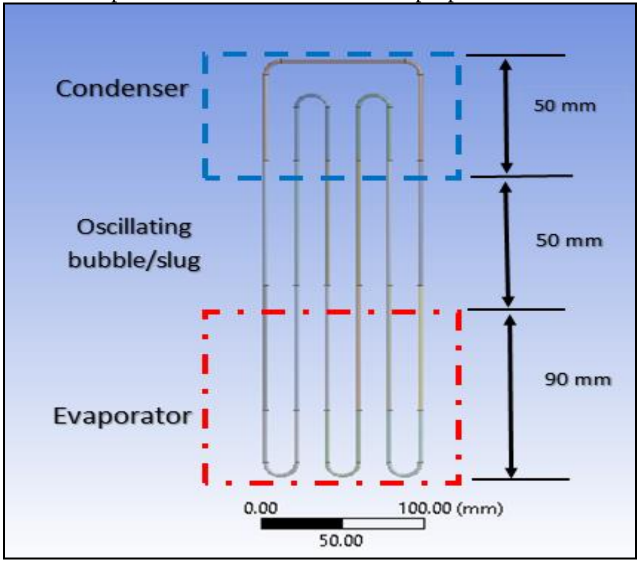

Fig.1: Schematic diagram of oscillating heat pipe

The OHP has been divided into three fragments – the evaporator, the condenser and the adiabatic part, which are 0.09m, 0.05m and 0.05m in their heights respectively. A small copper plate was used as cooling fin to increase the heat dissipation in the condenser region at some distance. Total 6 (LM 35) temperature Sensors of (+_0.5°C) accuracy, operating range (-55°C to 150°C) supply voltage 30V and 4V (max. and min.) respectively. Heat has been supplied through a heating pad of 45W with inbuilt thermostat and having dimension of 0.254 x 0.3302 x 0.0254 m in the evaporator section. Thermal compound was also applied for an efficient transfer of heat from the heater to evaporator. Condenser section length of 0.05 m was kept open to atmosphere with a high speed 12V DC fan motor having speed (4000– 5000) RPM with a speed controller. A 0.55 kW powered dual stage vacuum pump (VRI-8) used to develop vacuum in the OHP and AC refrigeration gauge was used to operating pressure of 600 psi. Table 1 shows the thermal physico properties of the working fluids.

Table 1 Thermo- physico properties of working fluids

Properties	Methanol	Diethyl ether
Boiling point (°C)	64.7°C	34.6°C
Density (kg/m^3)	792	713
Surface tension (mN/m^{-1})	22.5	17.4
Latent heat of vaporization(KJ/mol^{-1})	37.45	27.24
Thermal conductivity (mWm^{-1}K^{-1})	200	130

First, with the help of vacuum pump and the gauge, the oscillating heat pipe was evacuated. Working liquids in the different collaborating ratios were induced into the OHP set-up by means of a hypodermic needle. Temperature of the operating experimental set- up was determined using the thermocouples. The structure was stabilized and tested by constant values from the temperature sensors and in the display units. The system was connected to the heating element input with 220V AC supply and the heating was permitted. The thermal input was controlled by the potentiometer and the same was given by the ammeter and voltmeter. Three consecutive readings were taken and the mean value was taken as the final reading.

Fig. 2: Actual Experimental Setup

3. Results and Discussion

In experimental graph (fig.3), it was obvious that the temperature difference in the evaporator of the experimental installation was considerably less when tests were performed without any liquid since no fluid oscillation occurred in the device. In the evaporator temperature a gradually growing pattern was observed over time. And there was also an increase in the temperature of the condenser in the experimental setup due to the heat transferred from the tube wall.

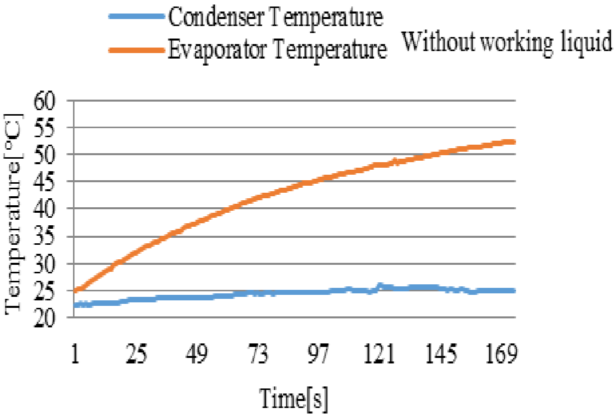

Fig.3: Time vs Temp without working liquid

With only methanol as the working substance, which was filled up to 70% of the total volume of the tube. In figure 3(a), it was observed that, there was rising trend with absorption of heat in the evaporator region. There was a drop in temperature from 59 to 55.5°C in time period from 47 to 49s. There may be system stabilization, as it again started increasing and the working substance reached to its boiling point in 60s. Later, the temperature increased at a very slow pace with subsequent fall as the maximum power was drawn from the battery. There was an increase in the temperature and with the increase in temperature, the system tried to control the temperature. Thus the fall in graph signifies the absorption of heat. Actually, for all cases the trend initially expanding quickly with time and afterward the pace of increment become delayed by some degree.

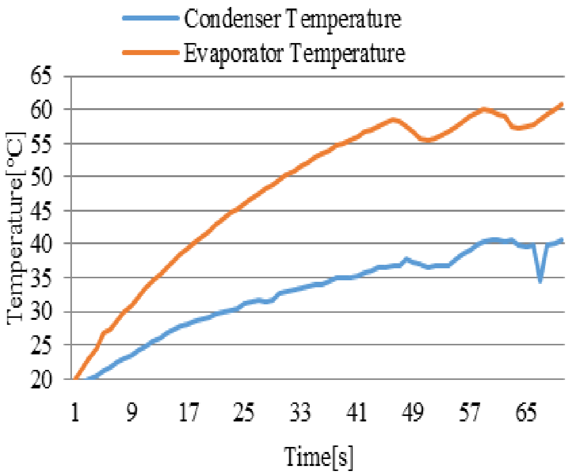

Fig. 3(a): Methanol with 70% charge

The amount of methanol was filled up to 50% of the total volume of the set-up. Figure 3(b), there was a fall in temperature at 51.5°C.The drop occurred for very short duration. The unequal dispensation at the beginning phase of liquid and vapour slug are the reasons behind this unsteady movement and if the motion of plug is stuck at the evaporator than there will be a rise in temperature.

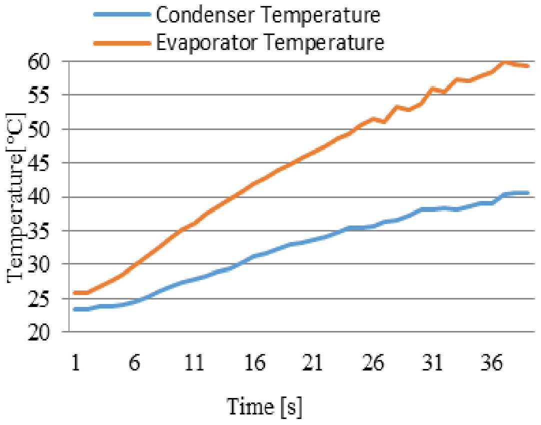

Fig.3(b): Methanol with 50% charge

In figure.3(c) is related with, when working substance was filled up to 30% of the system capacity. The temperature of start-up was 48°C.We could see many major fluctuations in the condenser part as well which was missing in previous reactions. The increment in charge ratio more prominent than 50% will additionally limit the liquid oscillation and temperature ascend at the condenser end.

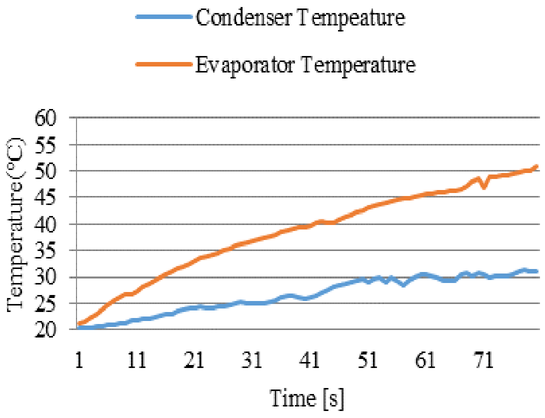

Fig.3(c): Methanol with 30% charge

Figure 4(a), 4(b) and 4(c) gives the effect of the blend of methanol and diethylether blended in mixing ratio (MR) of 1:0.25, 1:0.75 and 1:1. In figure 4(a), till 6 seconds there was no initial movement was observed in either of the sections, this may dominance of methanol part in the blend or presence of diethylether slowed the beginning of the reaction. However no such delay in starting of the reactions was observed with mixing ratio (MR) of 1:0.75 and 1:1 figure 4(b) and 4(c).At lowest mixing ratio the boiling point of the blend was achieved in more time whereas the time was decreased with increase in the blending percentage of the diethylether. This gives a clear idea about the occurring of reactions in the right directions. The trend of the all three graphs of the respective blend observed to be of same in nature i.e. with the rise in the evaporator temperature, the condenser temperature was increasing. This means the heat absorbed by the evaporator is successfully dissipated to the condenser and to the atmosphere. There by maintaining the system efficiency. However, in the MR of 1: 1 the difference between the evaporator temperature and the condenser temperature found to narrowing within a shorter time period.

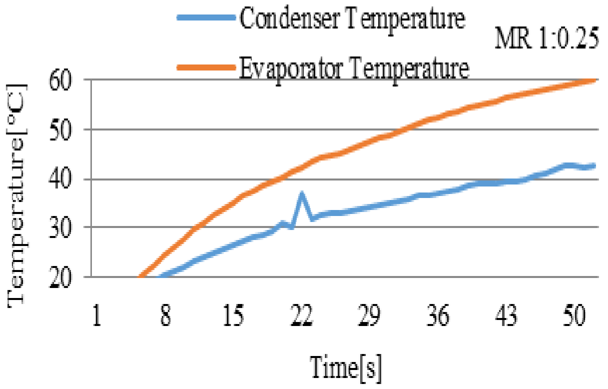

Fig. 4(a): Methanol-Diethylether MR 1:0.25

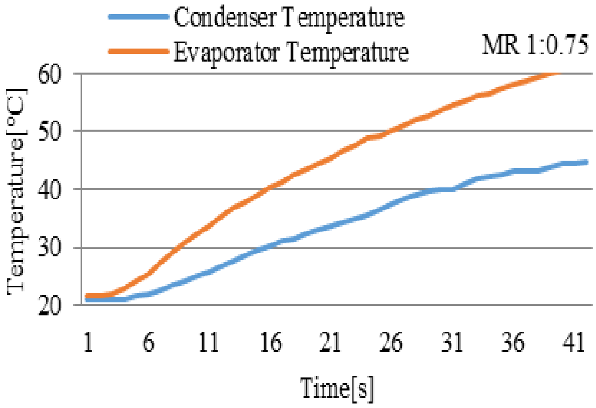

Fig. 4(b): Methanol-Diethylether MR 1:0.75

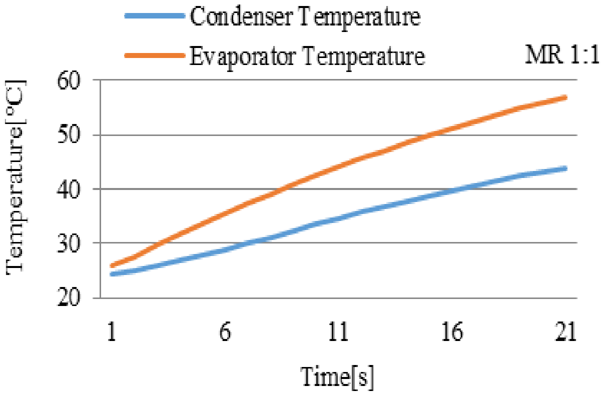

Fig. 4(c): Methanol-Diethylether MR 1:1

4. Conclusions

In the present experimental investigation, it is concluded as follows:

1. An exemplar battery management system for lithium ion battery was successfully designed and created.

2. The effectivity of the system was successfully tested using mono working fluid i.e. methanol. It was observed that the temperature difference between the two approximately uniform around 20°C. However, the time required to achieve this temperature difference was least with 50% methanol charge and strong fluctuation was seen in the methanol case with filling ratio 50%. Hence, filling ratios also gave major impact in the performance of oscillating motion.
3. The exemplar battery management system for lithium ion battery was successfully tested with blend of methanol and diethylether in different mixing ratios.
4. It was concluded that in the MR of 1: 1 the difference between the evaporator temperature and the condenser temperature found to be narrowing within a shorter time period.

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