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# Review of heat pipes for power batteries of new energy vehicles

Yuchen Huang

College of Civil Engineering, Hunan University, Changsha, China.

2278521649@qq.com

**Abstract.** With the global energy crisis becoming one of the most concerned topics, the application of new energy systems has become the most popular research at present. In addition, with the emerging new energy vehicles, problems such as high calorific value and insufficient heat dissipation performance of lithium batteries for new energy vehicles have not been solved, so the research on thermal management technology of lithium batteries is essential. Based on the analysis of heat pipe research, this paper summarizes heat pipe from three aspects, including structure and arrangement of the heat pipe, wall materials of the heat pipe and phase change materials of the heat pipe. This paper puts forward new insights and provides a reference for the research on the thermal management of lithium batteries for new energy vehicles.

**Keywords:** The application of new energy systems, thermal management technology of lithium batteries, analysis of heat pipe research.

## 1. Introduction

In recent years, the annual average temperature on earth has risen and the concentration of carbon dioxide has been increasing continuously [1], which promotes the adjustment of energy structure and the realization of low-carbon goals. In response to the national "dual carbon" goals, reducing carbon emissions and carbon pollution has been an irreversible trend in the development of modern society.

Up against all kinds of traditional fossil energy consumption, burning gasoline in traditional fuel vehicles leads to a large amount of carbon dioxide emissions. Thus, the new energy automobile industry is rising, with the automobile industry developing towards new energy vehicles. Battery-driven new energy vehicles have been widely recognized for their advantages of energy saving, environmental protection and simple structure [2-3].

Lithium-ion battery is preferred for its high energy density and long cycle life [4]. However, people pay too much attention to the cruising range and fast charging characteristics of lithium-ion batteries, thus ignoring their thermal safety. In recent years, spontaneous combustion, fire and thermal runaway of electric vehicles have occurred frequently [5]. It is precisely because of the potential safety hazards of lithium batteries featuring thermal safety, lithium dendrite and lithium thermal effect, that the research on thermal management of power lithium batteries has been one of the most vital research topics at present [6].

Hence, by summarizing the effects of different materials of heat pipe walls, comparing the thermal properties of phase change materials, and reviewing various types and arrangements of heat pipe on the heat dissipation performance of lithium battery thermal management system, this paper puts forward the idea and prospect of combining heat pipe and phase change materials for heat dissipation to lithium battery thermal management system in the future.

## 2. Structure and Arrangement of Heat Pipes

Structure and Working Principle of Heat Pipe:

Commonly used heat pipes consist of closed metal pipe, wick-suction liquid and end cover. The manufacturing of the heat pipe is as follows. The working schematic diagram of the heat pipe is shown in Figure 1. The heat absorption end of the heat pipe is the evaporation end, with the heat dissipation end as the condensation end. When the heating end of the heat pipe is heated, the working medium is heated and evaporated, which flows to the condensing end under the force of the fluid in the pipe. Then the steam dissipates heat at the condensing end and turns into liquid again, and the liquid at the condensing end flows back to the evaporating end under the gravity or capillary force of porous materials to achieve heat dissipation. In this way, the heat generated by the battery is conducted to the outside air, thus transmitting small temperature difference and large heat flow, and reducing the temperature of the battery [7-9].

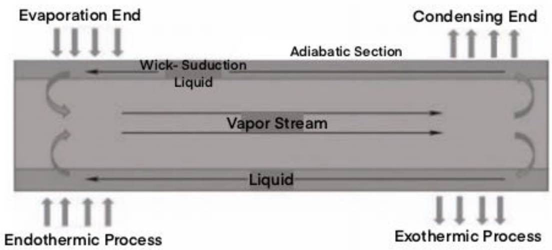


Figure 1 Working Principle of Heat Pipe [10]

Heat Transfer Capacity of Heat Pipe:

Compared with other cooling systems, heat pipe has stronger heat transfer capacity, but it does not mean that it can increase its heat load indefinitely. The thermal efficiency of heat pipe is restricted by many factors:

1. Heat Transfer Limit: When the heat pipe reaches the limit, the heat transfer amount will not continue to increase. [11-13].

2. Size of Heat Pipe: The larger the cross-sectional area of the heat pipe, the greater the amount of steam allowed to be conducted from the evaporator to the condenser.

3. Working Environment: The average operating temperature of the heat pipe will affect the performance of the heat pipe. The higher the average temperature, the better the performance.

4. Shape of Heat Pipe: The elbow of the heat pipe may reduce the heat that can be conducted.

Five Common Types of Heat Pipe:

Flat Heat Pipe:

Compared with ordinary heat pipes, flat heat pipe (FHP) can contact the battery surface more fully and conduct heat more quickly and evenly, with its system shown in Figure 2 [14]. According to test results, the thermal resistance of ordinary radiators with heat pipes is reduced by 30% through natural convection, and the thermal resistance is reduced by 20% under the condition of small wind speed, thus keeping the battery temperature below 50°C. According to the space allocated for the battery pack in the electric vehicle, the flat heat pipe can be placed vertically or horizontally.

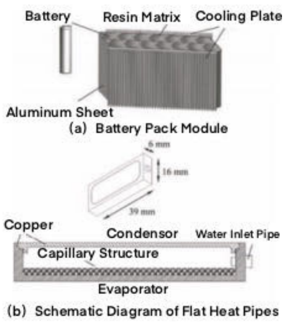


Figure 2 Cooling System of Flat Heat Pipe

Gravity Heat Pipe:

The gravity heat pipe, also known as a thermosiphon, has a structure as shown in Figure 3 [15], which can be composed of a condensation end, adiabatic section and evaporation end from the perspective of heat transfer. Because the gravity heat pipe has directivity, the evaporation end needs to be set below the condensation end, and the gravity of the liquid working medium returns to the evaporation end [16], so the gravity heat pipe has simple structure, convenient manufacture, low cost and good stability.

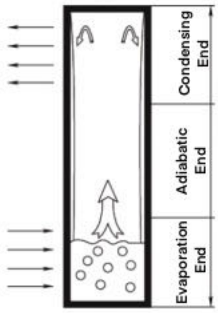


Figure 3 Gravity Heat Pipe

Sintered Heat Pipe:

To solve the problem that the coolant in the heat pipe is difficult to return to the evaporation end under microgravity, scholars have adopted a sintered heat pipe with a wick structure. Sintered heat pipe is composed of a sintered powder capillary structure, which can conduct the coolant from the condensing end to the evaporating end under the capillary force. At the same time, the wick structure is faster in the cycle, which is beneficial to the heat transfer and diffusion, improving the heat transfer efficiency of the heat pipe.

Loop Heat Pipe:

To overcome the shortcomings of traditional heat pipes in long-distance transmission and anti-gravity operation, based on the traditional heat pipe structure, Soviet scientist MAYDANIK [17] first proposed loop heat pipes in the 20th century, with its structure shown in Figure 20 [18]. On this basis, loop heat pipe (LHP) and capillary pumped loop (CPL) are developed, with the schematic diagrams of LHP and CPL shown in Figure 4.

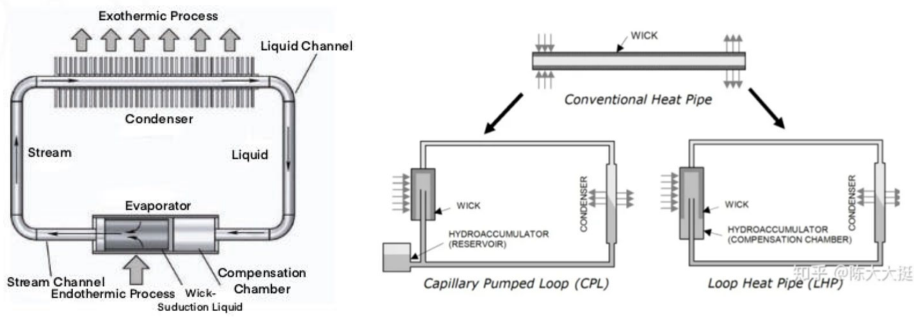


Figure 4 Schematic Diagram of Loop Heat Pipe and Capillary Pumped Loop [19]

Pulsating Heat Pipe:

A pulsating heat pipe is also called an oscillating heat pipe, with its structure shown in Figure 5 [20]. It is a new device with broad application prospects in the two-way heat transfer device. Pulsating heat pipe can be divided into closed type and open type. The open type is a unidirectional flow, while the closed type forms a loop at both ends. One or more one-way valves can be added in the middle to derive it.

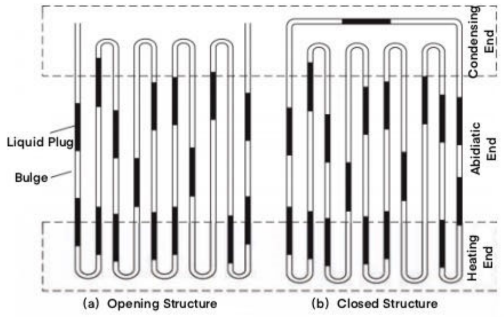


Figure 5 Basic Structure of Pulsating Heat Pipe

Thoughts on the Structure and Arrangement of Heat Pipes:

Considering that the car may tilt due to uneven road surfaces during driving, to ensure that the battery pack can still maintain stable heat dissipation under reverse gravity, the capillary wick heat pipe structure is adopted. At the same time, to fit the shape and structure of the battery pack, a flat heat pipe can be designed. As a heat pipe wall material, the following characteristics are needed:

1. High thermal conductivity.
2. Good mechanical properties.
3. Corrosion resistance.
4. Appropriate thermal expansion coefficient.

## 3. Heat Pipe Wall Material

Pure copper is widely used in mechanical, transportation and electronic fields because of its excellent thermal conductivity and chemical stability. However, due to its low strength, hardness and poor wear resistance, its application and development scenarios and fields are greatly limited. As mentioned above, the materials used in the heat pipe wall need to have good mechanical properties. Especially if the heat pipe materials are used in the thermal management system of lithium batteries for new energy vehicles, they need to have wear resistance. Hence, we envisage adding another substance into copper to make up for its shortcomings such as low strength, low hardness and poor wear resistance, so as to make it a composite material to improve its comprehensive properties. Feng Junjun et al. [21] introduced graphene as the second phase into copper-based bulk composites in the preparation and properties research of modified graphene reinforced copper-based bulk composites. It’s found that this method can improve the mechanical properties of composites to a certain extent.

Tungsten is a silvery white metal with a high melting point and slow evaporation rate, with its main physical properties shown in Table 1[22].

Table 1 Main Physical Properties of Tungsten [23]

| Melting Point | Boiling Point | Density | Temperature Coefficient of Resistance | Thermal Conductivity | Moh's Hardness | Young's Modulus | Vickers Hardness |
|---|---|---|---|---|---|---|---|
| 3410±20 ℃ | 5927 ℃ | 19.35 g/cm$^3$ | 0.004824/℃ | 173W·m$^{-1}$·K$^{-1}$ | 7.5 | 411GPa | 3430GPa |

Tungsten-copper composites have the advantages of both tungsten and copper. Because copper has good ductility, tungsten-copper composites can make up for the brittleness of tungsten at low temperatures with excellent high-temperature resistance, corrosion resistance and high hardness. For example, tungsten-copper alloy has the advantages of tungsten and copper simultaneously, which is a composite material with excellent thermal conductivity, electrical conductivity and low expansion.

12Cr1Mov Alloy:

12Cr1MoV alloy is a low-alloy high strength steel, where 12 in its name means about 12% chromium content, 1 refers to 1% molybdenum content, and MoV means the existence of molybdenum and vanadium.

Table 2 Composition of 12Cr1MoV Alloy

| Component | C | Si | Mn | Cr | Mo | V | P | S | Cu |
|---|---|---|---|---|---|---|---|---|---|
| Content/% | 0.08 ~ 0.15 | 0.17 ~ 0.37 | 0.40 ~ 0.70 | 0.90 ~ 1.20 | 0.25 ~ 0.35 | 0.15 ~ 0.30 | ≤ 0.35 | ≤ 0.35 | ≤ 0.25 |

Compared with 12CrMoV steel, 12Cr1MoV alloy has many advantages:

Higher antioxidant activity. (2) High strength: 12Cr1MoV alloy has good mechanical properties under high temperature and high-pressure environment. (3) Good heat resistance. (4) Good creep resistance. (5) Good welding performance.

Carbon Nanotube:

Carbon Nanotubes (CNTs), known as Bucky tubes, belong to the Fullerian carbon system. As a new nano-material, CNTs have many advantages, such as unique one-dimensional structure, high thermal conductivity, low expansion coefficient, high strength and lightweight, where the axial thermal conductivity can reach 3000 W/(m·K) [24]. This value is much higher than the widely used metal materials such as aluminum alloy and copper, and even surpasses diamond. Meanwhile, CNTs have many advantages such as good chemical stability and corrosion resistance.

Raytheon Company, together with Purdue University, Thermacore Company and other institutions, adopted the technology of growing CNTs on the surface of copper sintered powder to improve the thermal conductivity of flat heat pipes [25-26] as shown in Figure 6. The team believes that CNTs can form a capillary structure with controllable size and extremely high axial thermal conductivity, which can be one of the best choices for liquid wick materials. However, due to the hydrophobicity of CNTs, their permeability is extremely low, and the expected heat transfer effect cannot be achieved with the small evaporation area. To break through this limitation, a method of growing CNTs on the surface of the copper sintered powder is proposed. It's proved that this method can effectively reduce the evaporation resistance, so that the evaporation section of the flat heat pipe starts to evaporate or boil at a lower hot end temperature, and the planar thermal conductivity can reach three times that of copper.

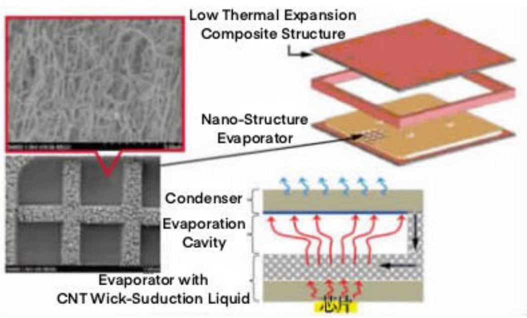


Figure 6 Schematic Diagram of Heat Pipe Structure in RFPG Project [27-28]

Outlooks and Ideas on Pipe Wall Materials:

Firstly, the current nanotechnology has been applied in the heat pipe phase change materials, and nanofluids play an important role in heat pipe phase change materials. Secondly, considering the fretting damage mechanism of heat pipes in the application of new energy vehicles, we can devote ourselves to finding a self-repairing material, so that future heat pipe wall materials may have self-repairing ability and can automatically repair cracks and defects at the damaged parts. Finally, from the perspective of green environmental protection and sustainable development, the resources on the earth are limited, and every material should give full play to its use value. Future heat pipe wall materials should pay more attention to environmental protection and sustainability. Hence, it is possible to develop recyclable materials, reduce the load on the environment, and decrease the energy consumption in production and maintenance.

## 4. Heat Pipe Phase Change Material

Ethanol

Because of the appropriate thermophysical properties of ethanol, non-toxic and cheap, scholars at home and abroad have conducted a lot of experimental research on pulsating heat pipes with ethanol as a working medium. The results show that the start-up power of a pulsating heat pipe (PHP) with ethanol as a working medium is lower than that of water. Through the experimental research by Xu Yanyan et al. [29] on the heat transfer performance of graphene nanofluid pulsating heat pipes with ethanol as the working fluid, the following results can be obtained: According to experimental studies, 50% is the best liquid filling rate of ethanol PHP [30].

Nanofluid

"Nanofluid" refers to a multiphase system formed by adding nano-sized additives to the traditional heat transfer working fluid as the base liquid. As a new type of heat transfer medium with high efficiency, nanofluids have been widely used in heat transfer.

The types of nanofluids are ionic liquids, micro-metals, self-wetting fluids, carbon nanotubes, etc. [31-34]. Compared with traditional heat transfer media such as water and ethylene glycol, nanofluids can enhance heat transfer. The performance advantages of nanofluids are roughly reflected in the following aspects, including excellent thermal conductivity, good stability and resistance reduction. Hence, to a pursue higher heat transfer effect, many scholars use nanofluids in pulsating heat pipes to study heat transfer characteristics.

According to the research [29], the fundamental reason for the influence of different working fluids on the heat transfer performance of PHP is the difference in physical properties of various working fluids. The thermal conductivity of graphene is much higher than that of other carbon nanomaterials (such as nano-diamond, carbon nanotubes and graphene oxide).

When the thermal load is 20~50W and the volume concentration of graphene/ethanol nanofluids is 0.01~0.05%, the thermal resistance of PHP is the smallest. When the concentration of graphene/ethanol dispersion is 0.05%, the heat transfer performance of PHP with graphene/ethanol nanofluids as a working medium is the strongest. Meanwhile, considering economic factors comprehensively, in practical application, choosing graphene/ethanol nanofluid with a volume concentration of 0.05% as PHP working fluid is the most cost-effective.

Graphene Oxide:

For graphene is hydrophobic and insoluble in water and can coalesce, researchers use graphene oxide to improve its solubility and further enhance the heat transfer effect.

Polar oxygen-containing functional groups on the surface of graphene oxide (GO) can be well dispersed in liquid to form stable GO nanofluids. Kyung et al. [35] studied the heat transfer performance of mesh wick heat pipe with water, 0.01% and 0.03% graphene oxide as working fluids. It is found that compared with the heat pipe filled with water, the evaporation thermal resistance of the heat pipe with GO/water nanofluid is reduced by about 25%, and the heat transfer performance is higher.

According to experiments by Jin Zhihao et al. on the heat transfer performance of graphene oxide gravity heat pipe [36], with the increasing GO nanofluid mass fraction, the thermal conductivity of solution will increase to varying degrees, while the thermal resistance will decrease, so adding GO nanoparticles can improve the heat transfer performance of liquid. Based on the experiment about the influence of graphene oxide on the start-up and heat transfer characteristics of pulsating heat pipes, Zhang Tiantian et al. obtained the following results [37]:

The increase of graphene oxide concentration can alleviate heat pipe drying. At the same time, the total thermal resistance of the heat pipe decreased after adding graphene oxide nanofluids, and the thermal resistance was the smallest at a 0.08wt% concentration.

Shi Jiyuan et al. found out the influence on the thermal conductivity of nanofluids [38]. The thermal conductivity of graphene oxide nanofluids increases with the increasing temperature and mass fraction.

Outlooks and Ideas on Phase Change Materials:

Is it possible that there is a working medium that can change the heat pipe includes the solid phase-liquid phase-gas phase. So the author came up with the process of solute and solvent dissolving each other in a chemical reaction. Solute dissolution is accompanied by an endothermic or exothermic process. When water is used as solvent and ammonium nitrate is used as solute, ammonium nitrate dissolved in water is an endothermic process, which will reduce the temperature of solutions. Then assuming that there is a certain amount of ammonium nitrate particles at the heat absorption end, that is, the evaporation end of the heat pipe, when the low-temperature water flows back to the evaporation end, ammonium nitrate dissolves in the water to absorb heat, which can further cool the solution. Assuming that the current ammonium nitrate solution is 90% sodium nitrate solution, which is reasonable, because the solubility of ammonium nitrate solution increases with the growing temperature. Hence, when the evaporation end heats up the water temperature, more dissolved ammonium nitrate will continue to absorb heat. The boiling point of 90% sodium nitrate solution is 150℃, which is higher than that of pure water at 100℃. When the temperature at the evaporation end is higher than 150℃, the water in the ammonium nitrate solution begins to evaporate and transport to the condensation end, while the ammonium nitrate solute in it precipitates and stays at the evaporation end. When the steam reaches the condensing end, the temperature drops and condenses into water, which reflows to the evaporating end, the dissolution process is carried out again. Thus, there is a material change of solid phase, liquid phase and gas phase across three phases in the working process of heat pipe working medium. Compared with pure water, this working medium has higher heat transfer efficiency, and the secondary cooling in the dissolution makes the evaporation end absorb more heat. It is believed that this innovative idea will have broad research room and application prospects after further research and confirmation in the future.

## 5. Summary

New energy vehicles are beneficial to energy and the environment, but the heat dissipation problem of lithium batteries still exists. Solving the high calorific value and insufficient heat dissipation performance of lithium batteries is the key, which makes heat pipe technology a crucial direction in the research of new energy vehicles. In this paper, the structure and arrangement of heat pipes, wall materials and phase change materials are reviewed, with the conclusions as follows. As for the structure and arrangement of heat pipes, a capillary wick flat heat pipe structure is used, which is staggered with a blade battery pack. As for the selection and use of heat pipe materials, nanofluids containing graphene oxide can be used as phase change materials for heat pipes, and carbon nanotubes can be used as wall materials. Meanwhile, other materials are also promising to be heat pipe materials in the future, such as graphene as nano additives, ethanol aqueous solution as dispersion nanofluids, 12Cr1Mov alloy and nickel-tungsten-copper composites, etc. The research on heat pipes in academia never stops. We should continue to explore more materials that may be used as heat pipes in the future and tap their potential and application prospects.

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