Study on Long Solar Electro-Hydro-Dynamical Heat Pipe

M. Sato, H. Noda and Y. Ito

Hachinohe Institute of Technology
88-1, Myo Ohbiraki, Hachinohe
Aomori, 031-8501 Japan.
Tel:+81-178-25-3111, Fax:+81-178-25-8053
E-mail:masaki@hi-tech.ac.jp

(Received : 31 January 2004 – Accepted : 15 March 2004)

Abstract: This paper presents a long solar electro-hydro-dynamical (EHD) heat pipe that returns the condensed liquid from the condenser to an evaporator, i.e., a collector array of a solar thermal electric power plant by using a number of EHD pumps. It consists of the vapor space and the liquid space. Namely, instead of a wick of a normal heat pipe, the liquid space is used. The EHD pump is driven by the direct high voltage of power source out of doors using a solar panel and booster to transport the condensed liquid in condensed liquid space of solar EHD-heat-pipe. This demonstrates that a larger amount of solar heat can be transported by using the EHD-heat-pipe. As a result, the amount of the heat transfer would be naturally controlled according to direct solar radiation. We can

expect to transport a large quantity of the solar heat in a solar thermal electric power plant.

System of Heat Transportation Using Solar EHD Heat Pipe

Earlier, researcher proposed a system of transportation of solar heat using the solar EHD-heat-pipe that is combined with the thermosyphon[1]. The plural EHD pumps composed of a cylindrical electrode and a rod electrode are arranged in the liquid space as shown in Fig.1. An insulating liquid is used as the heat transporting medium. The direct high voltage is supplied to the EHD pump from an independent power source out of doors that is composed of a solar panel and a booster, which converts low output voltage of the solar panel into direct high voltage [2]. The EHD pump is driven by direct high voltage[3]. The transporting medium is retuned to the collector array by applying direct high voltage (2kV~24kV) between electrodes. The collector array is heated to cause the transporting medium to vaporize and the vapor to move to the storage tank where the vapor is condensed. The solar heat is transported at a high speed from the collector array to the heat storage tank according to solar radiation. As a result, the amount of the heat transfer would be naturally controlled according to direct solar radiation. In the usual solar thermal power plant, an electromagnetic pump transports the working fluid such as the oil with solar heat. As the speed of the oil flow in a pipe is slow, the heat transfer rate is smaller and the heat loss from the pipe is large, whereas side, the heat transfer rate of the solar EHD-heat-pipe is larger because the speed of the vapor is fast. The solar EHD-heat-pipe is able to transport the solar heat in large scale plant such as the thermal electric power plants.

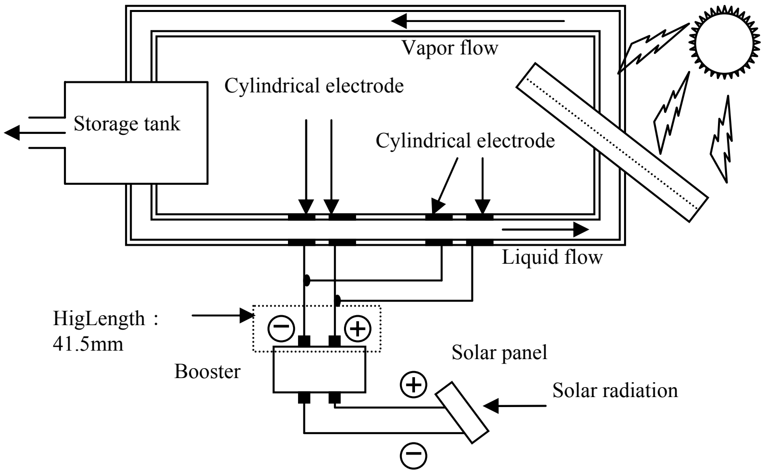


Figure 1. System of transportation of solar heat by using solar EHD heat pipe.

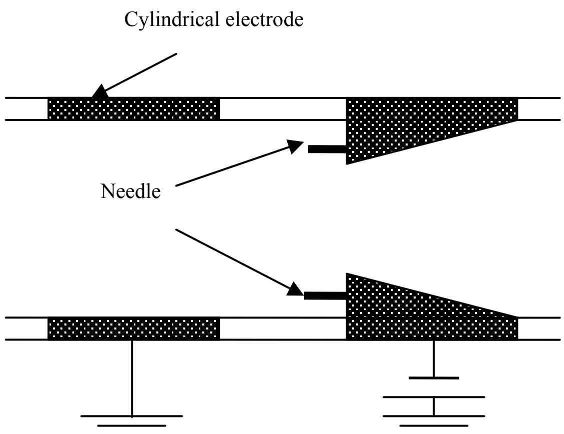


Figure 2. Ion drag EHD pump.

Principle of EHD heat pipe

A schematic diagram of the EHD-heat-pipe is shown in Figure 1. In the longitudinal direction, the EHD-heat-pipe is composed of the evaporator, i.e., the collector array and the condenser, i.e., the heat storage tank. The EHD-heat-pipe has the vapor space and the liquid space as shown in Figure 1. It does not have a wick that causes condensed liquid to return to the collector array. Instead of the wick, the liquid space exists. The cylindrical electrode and the disk electrodes, that is, the EHD liquid pump is arranged to make an axisymmetric flow in the path of condensed liquid as shown in Figure 1. The EHD-liquid-pump flow is caused by applying the direct high voltage between unsymmetrical electrodes. The body force ***fe*** that acts on condensed liquid under the influence of electric fields is expressed as

$$f_e = \rho_e E - \frac{1}{2}E^2\nabla\varepsilon + \frac{1}{2}\nabla\left(E^2\frac{\partial\varepsilon}{\partial\rho}\rho\right) \qquad (1)$$

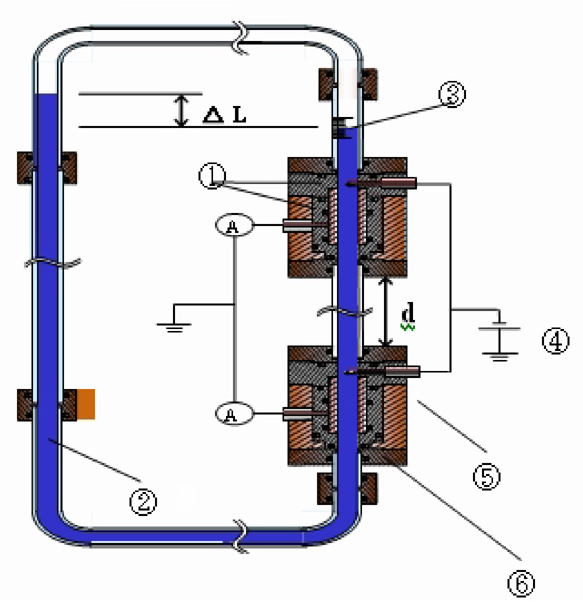
Where, ρe is density of electric charge; E is electric field strength; ρ is density of working fluid.

The first term represents Coulomb force due to interaction between true charges and electric field. The second term represents the force produced by the spatial change of permittivity ε. It appears that the second term is equal to zero in the case that the permittivity is approximately constant between electrodes. The third term represents the force caused by the inhomogeneity of the electric field strength and is called the electrostriction term. Although the net charge is zero in the case of polarization of condensed liquid, the polarization charges yielded at the stronger electric field are forced more strongly than the one yielded at the weaker electric field. Therefore, by the resultant force which is the sum of the forces exerted on each polarized charge, the condensed liquid element is also forced to the stronger electric field region. In the case that the corona discharge does not occur, Coulomb force is negligible. As the result, the flow of condensed liquid is caused by the electrostriction force. Therefore, condensed liquid is returned from the heat exchanger to the collector array by the EHD-liquid-pump.

Experimental Apparatus for Increasing Electrical Pressure of EHD Pump

The experimental apparatus for increasing the electrical pressure by using two EHD pumps is shown in Fig.2. The EHD pump is composed of the rod electrode and the cylindrical electrode. Two EHD pumps were arranged vertically in the insulating pipe to make measurement of the electrical pressure easier. The distance between the EHD pumps was 192.5mm. It includes the liquid space filled with the dielectric liquid. The insulating pipe was made of the Teflon. The rod and cylindrical electrodes were made of copper wire of 1(mm) diameter. The cylindrical electrode was 16(mm) in outer diameter and 9(mm) inner diameter. The length of electrode was

41.5(mm). The distance between electrodes was 2(mm). In an experiment, HCFC-123 which was the insulating liquid was used as the heat transporting medium. The direct high voltage (2kV～24kV) was supplied to the EHD pump. The HCFC-123 flowed from the rod electrode to the cylindrical electrode.



1. Teflon
2. HCFC-123
3. Levelgage
4. High voltage
5. Rod electrode
6. Cylindrical electrode

Figure 3. Experimental apparatus for increasing the electrical pressure by using a number of EHD pumps.

Results and Discussion

HCFC-123 as a working fluid was transported vertically against the gravity by apllying the direct high electric field between the cylindrical electrode and the rod electrode.

Figure 3 shows the effect due to two EHD pumps on the relation between the electrical pressure and the applied voltage.

The electrical pressure generated by an EHD pump at the applied voltage of 24 (KV) is 37 (Pa) and is insufficient to transport the working fluid as the heat transporting medium for a long distance. As shown in Fig.3, the electrical pressure generated by two EHD pumps is 2.0 times as much as that of a single pump. Since the arrangement of many EHD pumps within the condensed liquid space of EHD-heat-pipe make the electrical pressure higher, the mass flow rate of the condensed liquid becomes larger. This means that we can develop a long solar EHD-heat-pipe transporting a large quantity of solar heat.

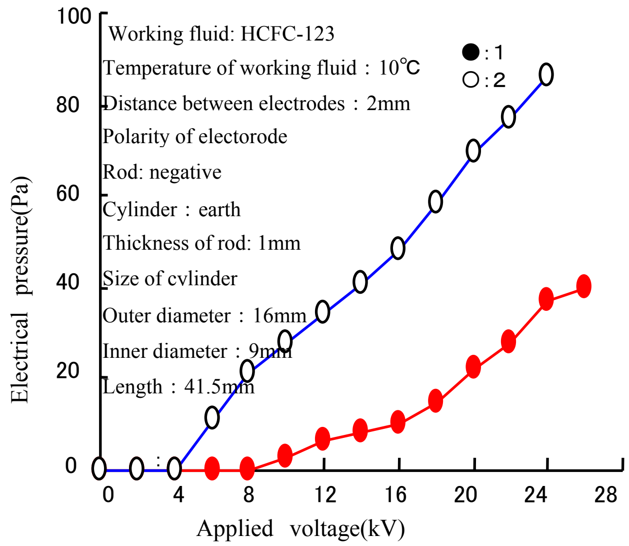


Figure 4. Effect of a number of EHD pumps on the relation between the electrical pressure and the applied voltage.

Conclusions

The main results are summarized below:

(1) The electrical pressure generated by two EHD pumps was 2.0 times as much as that of a single pump.

(2) It would be possible to transport a large quantity of solar heat for a long distance by using the solar EHD- heat-pipe with a number of EHD pump within the condensed liquid space.

References

[1] Sato, M., Mochizuki, M. and Noto, F. (1997) Solar Heat Transfer Enhancement by Electro-hydro-dynamical Effect, Proceedings of Solar World Congress, **3**, pp. 382-387.

[2] Sato, M., Nishida, S. and Noto, F. (1992) Study on Electrohydrodynamical Heat Pipe, *Solar Engineering ASME*, **1**, pp. 155-160.

[3] Sato, M., Yabe, A. and Taketani, T. (1991) Heat Transfer Enhancement by Applying an Electro-hydro-dynamical Pump Utilizing Dielectrophoretic Force, The 3rd ASME-JSME Thermal Engineering Joint Conference, pp.382-387

[4] Sato, M., Noda, H. and Ito, Y. (2001) Study on Solar Heat transfer by Solar Electro-hydro-dynamical Heat Pipe, Proceedings of ISES Solar World Congress, **3**, pp.727-733