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A Parametric Study of Water Pumping with Steam Power by Direct Contact Cooling

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Abstract

The aim of this research was to study and analyze effect of parameter of water pumping with steam power by direct contact cooling. A new thermal water pump gets power from hot water vapor and air pressure produced by a built-in electric heater 1,500 W. The vapor transfer from the heater tank to liquid piston tank acted as a pump to circulate water to a storage tank and vacuum as a result of condensation suctioned water into liquid piston tank. The overall head of this experiment was 3 m and not changed. Appropriate water fed into a liquid piston tank to cause the vacuum was about 300 cc. It was found that the vacuum gage pressure was about -49.1 kPa when the mixing temperature was around 38 ^{o}C. Pumping period was 12 minutes per cycle. The condensation period after the water from the overhead tank mixed with steam in the liquid piston tank was about 30 sec. The more important parameters in the system were temperature and mass of water from the overhead tank to make a condensation of vapor inside liquid piston tank.

Keywords: Condenser, Vacuum pressure, Electric Heater

1. Introduction

A development of water pumping with steam power by using thermal power for pumping in agriculture or irrigation in areas far from the power grids in order to reduce the fossil fuels. The research of the pumping from renewable energy was studied in 1976 by Sheldon et al [1] who presented a hydraulic pump by using transformation of thermal energy for the water pumping. A check valve controlled the flow of a working fluid. With a mechanism of the oscillations of vapor of the working fluid, this operation of the pumping system was applied to the water pumping work in the countryside. Meanwhile Rao and Rao [2] presented a study of a solar water pump for irrigation a development and test, by the principle of a thermodynamic analysis and construct. This system had no moving parts except the check valve and had no supplementary power or technique for the pumping operation. And this pumps was proper for irrigation in a remote county. In 1995 Sumathy et al. [3] had studied and given a brief description of the operation and analysis of a solar water pump. It was evident that the parameter affecting the performance of the pump is condensation time of the working fluid in each cycle. The condensation time in each cycle was determined through heart transfer analysis of the condenser. The effects of inlet water temperature, mass flow rate of the cooling water to the condenser, the condensation time and the pump performance had been studied and discussed. Other related works were in literatures [4-5].

In the present work, we studied the effect of parameters of water pumping with steam power by direct contact cooling: the pressure in the HT and the LT, the mean temperature in the LT and the mass of cooling water fed into the LT to create the vacuum.

2. Experiment setup

A new design of water pumping with steam power consists of parts as shown in Fig. 1. The OT serves as a supply of cool water into the LT when LT inside is equal to one atmosphere. Inside the OT installed a water control valve and floating valve. The two valves operate automatically and agree well with the vacuum occurring inside the LT. The LT acts as a pump to circulate water to the ST and to suction water from the WT below the LT, by using a steam produced from the HT. The ST was used to store water pumped from the LT directly. The HT was used to produce a high-pressure vapor for pumping purpose. The electric heater 1500 W installed inside the HT was used to heat the water and air and was well insulated with thermal insulation (Aeroflex), to prevent heat loss into the environment.

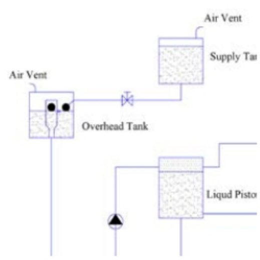

Fig. 1 a schematic sketch of a water pumping with steam power.


Fig. 2 The liquid piston tank (LT).


Fig. 3 The heater tank (HT).


Fig. 4 The overhead tank (OT).

A pressure transducer (Cole Parmer) could measure the gage pressure inside the HT and the LT with accuracy $\pm 0.25\%$. A set of K type thermocouples connected with hybrid recorder (Yokogawa) with accuracy $\pm 0.5\%$ were used to measure data from 3 point of the HT (top, middle and bottom), the same as the LT. Then, the thermocouple is installed inside the OT and outlet of the LT. All preliminary data were recorded for every 30 sec.

3. System analysis

The energy balance in the LT can be expressed as:

energy decrease in 105 °C vapor that condenses + energy decrease in hot water = energy increase in 30 °C water + latent heat of water that vaporizes at mixing temperature (Tmix)

$$m_v\left(h_{g,105} - h_{f,Tmix}\right) + \left(m_w \times c_{p,w}\right) \times \left(105 - T_{mix}\right)$$
$$= m_f\left(h_{f,Tmix} - h_{f,30}\right) + \left(m_e \times h_{fg,Tmix}\right) \qquad (1)$$

4. Results and discussion

The experimental result shows that when the water as well as air inside the HT receives heat from the electric heater, the pressure in the HT and the LT increases simultaneously because of the piping between the HT and the LT. The pressure increases until the value of the pressure in the LT is more than the system discharge head, this makes the system start circulating water. It can be seen that pressure graph of the LT is similar to a saw-tooth. During the water pumping stage, the water in the LT is being pumped by a steam flow from the HT. At this moment, the water in the LT flows to be stored at the ST. The volume of water in the LT decreases as the water flowing out continues. Consequently, the temperature in the LT increases as shown in Fig. 5 then the vapor flow stage can occur. When the LT water level reaches the entrance of the outlet duct, the vapor, inside the LT, flows into the

ST and to surrounding air at the air vent outlet. Therefore, the temperature and pressure inside the LT continue to decrease until it is equal to one atmosphere. Now temperature and pressure start decreasing. And when suction stage occurs, the low temperature water in the OT can move downward to the LT then the temperature in the LT suddenly decreases. The vacuum occurs in the LT and the system suction water into the LT. It was found that the graph of pressure in the HT and the LT fluctuate similarly. The pumped water in a cycle is 4 l per cycle. The operation period in a cycle is about 12 minutes. In addition, 30 sec is a suction period. Fig. 6 shows the changes of the pressure inside the LT and HT which occur suddenly due to the condensation when low temperature water mixes with high temperature vapor directly.

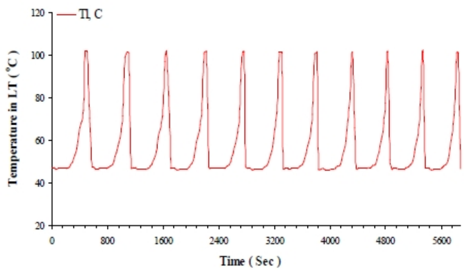

Fig. 5 Mean temperature (Tl) of the LT for the overall head 3 m (at the pumping 11 cycle).

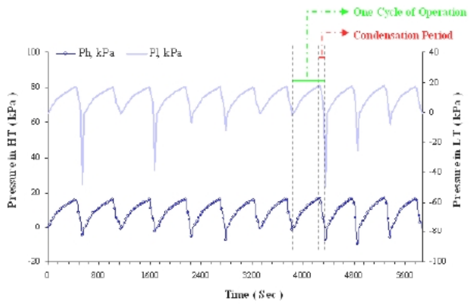

Fig. 6 HT vapor gage pressure (Ph, lower) and LT vapor gage pressure (Pl, upper) of the system for the overall head 3 m (at the pumping 11 pumping cycles).

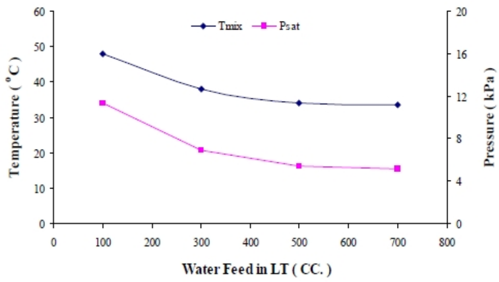

Fig. 7 Absolute suction vapor pressure and mixing temperature prediction as a function of cooling water in the LT.

The predicted mixing temperature and suction vapor pressure at mixing temperature occurring in the LT as a function of the amount of cooling water flowing from the OT to the LT are calculated from Eq. 1 (Fig.7). It was found that when varying cooling water fed into the LT by 100, 300, 500 and 700 cc, change in the mixing temperature and the suction pressure is still small. However, the researchers choose 300 cc as a suitable amount (use of a larger cool water amount will result in a larger CV and OT size, and less pumped water).

5. Conclusions

According to the experiments, it is found that the suction period in the LT is about 30 sec, which is more rapid than Ref. [3]. In addition, the cycle period is about 12 minute, because the mixing of low temperature water and high temperature vapor could create vacuum suddenly. The system has the potential to save energy by using waste heat instead of electricity.

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Nomenclature

$C_{p,w}$	Water specific heat (kJ/kg °C)
g	Acceleration of gravity (=9.81 m/s^2)
h_d	System discharge head (m)
h_f	Water enthalpy (kJ/kg)
h_{fg}	Latent heat of vaporization (kJ/kg)
h_g	Steam enthalpy (kJ/kg)
k_d	Loss coefficient for discharge (dimensionless)
m_a	Air mass (kg)
m_e	Water mass vaporizing at T_{mixing} (kg)
m_f	Water mass feed in the LT (kg)
m_v	Steam mass (kg)
m_w	Water and steam masses at the HT (kg)
N	Number of a water circulating cycle
T_{w2}	New water temperature in the HT (°C)
T_{w1}	Previous water temperature in the HT (°C)
ρ_w	Water density (kg/m^3)
V_d	Discharge velocity at the LT outlet
γ	Specific weight (N/m^3)

Acronyms

CV	Control valve
HT	Heater tank
LT	Liquid piston tank
OT	Overhead tank
ST	Storage tank
WT	Well tank

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