The International conference of the Thai Society of Agricultural Engineering 2012
April 4 – 5, 2012, Chiangmai, Thailand

AIS 011

A Development of Water Pumping with Steam Power

Kittiwoot Sutthivirode[1,*], Pichai Namprakai[1],
Natthaphon Roonprasang[2] and Naris Pratinthong[1]

[1]Division of Energy Technology, School of Energy Environment and Materials, King Mongkut's University of Technology Thonburi, 126 Pracha Utid Road, Bangmod, Thongku, Bangkok 10140
[2]Department of Energy Technology, Faculty of Science and Technology, Rajamangala University of Tachnology Tawan-ok, 43 Moo 6, Bangpra, Sriracha, Chonburi 20110
*Corresponding Author: kittiwoot_05@hotmail.com, Telephone 02-4708695 ext 101

Abstract

The aim of this research study was to develop a water pumping system with steam power. The operations of this system used a self-pumping and self-regulating method for circulating water in the system. This system consisted of five main parts, which are a vapor-producing heater tank with a built-in electric heater, a liquid piston tank, a storage tank, an overhead tank and a simulated well tank. The general operation of this pump had four stages for each cycle: heating, water circulating, vapor circulating and water suction. This system had a fixed discharge and suction heads of 3 m, overall head of the system. According to the experiment, it was found that the pump could operate at an average heater tank temperature of about 98–105 °C leading to 57-60 °C outlet water temperature of the liquid piston tank and 24 pumping cycles. The pumping rate of the system was 96 L in 4 h when the mean consumed energy input was 5 MJ and the mean pump efficiency was about 0.055 %. The discharge and suction heads were the more important parameters in the system.

Keywords: Water Pumping, Steam Power, Discharge Head, Suction Head

1. Introduction

The problem of agriculturist is that the water for cultivation and animal husbandry does not depend only on a natural rainfall. In most cases, it will also need to pump some water using electricity. Furthermore, the locality far from power grid uses oil as a fuel to pump which may face a problem of transportation of fuel into the local site and an expensive fuel.

It also causes energy crisis of the country. From previous problem, research and development of water pump by renewable energy such as wind turbine is possible only in location with continuously high wind energy potential.

Moreover, various researches and developments on the solar water pump by other processes were carried out.

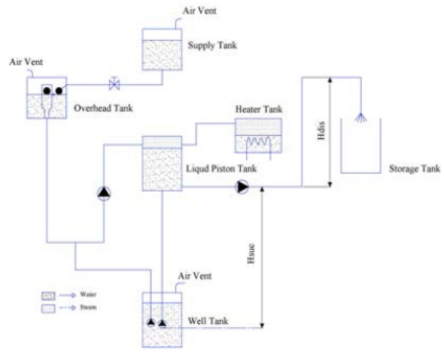
Reviews of the historical development of the use of solar energy installation for pumping irrigation water are as followed. Pytlinski [1] and Bahadori [2] showed the operation principles of solar energy water pumping with thermodynamic and direct conversion. Jenness [3] did a consideration relative to solar water pump by using the Savery technique. Hirano et al. [4] showed experimental study of a downward heat pipe used for driving pump. Sudhakar et al. [5] used a solar water pump for irrigation and did an analysis and simulation. Sumathy et al. [6] analyzed a solar water pump with n-pentane as a working fluid. Recently, Liengjindathaworn et al. [7] presented an experiment and the parametric studies of a pulsating-steam water pump. Their system used electric heater to supply thermal energy to produce a steam working fluid at low temperature. However, the system control of all valves was operated by hand.

The purpose of this research was to study an automatic operation, performance and the more important parameters of a water pumping system with steam power. The previous design of such system was done by Liengjindathaworn et al. [7] whose system was not automatically operated. A new design of the automatic water pumping system with steam power was presented in Fig. 1, which involved 4 stages.

2. Experiment setup

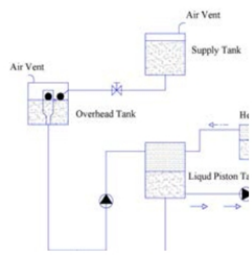
Description of operation of a new design of water pumping with steam power was presented in Fig. 1 as followed:

2.1 Heating stage: When inputting electric power to the heater as shown in (Fig. 1a), the water in HT is heated and vaporized by the thermal energy. The temperature and pressure increase continually until the pressure in HT is high enough for vapor to flow into the LT. The pressurization continues until the pressure in the LT is more than the pressure loss in the discharge tube.



1a. Heating Stage

2.2 Water pumping stage: As soon as the pressure in the LT reach threshold, the LT water then can flow to the ST. This stage continues until the LT water level reaches the entrance of the outlet duct in (Fig. 1b).

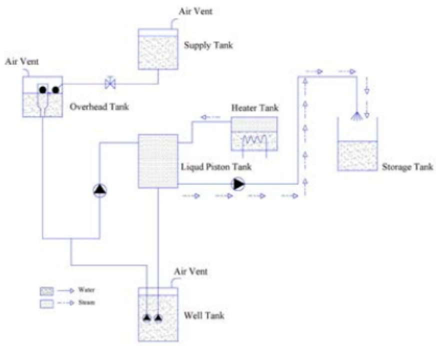


1b. Water Pumping Stage

2.3 Vapor flow stage: Fig. 1c, when the LT water level reaches the entrance of the outlet duct, the vapor inside the LT flows into the ST and

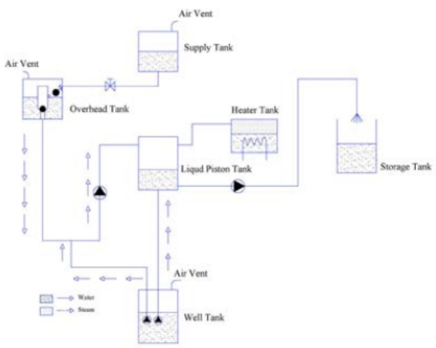
The International conference of the Thai Society of Agricultural Engineering 2012
April 4 – 5, 2012, Chiangmai, Thailand

surrounding air at the air vent outlet. Therefore, the temperature and pressure inside the LT decrease, this stage continues until the pressure is equal to that of surrounding air.



1c. Vapor Circulating Stage

2.4 Water suction stage: when the pressure inside LT is equal to one atmosphere, the low temperature water in the OT can move downward through control valve to the LT by the gravitational force. This provides vapor condensation and hence vacuum within the LT, sucking water from the WT into the LT. One cycle of the pumping therefore ends and the system is now ready for the next step (Fig. 1d), the system circulating water per cycle is 4 L.



1d. Water Suction Stage

Fig. 1 The operation of the water pumping with steam power

As shown in Fig. 1 the HT is a stainless steel cylinder with 0.4 cm thickness, 20.5 cm diameter and 31 cm length. A controlled electrical heater, well insulated, heats the HT. The LT (or condenser in this system) is made from stainless steel sheet cylinder with 0.3 cm thickness, 16 cm diameter and 24.5 cm length. The LT and HT are connected by an 1/2 inch copper tube with 5 cm insulation. The gage pressure inside the HT and the LT could be measured by a pressure transducer (Cole Parmer) 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 points 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.

During heating stage, the thermostat was set at 110 $^{\circ}$C in order to ensure water boiling. As electric heater supplies a constant energy rate to the HT water, the overall head was 3 m in the experiment.

3. System analysis

3.1 The Heating Stage

For heating of the HT water, lumped model is assumed [8-9]:

$$Q = m_{w} \times c_{p,w} \times \left(T_{w_2} - T_{w_1} \right) + Loss \qquad (1)$$

The pressure in the HT was calculated from a perfect gas law:

$$PV = mRT \quad (2)$$

The discharge pressure of system was expressed as follows:

$$P_{discharge} = \left(\rho \times g \times h_{discharge}\right) + P_{atm} \quad (3)$$

3.2 The Water Pumping and Steam Flow Stage

The fluid flow to the ST according to the following Bernoulli's equation [8-9]:

$$\frac{P_{LT}}{\gamma} = h_{discharge} + \left(1 + k_d\right)\frac{v_d^2}{2g} \quad (4)$$

The required hydraulic work per cycle is expressed by:

$$W_h = V_c \times \rho_w \times g \times h \quad (5)$$

3.3 Water Suction Stage

The energy balance during the vacuum in a thermal pump is analyzed. Steam at 105 °C inside the LT transfers heat to the 30 °C water from the OT. All steam condenses. The temperature of remainder air and hot water decreases. Some water at mixing temperature vaporizes. Energy balance in the LT is then as follows:

$$m_v\left(h_{g,105} - h_{f,Tmix}\right) + \left(m_w \times c_{p,w} + m_a \times c_{p,a}\right)\left(105 - T_{mix}\right)$$
$$= m_f\left(h_{f,Tmix} - h_{f,30}\right) + \left(m_e \times h_{fg,Tmix}\right) \quad (6)$$

The suction pressure of system is expressed as follows:

$$P_{suction} = P_{atm} - \left(\rho \times g \times h_{suction}\right) \quad (7)$$

Pump efficiency of a water pumping system with steam power is defined as a ratio of total hydraulic work required by the pump to total electric energy input to the pump during the experiment:

$$\eta_p = \frac{NW_h}{H_{tot}} \times 100\% \quad (8)$$

Table. 1 The analysis parameter of system efficiency

Symbols	**Parameter**
$C_{p,w}$	Water specific heat, kJ/kg °C
g	Acceleration of gravity, =9.81 m/s^2
$h_{discharge}$	System discharge head, m
$h_{suction}$	System suction head, m
H_{tot}	Total energy input to an electric heater, kJ
k_d	Loss coefficient for discharge, dimensionless
m_f	Water mass feed in the LT, 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
V_c	Volume of circulated water per cycle, m^3

4. Results and discussion

During water in the HT is heated by heater, the thermostat was set at 110 °C. The electric heater supplies a constant energy rate to the HT water. The temperature of the water, as well as, air increase to near the temperature level setting. The vaporization of water and the constant air mass expansion under the HT temperature then create new total pressure. Presently, the system can start circulating water from the HT to LT and ST (water pumping stage). Therefore, the water in the LT decreases continuously, this makes the LT temperature has rapidly increased until the steam flow stage occurs. Then the low temperature water in the OT flows into the LT that is filled with high temperature steam. Then the mixing occurs between the low temperature water and high temperature steam in the LT and causes the temperature and the pressure suddenly decrease, the vacuum pressure is then produced consequently. The water is suctioned from the WT into the LT as shown in Fig. 2 and Fig 3. A mean temperature in one cycle happening in the HT and the LT are about (98 - 104 °C) and (57.9 - 104 °C) respectively, and then to the lowest value at the end of each cycle. At the same time, pressures in cycle occurring in the HT and the LT are about (-9.78 – 18.52 kPa) and (-49.1 – 18.43 kPa) respectively. From the experiment, it is found that the system can pump water for 24 cycles in 4 h. Pumping time is 12 min per cycle. Moreover, the average pumped water per cycle is 4 L (net). Fig. 4 shows the thermal energy stored in the ST. The average ST water temperature is around 57 - 60 °C because of heat transfer from the LT envelope and steam. The maximum thermal energy stored in the ST is about 5.52 MJ. The mean pump efficiency maximum is about 0.055% for the overall head of 3 m.

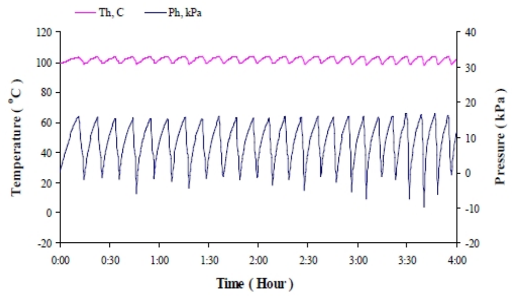


Fig. 2 Mean water temperature (Th) and vapor gage pressure (Ph) in the HT for the discharge head of 3 m.

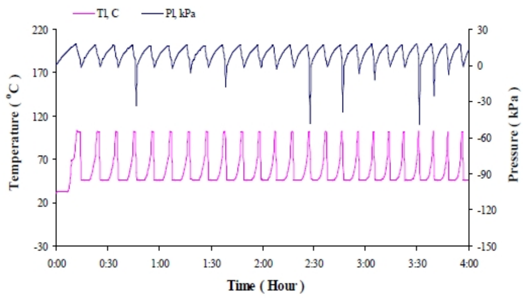


Fig. 3 Mean water temperature (Tl) and vapor gage pressure (Pl) in the LT for the discharge head of 3 m.

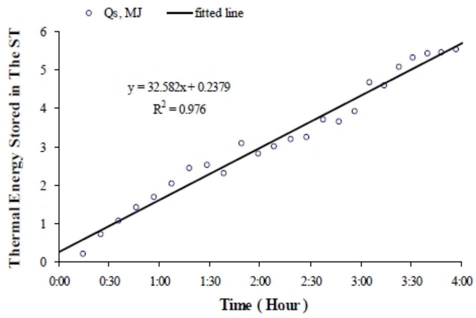


Fig. 4 Mean water temperature (Ts) in the ST from the experiment and fitted line for the discharge head of 3 m.

5. Conclusions

System advantage is that the cooling time is very rapidly. Its operation is automatic compared to the previous work [7]. This system can use various energy sources such as thermal energy from woods found in the local area far from power grid. Besides, it is simple in operation, uses fewer materials or parts, is easy in construction and has no moving parts: solid piston. Another advantage of this system is that the pumped water temperature is around 57 - 60 °C appropriate for bathing. However, the possible water vapor lost to the environment is around 0.172 kg. In conclusion, the system pumped water is 96 L in 4 h. Moreover, the maximum pump efficiency is about 0.055%. Only 4 h operating time is selected in order to keep the control valve long life. We also plan to construct a larger thermal water pump that can have 1000 L capacity or more. Usually, the pump (heat engine) efficiency increases with temperature as found in a steam power plant.

6. Acknowledgements

The authors gratefully acknowledged the financial support provided by National Research Council of Thailand and the Energy Technology Division, School of Energy Environment and Materials, King Mongkut's University of Technology Thonburi. This work also was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission.

7. Reference

[1] Pytilinski, J. T. (1978). Solar Energy Installations for Pumping Irrigation Water, *Solar Energy,* Vol. 21(4), 1978, pp. 255-262.

[2] Bahadori, M. N. (1978). Solar water pumping, *Solar Energy,* Vol. 21(4), 1978, pp. 307-316.

[3] Jenness, Jr. and James, R. (1961). Some Consideration Relative to a Solar Power Savery Water Pump, *Solar Energy*, Vol. 5(2), April-June 1961, pp. 58-60.

[4] Hirano, S. Yamamoto, T. Takamura, Y. and Katsuta, M. (1996). Experimental Study of Downward Heat Pipe Using Principle of Heat-Driven Pump, paper presented in *the international Heat Pipe Symposium 1996*, Australia.

[5] Sudhakar, K. Krishna, M.M. Rao, D. P. and Soin, R. S. (1980). Analysis and Simulation of a Solar Water Pump for Lift Irrigation, *Solar Energy*, Vol.24(1), 1980, pp. 71-82.

[6] Sumarthy, K. Venkatesh, A. and Sriramulu, V. (1996). Thermodynamic Analysis of a Solar Thermal Water Pump, *Solar Energy*, Vol. 57(2), August 1996, pp. 155-161.

[7] Liengjindathaworn, S. Kirtikara, K. Namprakai, P. and Kiatsiriroat, T. (2002). Parametric Studies of a Pulsating-Steam Water Pump, *Ambient Energy*, Vol. 23(1), January 2002, pp. 37-46.

[8] Sutthivirode, K. Namprakai, P. and Roonprasang N. (2009). A New Version of a Solar Water Heating System Coupled with a Solar Water Pump, *Applied Energy*, Vol. 86(9), September 2009, pp. 1423-1430.

[9] Roonprasang, N. Namprakai, P. and Pratinthong, N. (2009). A Novel Thermal Water Pump for Circulating Water in a Solar Water Heating System, *Applied Thermal Engineering*, Vol. 29(8-9), June 2009, pp. 1598-1605.