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Performance evaluation of bubble pump used on solar water heating system

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ABSTRACT: The application analysis of bubble pump on the domestic solar water heater system is presented. The system investigated in this study is a passive device, self pumping and self regulating. It was test to use the bubble pump on solar water heater system. The test experiment has been taken on the existed vacuum tube about the efficiency, working fluid temperature and pressure and circulated power. In order to check the working temperature and working pressure effectively, the bubble pump was test separated from the solar water heater. The equipment consists of the bubble pump, heater and heat exchanger. The main structure of bubble pump was design depend on the character of two phase flow. The complete system was instrumented to measure pressures, temperatures and their relationship with the solar radiation intensity. The theory analysis of design bubble pump has been given and the experiment result analysis has been included in the paper.

Key words: Solar water heater, Bubble pump, Pressure, Temperature

Nomenclature

A Cross-sectional area, m^2

x Dryness fraction

m Mass flow rate , kg/s

G Mass velocity, kg/m^2s

g Acceleration due to gravity, m/s^2

P Pressure, kPa

Greek letters

Σ Surface tension, N/m

α Void fraction

v Specific volume, m^3/kg

1. Introduction

The solar water heater is very commonly used nowadays. At present, the heater is mainly component of collector storage tanks and electric pump(depending on the system). The solar water heater system can be separated into two kinds: one is active which use an electric pump to circulate the heart-transfer fluid between the collector and the storage tank; the other is passive which relies on gravity and the tendency for water to naturally circulate as it is heated. Active system has much higher heat exchange efficiency but needs an additional electric pump and in order to control the pump it needs additional control panel which can stop the pump when the temperature from the heater is low enough to stop the circulation and with the help of control panel the energy can be saved. The passive system doesn't need the pump but sometimes circulation condition is not good as the active system which reduces the heat exchange efficiency. In the passive system the heat exchanger must be installed at the same level or higher then the heater to ensure the automatic circulation in the system. But due to the mass and volume of the water tank we can not sure there is a good place to install them. Compare these two systems we want to find a way to save the electronic energy and increase the heat exchange efficiency together.

The most common applications of bubble pumps are electric drip and percolating coffee makers. Bubble pumps are also known as vapor lift pumps. In the active solar water heater system which the heat exchanger is in low level then heater we have to use electronic pump as the circulated power. As we know the working fluid in solar water heater system is water and the temperature is very high. Naturally, the idea of use bubble pump on solar water heater system come out. We can use the bubble to lift the water and separate the water and gas to get a pressure difference as the circulate power.

2. Application analysis

The working temperature of bubble pump in vacuum tube solar water heater is checked on the available water heater system. It was illuminated in Figure 1.From the figure we can found that the working temperature is from the 60℃ to 80℃ ,the boiling pressure under this temperature is from 25kPa to 35kPa. To the isolate loop system it's easy to deal with the sealing problem.

2.1 Two phase flow

A two-phase flow is defined as a flow of two separate parts of a heterogeneous body or system. Vapor liquid mixtures, where the

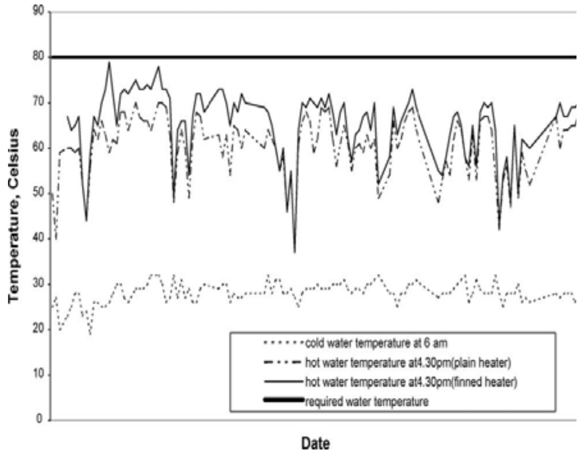


Figure 11 The temperature of vacuum tube heaters

vapor and liquid are phasesof the same fluid are referred to as two-phase single component mixtures (e. g. vapor-liquid mixture in a bubble pump) while gas-liquid mixtures where the vapor and liquid are different fluids are referred to as two-phase two component systems (e. g. air-liquid mixture in an air-lift pump). Following are some commonly used terms in two-phase flow. Dryness fraction: It is defined as a ratio of mass flow of gas to the total mass flow.

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g} \quad (1)$$

Void fraction:- The void fraction is the ratio of the gas flow cross-sectional area to the total flow cross-sectional area.

$$\alpha = \frac{A_g}{A} = \frac{A_g}{A_f + A_g} \quad (2)$$

Mass velocity: In two-phase flow literature, mass velocity is extensively used. It is the ratio of mass flow rate to the total flow cross-section area of the mixture.

$$G_g = \frac{m_g}{A} \quad (3)$$

$$G_f = \frac{m_f}{A} \quad (4)$$

The calculation of two-phase pressure drop involves some complex calculations. Various correlations and charts are used to calculate the pressure gradients developed due to friction in the flow and change in momentum.

2.2 Flow patterns

The flow patterns encountered in vertical upwards co-current flow are shown in Figure 2. Following flow patterns are encountered when a mixture of vapor and liquid flows through a vertical pipe.

1. Bubbly flow. In bubbly flow, the gas phase is distributed as discrete bubbles in a continuous liquid phase. At one extreme, the bubbles may be small and spherical and at the other extreme the bubbles may be large with a spherical cap and a flat tail. In this latter state although the size of bubbles does not approach the diameter of pipe, there may be some confusion with slug flow.

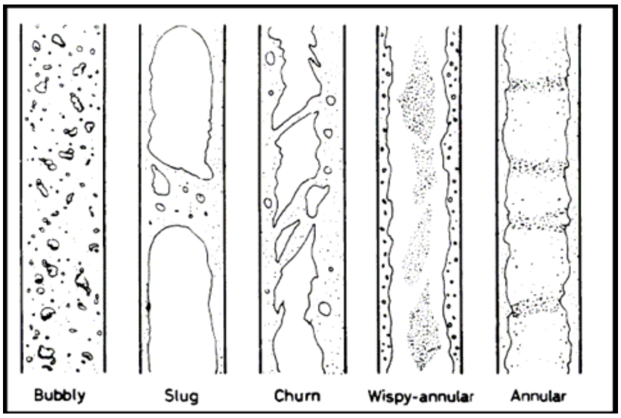


Figure 2 Flow patterns in the vertical co-current flow

2. Slug Flow. In slug flow the gas or vapor bubbles are approximately the diameter of the pipe. The nose of the bubble has a characteristic spherical cap and the gas in the bubble is separated from the pipe wall by a slowly descending film of liquid. The liquid flow is contained in liquid slugs which separate successive gas bubbles. These slugs may or may not contain smaller entrained gas bubbles carried in the wake of the large bubble. The length of the main gas bubble can vary considerably.

3. Churn flow. Churn flow is formed by the breakdown of the large vapor bubble in the slug flow. The gas or vapor flows in a more or less chaotic manner through the liquid which is mainly displaced to the channel wall. The flow has an oscillatory or time varying character. This region is also sometimes referred to as semi-annular or slug annular flow.

4. Wispy annular flow. Wispy-annular flow has been identified as a distinct flow pattern. The flow in this region takes the form of a relatively thick liquid film on the walls of the pipe together with a considerable amount of liquid entrained in a central gas or vapor core. The liquid in the film is aerated by small gas bubbles and the entrained liquid phase appears as large droplets which have agglomerated into long irregular filaments or wisps. This region occurs at high mass velocities and because of the aerated nature of liquid film could be confused with high velocity bubbly flow.

5. Annular flow. In annular flow a liquid film forms at the pipe wall with a continuous central gas or vapor core. Large amplitude coherent waves are usually present on the surface of the film and the continuous break up of these waves forms a source for droplet entertainment which occurs in varying amounts in the central gas core. In this case, as distinct from the wispy-annular pattern, the droplets are separate rather than agglomerated.

2.3 The maximum tube diameter

As already discussed, there are four flow regimes for two phases up flow in a fixed diameter vertical pipe. For low vapor flow rates, small, finely dispersed vapor bubbles will rises in a continuous liquid phase. This is a bubble flow regime. Increasing the vapor flow causes the vapor bubbles to coalesce into bullet shaped slugs of vapor which rise in the liquid phase. This is a slug flow regime.

Further increase of vapor flow causes a highly oscillatory flow with a tendency for each phase alternatively to fill the tube. This is a churn flow regime. The last flow regime, reached by even further increase of vapor flow, is annular flow regime in which the liquid forms a film around the pipe wall and the vapor rises up the core.

A bubble pump operates most efficiently in the slug flow regime. The maximum diameter tube in which slug flow occurs is given by the following equation :

$$d \le 19 \cdot \left[\frac{\sigma \cdot v_f}{g \cdot \left(1 - \frac{v_f}{v_g} \right)} \right]^{1/2} \qquad (5)$$

Where v_f and v_g are the specific volumes of the liquid and vapor respectively, and σ is the surface tension.

For a given fluid in a tube of diameter greater than that predicted by the above equation, slug flow will never occur.

$$20^{\circ}\text{C}, \qquad \sigma = 0.073 N/m$$

$$70^{\circ}\text{C}, \qquad \sigma = 0.065 N/m$$

$$d \le 19 \cdot \left[\frac{0.065 \times 1.0 \times 10^{-3}}{9.8 \times \left(1 - \frac{1.0 \times 10^{-3}}{5.0} \right)} \right]$$

$$d \le 49 mm \qquad (6)$$

As diameter increases, the friction factor decreases thereby increasing the efficiency of the pump. However, the largest possible diameter bubble pump for air-water in which slug flow will occur is predicted by equation (6) to be 49 mm.

As discussed in the previous paragraph, there are four flow regimes for two phase vertical flow in a pipe. The bubble pump model presented here assumes all flow to take place in the slug flow regime. Somewhere to the left of the maximum, transition to bubbly flow will occur while somewhere to the right of the maximum, transition to churn flow and then annular flow occurs. At first, it may seem that a larger diameter pump tube would always be advantageous. However, increasing the diameter with a fixed liquid flow will eventually cause transition from the assumed slug flow to bubbly flow.

Therefore, a bubble pump will always be assumed to operate at its maximum liquid flow rate for a fixed h/L of 0.2. If the liquid flow rate needs to increase or decrease, then the diameter and vapor flow rate of the pump will be chosen such that this liquid flow rate is the maximum. The vapor flow rate which produces the greatest liquid mass flow rate for any given diameter tube can be linearly related to the liquid mass flow rate as seen by the straight line drawn through all the maximums in Figure 2. The thermodynamic model of the cycle requires the bubble pump's heat input and mass flow rates. The following linear equation is useful in this study.

$$m_{1v} = 0.0426 \cdot m_2 \qquad (7)$$

The liquid mass flow rate in equation (7), m_{1v}, is the mass flow of vapor in kg/min

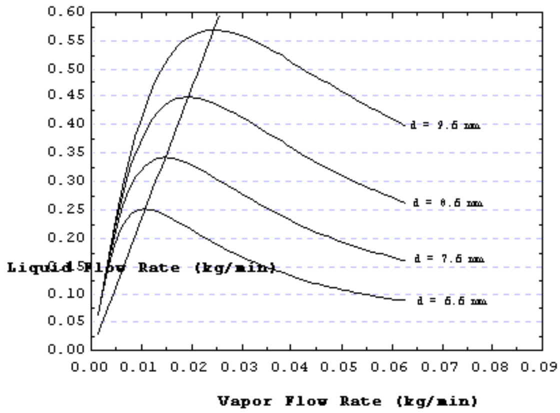


Figure 3 Bubble pump performance for varying tube diameter and a fixed h/L=0.2

leaving the bubble pump, and m_2, is the mass flow of liquid in kg/min leaving the bubble pump. The complete description of the theoretical model and its computer implementation is described by Bahomed (1995).

3. Experimental design

The bubble pump is a glass tube 65 mm in diameter mounted vertically. The total height of the pump is 770 mm. In order to find a perfect length of the separate part of the bubble pump we divide the tube into two part, the distance from interlayer to the top is 530mm. The core tube in the middle where the slug boil occurs is 11 mm in diameter. The other tube in side the pump is 5 mm in diameter account for the mass balance and the space. The structure of bubble pump is illustrated in Figure 4. Working fluid in the bubble pump is 40% water and 60% propylene glycol. The working temperature is 338K-348K and working pressure is 25kpa. The temperature is depend upon the solar water heater, commonly the fluid temperature is from 338K-348K.

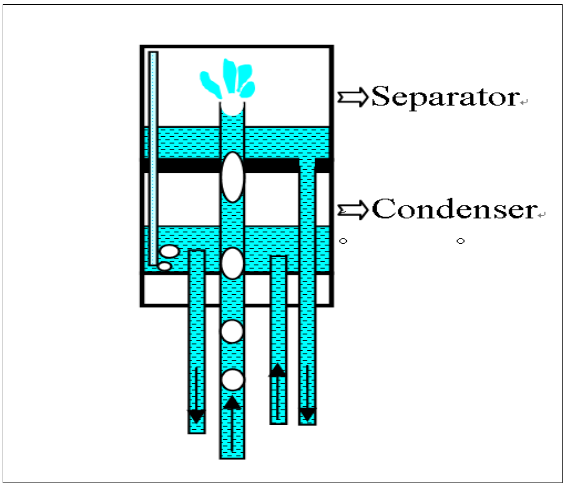


Figure 4 the structure of bubble pump

Based on the theoretical analysis, a compendious cycle for the bubble pump system was constructed on a Temperature versus Enthalpy diagram, Fig 5. Referring to this figure, process 1-2 represents the energy absorb in the heater section. From state 2 to 3 the pressure is reduced with a corresponding lowering of the saturation temperature, state 3. In the separator section of the bubble pump, the two fluid phases are separated producing two streams at the saturated liquid and vapour states. The quality of the mixture in the separator is assumed to be defined by point 3. Saturated liquid exits the separator (state 3a) and enters the heat exchanger where it is cooled to point 5. This fluid exits the heat exchanger at state 5 and is mixed in the condenser of the bubble pump with vapor from the separator at state 4. It then exits the condenser as a sub-cooled liquid (state 6) and flows back to the heater inlet at state 1 where it is reheated back to state 2, completing the cycle.

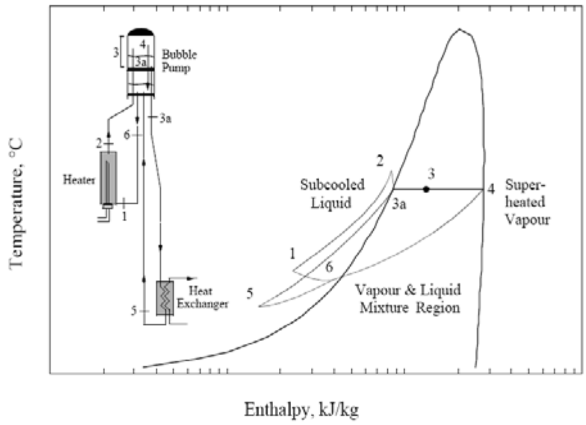


Figure 5 Thermodynamic cycle of bubble pump

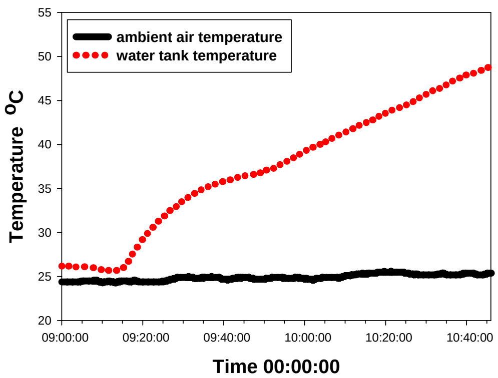
4. Experiment result analysis

The first target for experiment is to find the proper location to separate the bubble pump in two to parts, the separator and condenser.

At the mean time, experiment helped to find the lowest circulated temperature at the assumed working condition, also from the experiment the sealing problem can be checked.

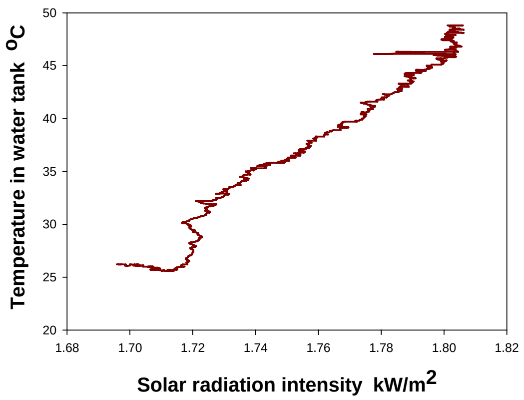
In the Experiment , we applied 6 temperature sensors in order to measure the temperature

of separator, condenser, ambient, water tank, heat exchanger inlet and heat exchanger out let. Also we install two pressure sensors on the separator and condenser. A mass flowmeter was installed on the outlet of heat exchanger and the solar radiation intensity gage was installed on the rooftop.
The water tank has an volume of 200L. From Graph.1 we can see that the temperature of water tank increased after worked two hours in a sunny day.



Graph 1 the temperature in water tank

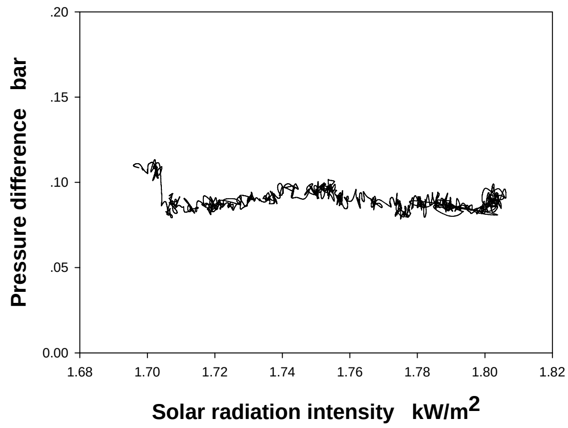
The water temperature of water tank is related to the solar radiation intensity, they have a linear relationship can be confirmed from Graph 2



Graph 2 temperature related with solar radiation intensity

Pressure difference which produced by the bubble pump was stable to the solar radiation intensity. Which can be illuminate by Graph 3.

Graph 3 pressure difference related with solar



radiation intensity

5. Conclusion

An application analysis and the experimental test apparatus has been constructed to characterize the performance of a bubble pumped solar domestic hot water package. Experiment result analysis of the system, coupled with a thermodynamic cycle for the device indicated that the bubble pump can be applied on the solar water heater system.

Acknowledgement

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