PERFORMANCE EVALUATION OF BUBBLE PUMP USED IN A PASSIVE SOLAR WATER HEATER 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 flow-rates at various locations. The theory analysis of design bubble pump has been given and the experiment design has been included in the paper.

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.

2. APPLICATION ANALYSIS

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 vapor and liquid are phases of 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.

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g} \tag{1}$$

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

$$a = \frac{A_g}{A} = \frac{A_g}{A_f + A_g} \tag{2}$$

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.

$$G_g = \frac{m_g}{A} \tag{3}$$

$$G_f = \frac{m_f}{A} \tag{4}$$

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 was shown in Figure 1. 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.
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.

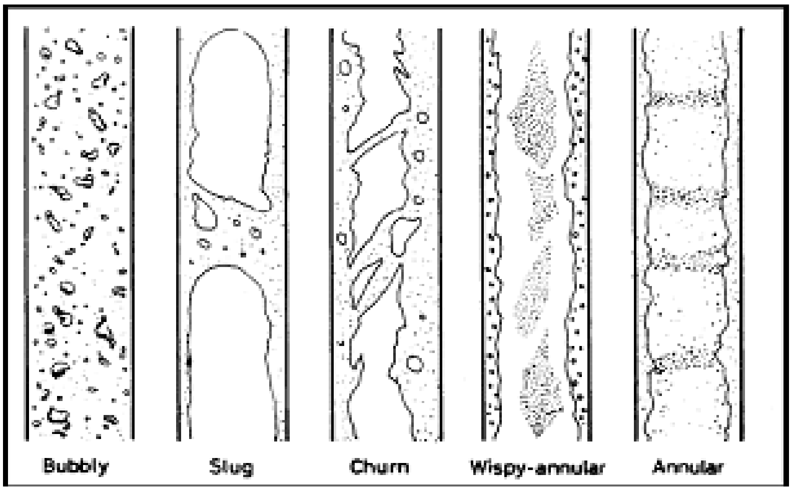

Figure 1– Flow patterns in the vertical co-current flow

4. Wispy annular flow. Wispy-annular flow has been identified as a distinct flow pattern.

5. Annular flow. In annular flow a liquid film forms at the pipe wall with a continuous central gas or vapor core.

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:

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

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°C, $\sigma = 0.073 N/m$

70°C, $\sigma = 0.065 N/m$

$$d \leq 19 \cdot \left[\frac{0.065 \times 1.0 \times 10^{-3}}{9.8 \times \left(1 - \frac{1.0 \times 10^{-3}}{5.0}\right)} \right]^{1/2} \tag{6}$$

$$d \leq 49mm$$

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.

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 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.

$$m_1 = 0.0426 \cdot m_2 \qquad (7)$$

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

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. Experiment scheme is illuminated in Figure 2.

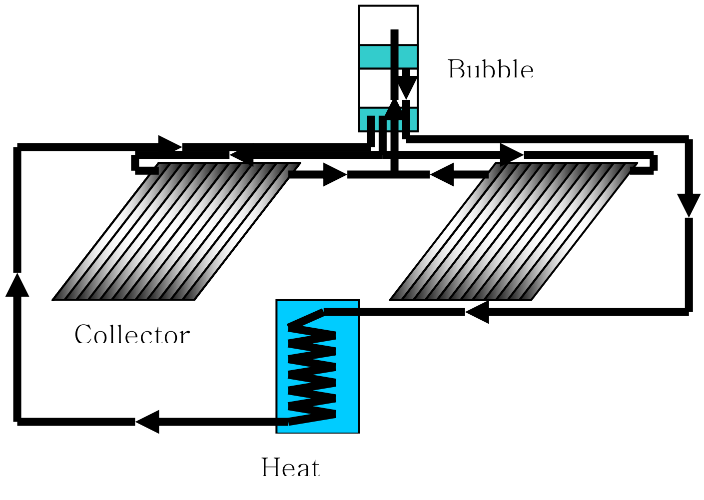

Figure 2–The scheme of experiment

4. CONCLUSION

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

ACKNOWLEDGEMENTS

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