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Numerical simulation of bubble's Motion in Vertical Tube

Li Xuesong, Hanshik Chung*†, Hyomin Jeong*
Department of Mechanical and Precision Engineering, Gyeongsang National University, Tongyeong 650-160, Korea

*School of Mechanical and Aerospace Engineering, The Institute of Marine Industry, Gyeongsang National University, Tongyeong 650-160, Korea

ABSTRACT: The problem was derived from a simple process in solar water heating system. In a new designed electro less separated system we involved a kind of bubble pump. Beside experiment analysis, numerical simulation of the core of bubble pump is also very important. In this paper we investigated the motion of bubbles in vertical tube in two dimensions. The heat and mass transfer was simulated. The result of numerical simulation give a significant help of optimize design of bubble pump.

Key words: bubble pump, two-phase flow, bubble flow, churn flow

1. INTRODUCTION

Compare with the single phase flow, gas-liquid two phase flow is more complicated because the deformable interfaces which shape and distribution determined the characteristics of the flow. But many effort has been madeto develop the numerical methods for simulate gas-liquid flow with deformable interfaces. The volume-of- fluid (VOF) method is one possible way to track the moving interface using the transport equation for volume fraction occupied by each phase. But it's limited to simulate the immiscible two fluids. It can predict the shape of interface between fluids accurately.

For solar heating of domestic hot water, two common system types are thermo-syphon and pumped. In the thermo-syphon system, a storage tank is placed above the collector. As the water in the collector is heated, it will rise and naturally start to circulate around the tank. This draws in colder water from the bottom of the tank. This system is self-regulating and requires no moving parts or external energy, so is very attractive. Its main drawback is the need

† Corresponding author
Tel.: +82-55-646-47661; fax: +82-55-646-3188
E-mail address: lixuesong19840624@yahoo.com.cn

for the tank to be placed at a level higher than the collector, which may prove to be physically difficult. A pumped system uses a pump to circulate the water, so the tank can be positioned independently of the collector location. This system requires external energy to run the pump (though this can be solar, since the water should only be circulated when there is incident sunlight). It also requires control electronics to measure the temperature gradient across the collector and modulate the pump accordingly.

According to the above statements, compact system can automatically cycle without the need for other energy input, but the lack of the freedom of installation, and the roof load than great. Separated-system with sufficient freedom, but must use the circulating pump, the need to import electricity, while simultaneously increasing control of the circulating pump control panel, due to the importation of electricity, solar energy cannot rely on a single drive system, in some is restricted. For examples, in remote mountain areas without electricity and operations at sea the electric power is not available and so on. As a bubble pump air-pumped pump, we can use the mobile water bubbles up from the lower elevated to a height, so as to achieve the purpose of upgrading cycle pressure. Therefore, the bubble pump can be applied to split-type solar water heating system to replace the electric circulating pump, in the application of solar energy only at the same time to achieve the purpose of automatic cycle.

2. BUBBLE PUMP

2.1 Bubble Pump Structure

The bubble pump is steel less metal tube 70 mm in diameter mounted vertically. The total height of the pump is 800 mm. In order to find a perfect length of the separate part of the bubble pump we divide the tube into two parts, the distance from interlayer to the top is 600mm. The core tube in the middle where the slug boil occurs is 30 mm in diameter. The other tube inside the pump is 2mm in diameter account for the mass balance and the space.

Working fluid inside of bubble pump is water, the core tube was connected with solar collector and the low part of this pump was connect with heat exchanger by two tube. This lower part named as condenser by its function, and the higher part named separator.

2.2 Core 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.

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 to be 49 mm.

3. EXPERIMENT RESULT

The experiment was set in a $3m^2$ vacuum tube heat pipe solar collector which has a efficiency around 80%. Solar radiation intensity was measured by an insolation meter. Figure 1 shows the result from 7:00 to 9:00 in the morning in summer.

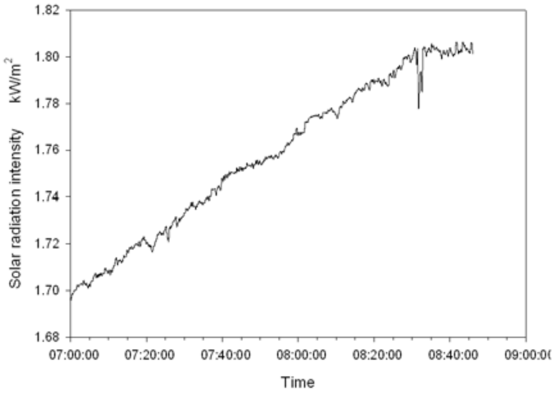

Figure 1: Solar radiation intensity

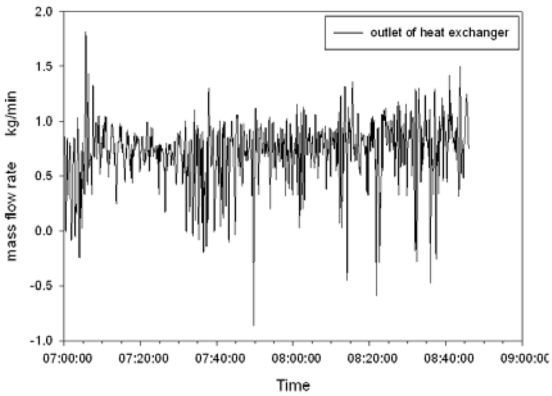

Figure 2: Mass flow rate

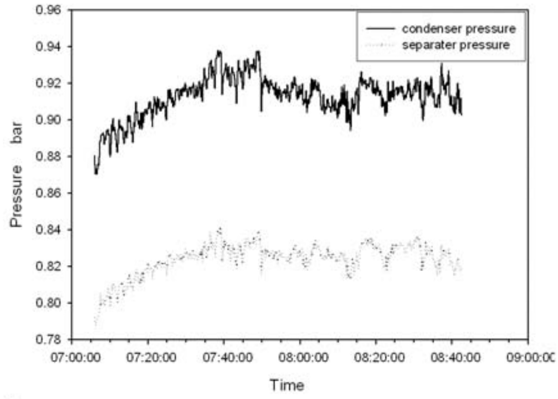

Figure 3: Pressure in bubble pump

During this time mass flow rate was shown in Figure 2, it has a value about 0.6kg/min. Since all the circulation water in this close loop was initially pump by the bubble pump, flow rate is also core tube water-lift efficiency.

The circulation power was generated by bubble pump. The pressure and pressure difference in bubble pump illuminated it which can be seen from Figure 3 and Figure 4.

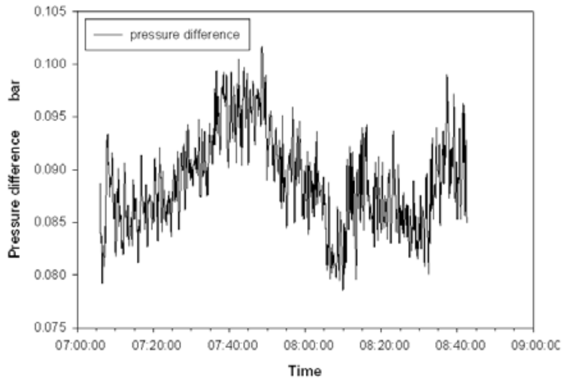

Figure 4: Pressure difference in bubble pump

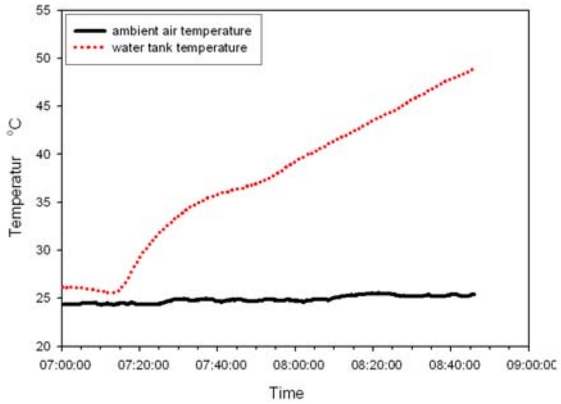

Figure 5: Water tank temperature

The target of applying bubble pump in solar water heating system is developing a self-circulating system conserving the solar energy in a water tank which supplied to the consumer. Figure 5 shows the temperature in water tank. This tank volume is a 50 L barrel with heat isolate layer. In this two hours working time, the system have efficiency about 43% which can increase if reduce the heat-loss in water pipe.

4. NUMERICAL SIMULATION

Numerical simulation in this research is focus on water delivery ability of bubbles, especially the Taylor bubbles in slug flow. Bubbles generated in solar collector when the water was heated and the bubble's size is related with the boiling condition. While the water delivery by upward moving bubbles has the best efficiency in slug flow region as mention above. So the diameter of core tube is the critical factor to ensure a slug flow.

Figure 6: Initial phase distribute of bubbly flow

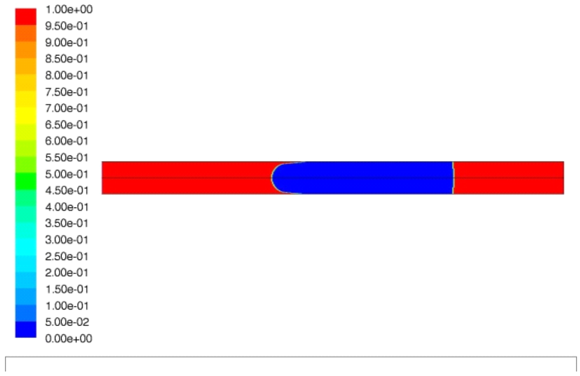

Figure 7: Initial phase distribute of slug flow

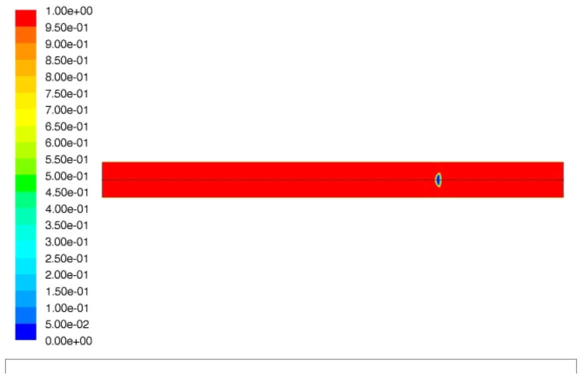

Figure 8: Initial phase distribute of slug flow

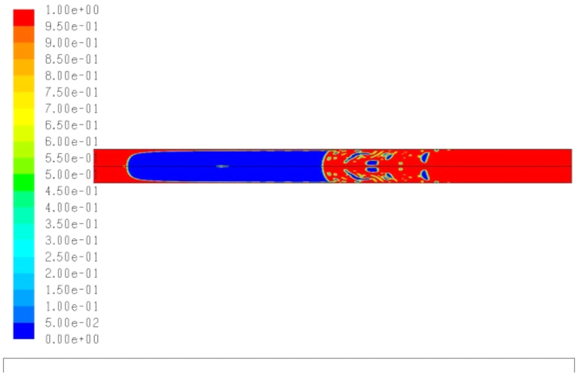

Figure 9: Initial phase distribute of slug flow

In numerical simulation, two dimensional grids were applied and different size bubbles flow in the same diameter tubes, 15mm. The tube length is 500mm. The initial regions of bubbles are 27mm^2 and 5000mm^{2}showed as Figure 6 and Figure 8. Red colour is water and blue colour is bubbles. This initial shape of bubbles will change as the flowing in the tube.

After 0.7s flow time both bubbles shape change a lot and they were showed in Figure 8 and Figure 9. Bubbly flow shape was compared with Zhang's experiment photo. And the slug flow was compared with F.Viana's experiment result. The bubbly tail from numerical analysis is similar with the experiment photograph.

Compared velocity regime of bubbly flow and slug flow from Figure 10 and Figure 12, it's can be found that in a bubbly flow column the liquid speak near to zero and the bubbles has a maximum velocity about 0.34m/s. The directions of these velocities are showed in Figure 11 with mainly upward vectors. Slug flow has a different velocity in magnitude. The Taylor bubble has a velocity around 0.48m/s and the liquid has a velocity about 0.35m/s, showed in Figure 14. The maximum velocity is the downward liquid film near the wall which values is 1.43m/s. velocity. Generally, the liquid velocity is upward together with the bubbles in a slug flow since the big velocity downward flow is not a significant amount. But in a bubbly flow, since the bubble is relatively small, the buoyancy is from air-phase is not enough to lift water.

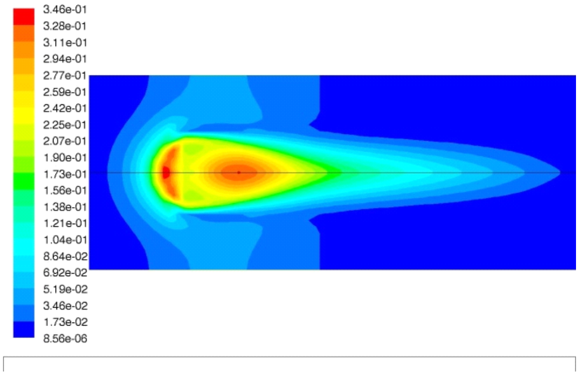

Figure 10: Velocity regime of bubbly flow

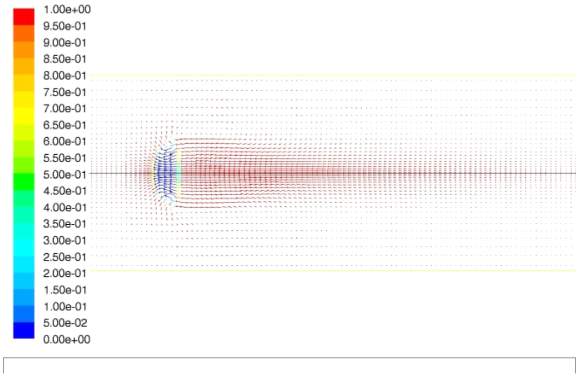

Figure 11: Velocity vector regime of bubble flow

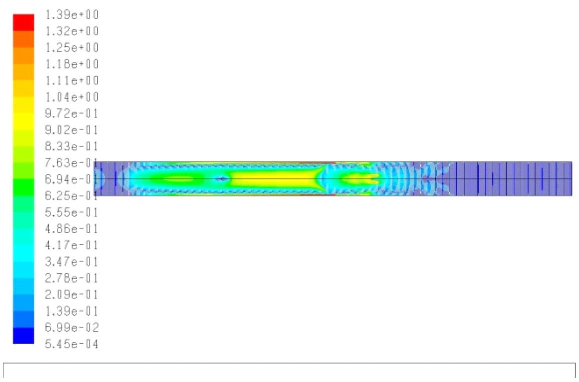

Figure 12: Velocity vector regime of slug flow

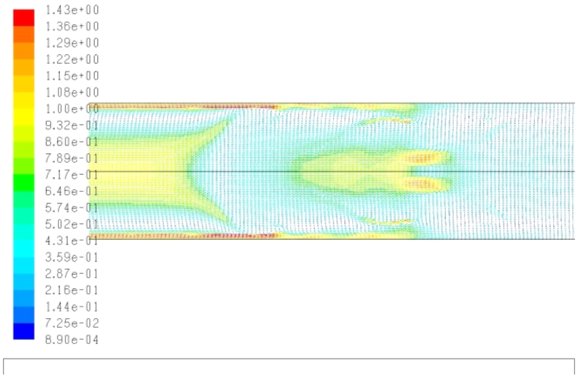

Figure 13: Velocity vector regime at the tail of slug flow

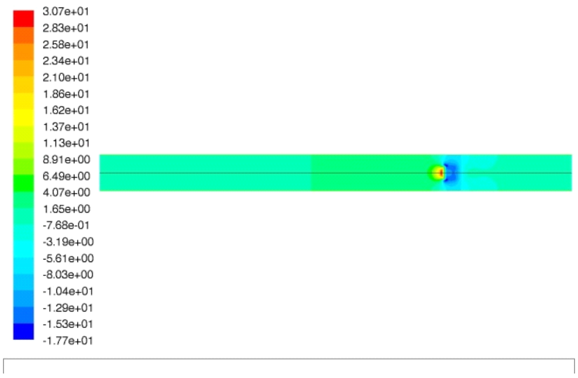

Figure 14: Pressure regime of bubbly flow

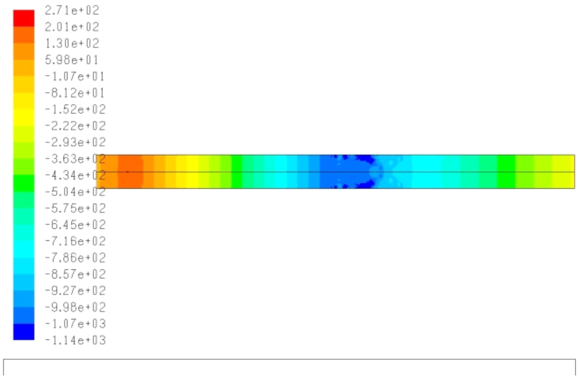

Figure 15: Pressure regime of slug flow

The pressure regime of bubbly flow and slug flow were showed in Figure 14 and Figure 15. The pressure distribute inside of column is not uniform. In a bubbly flow column, maximum and minimum values difference is about 48.4pascal. The difference in slug flow is about 1411bar. From Figure 15 it can be found the high pressure part is connect with separator and low pressure is occurred in the middle of simulation region, this force drag the liquid up from collector to bubble pump. Also, this value is near to the experiment result from Figure 4.

5. 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.

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