

Bubble Pump used in Passive Solar Water Heater System

Li Xuesong¹, HanShik Chung² and HyoMin Jeong³

¹Department of Mechanical and Precision Engineering, Gyeongsang National University, Tongyeong, Korea, lixuesong19840624@yahoo.com.cn

²School of Mechanical and Aerospace Engineering, Gyeongsang National University, Tongyeong, Korea, hschung@gnu.ac.kr

²School of Mechanical and Aerospace Engineering, Gyeongsang National University, Tongyeong, Korea, hymjeong@gnu.ac.kr

ABSTRACT: The problem was derived from a simple process in solar water heating system. In a new designed electric less split system we involved a kind of bubble pump. The main structure of bubble pump was design depend on the character of two phase flow. Beside experiment analysis, numerical simulation of this pumping action in the core tube of bubble pump is very important. In this paper we investigated the motion of bubbles in vertical tube in two dimensions. The testing experiment has been taken on the existed vacuum tube on the efficiency, temperature, pressure and circulates power. The heat and mass transfer was simulated. The result of numerical simulation gave worthful help of optimize design of bubble pump. The optimal dimension design of core tube inside of bubble pump is presented.

Keywords: bubble simulation, solar water heater, two phases flow

NOMENCLATURE

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 made to 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 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.

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. 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.

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.

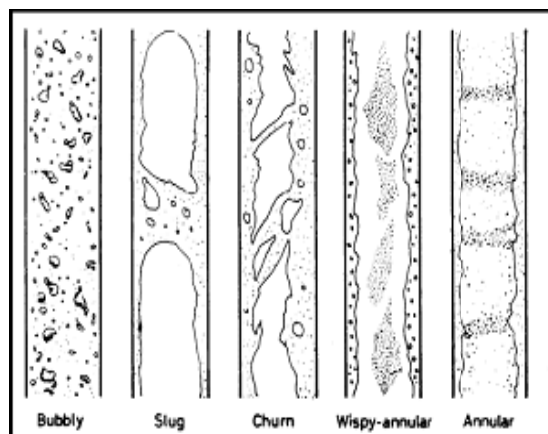


Figure 1: Flow pattern of vertical columned tube

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.

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 entrainment which

occurs in varying amounts in the central gas core.

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 2 mm 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 3m² vacuum tube heat pipe solar collector which has a efficiency around 80%. Solar radiation intensity was measured by an insolation meter. Fig 2 shows the result from 7:00 to 9:00 in the morning in summer.

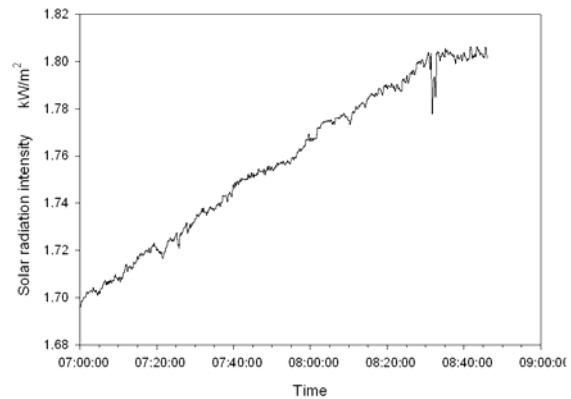


Figure 2: Solar radiation intensity

During this time mass flow rate was shown in Fig 3, 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.

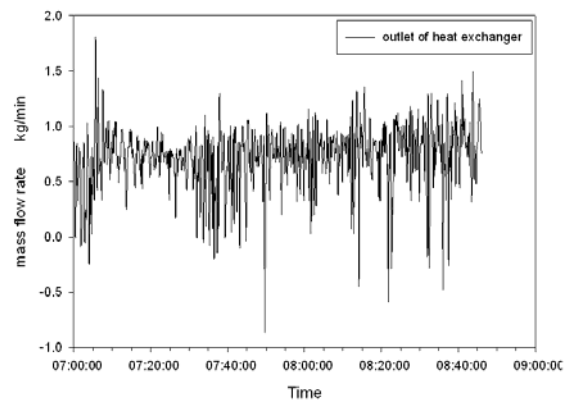


Figure 3: Mass flow rate

The circulation power was generated by bubble pump. The pressure and pressure difference in bubble pump illuminated it which can be seen from Fig 4 and Fig 5.

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. Fig 6 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.

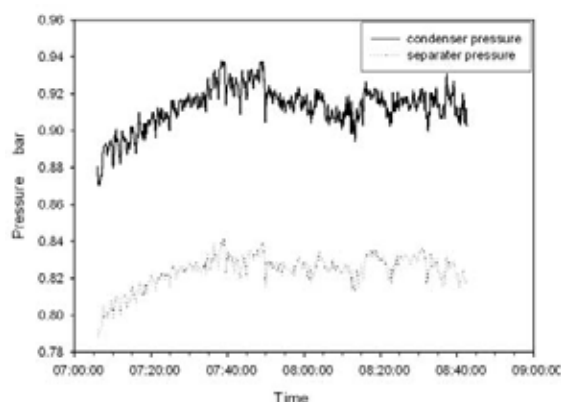


Figure 4: Pressure in bubble pump

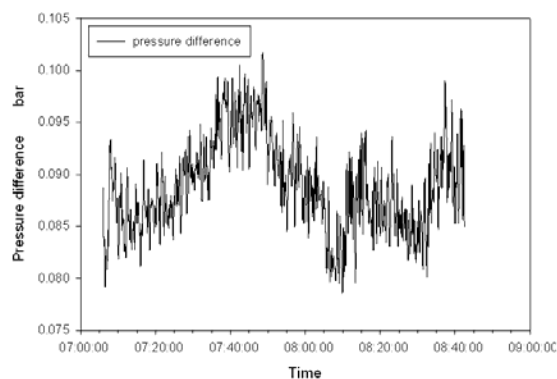


Figure 5: Pressure difference in bubble pump

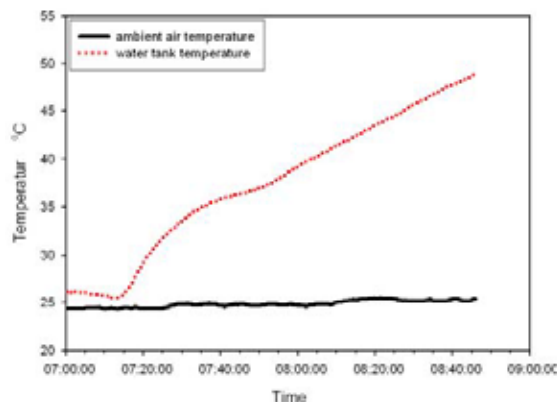


Figure 6: Water tank temperature

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.

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 Fig 7 and Fig 8. Red colour is water and blue colour is bubbles. This initial shape of bubbles will change as the flowing in the tube.



Figure 7: Initial phase distribute of bubbly flow

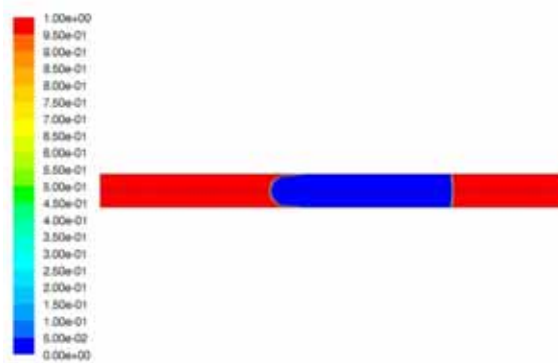


Figure 8: Initial phase distribute of slug flow

After 0.7s flow time both bubbles shape change a lot and they were showed in Fig 9 and Fig10. 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.

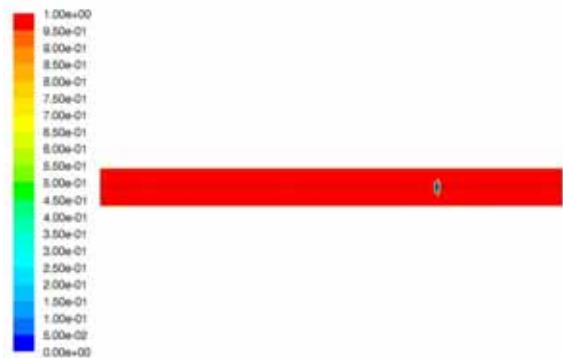


Figure 9: Initial phase distribute of slug flow

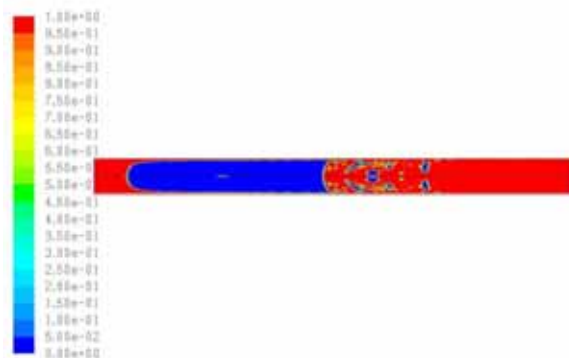


Figure 10: Initial phase distribute of slug flow

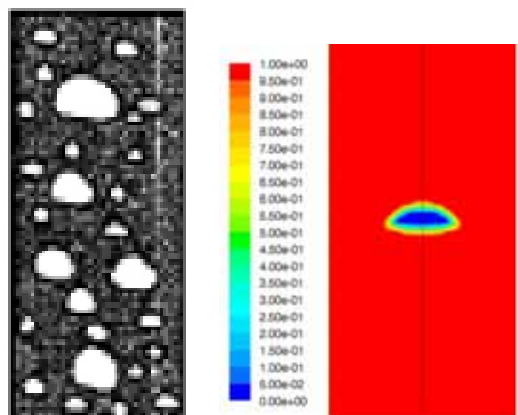


Figure 11: Flow regime in a bubbly column (From Zhang et.al., 1997)

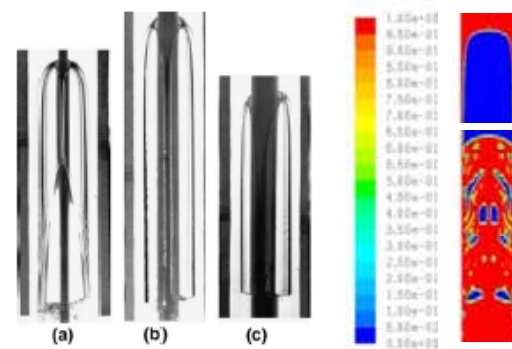


Figure 12: Flow regime in a slug column (Photographs (unpublished, courtesy of F. Viana and R. Pardo) diameter (ID): (a) water (1 mPa s, 997 kg/m³), ID = 12.7 mm; (b) water, ID = 25.4 mm; (c) water, ID = 38.1 mm.)

Compared velocity regime of bubbly flow and slug flow from Fig 13 and Fig 15, 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 Fig 14 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 Fig16. 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.

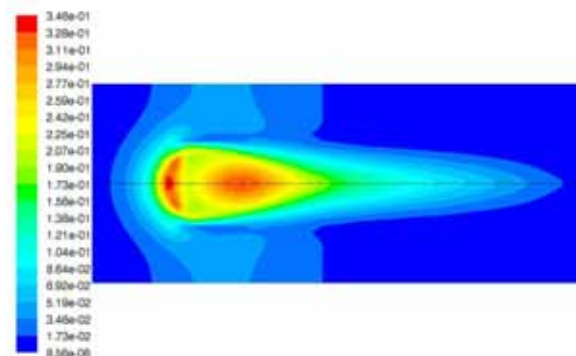


Figure 13: Velocity regime of bubbly flow

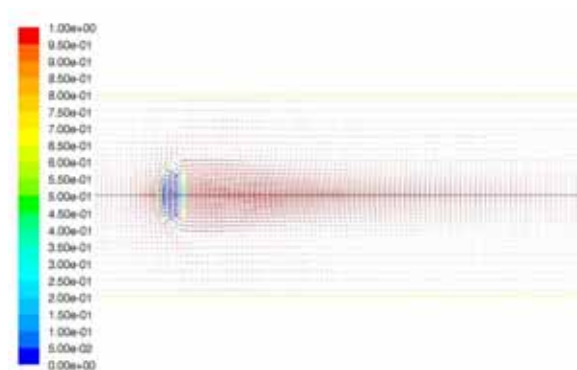


Figure 14: Velocity vector regime of bubble flow

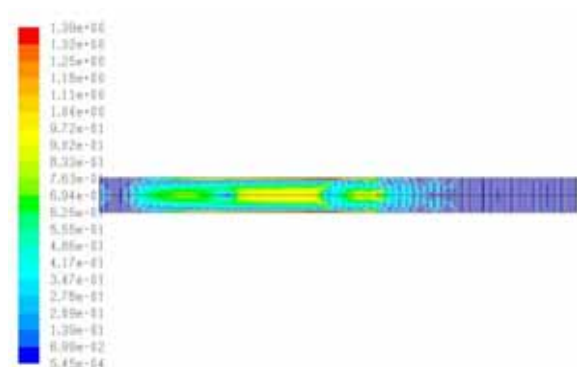


Figure 15: Velocity vector regime of slug flow

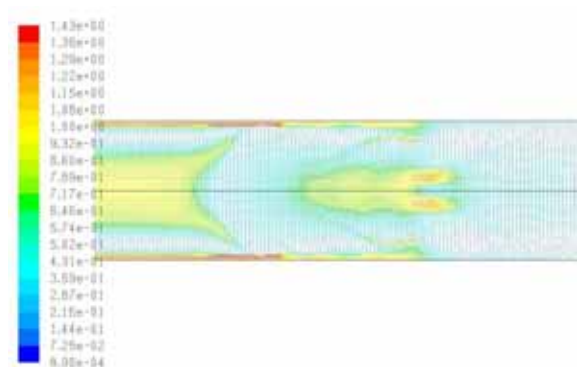


Figure 16: Velocity vector regime at the tail of slug flow

The pressure regime of bubbly flow and slug flow were showed in Fig 17 and Fig 18. 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 Fig 18 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 Fig 5.

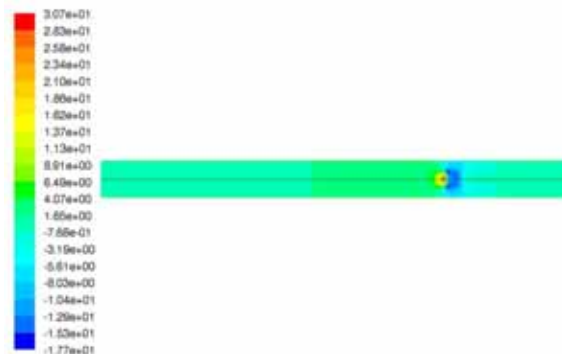


Figure 17: Pressure regime of bubbly flow

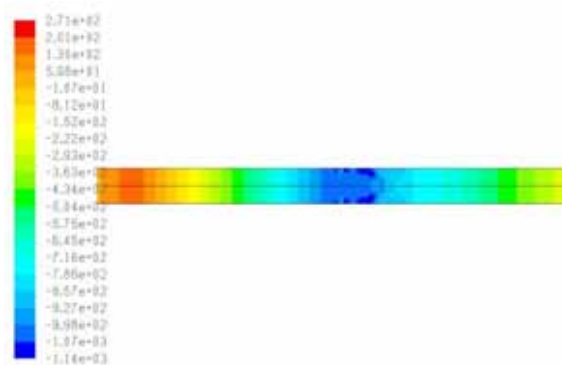


Figure 18: Pressure regime of slug flow

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.

ACKNOWLEDGEMENT

This research was financially supported by the 20 Years Future Project of Green Energy City - JinHae and the second-phase of Brain Korea 21 Project.

REFERENCES

- [1] Wallis G. B, 1969, "One Dimensional Two-Phase Flow" , McGraw Hill, New York.
- [2] Chisholm D., 1983, "Two-phase Flow in Pipelines and Heat Exchangers " , George Godwin, London and New York.
- [3] Bahomed TO, 1995, "Thermal Modeling of The Bubble Pumped Solar Domestic Hot Water System" Master's thesis, Dept. of Mechanical Engineering, Queen's University, Canada.
- [4] Cataford RJ, Harrison SJ, 1988, "Performance Monitoring of a Bubble Pumped SDHW System", Proceeding of the Solar '88 conference, June 1988, MIT, Cambridge, Mass., pp. 485-490.
- [5] DeBeni G, Friesen R, 1985, "Passive Downward Heat Transport: Experimental Results of a Technical Unit. Solar Energy", Vol. 34, No. 2, pp. 127-134.
- [6] Hoffman EW, 1985, "The Bubble Action Pump Solar Heating System", Montreal, Canada.
- [7] Sorensen W, 1987, "The Bubble Pumped D.H.W. System", ISES Solar World Congress, Hamburg, F.R.G.
- [8] Zhang, J.P., Grace, J.R., Epstein, N., Lim, K.S., 1997. Flow regime identification in gas – liquid flow and three-phase fluidized beds. Chemical Engineering Science, 52, 3979–3992.
- [9] T. Funada, D.D. Joseph, T. Maehara, S. Yamashita, Ellipsoidal model of the rise of a Taylor bubble in a round tube. In J Multiphase flow, Shizuoka, Japan