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https://doi.org/10.15017/17309

出版情報：九州大学大学院総合理工学報告. 15 (2), pp.209-215, 1993-09-01. 九州大学大学院総合理工学研究科
バージョン：

九州大学大学院総合理工学研究科報告
第15巻 第2号 209-215頁 平成5年9月

Engineering Sciences Reports, Kyushu University
(KYUSHU DAIGAKU SOGORIKOGAKU KENKYUKA HOKOKU)
Vol. 15, No. 2, pp. 209 - 215, SEPT. 1993

On the Mechanism of the Geysering in a Double Tube Thermosyphon

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(Received May 31, 1993)

An experimental study has been carried out to investigate into a two-phase flow instability called the "geysering". The regions are divided by the frequency and amplitude of pressure fluctuations caused by periodical bubble nucleations and its expansions. Experiments are conducted with a double tube closed thermosyphon which is made of glass to make visual observation possible. As the working fluid R113 is adopted. The mechanism of the geysering is described based on the visual observation of the phenomena as well as on the transients of temperature distributions of the outer tube.

1. Introduction

Instabilities may make problems in maintaining smooth and safe operation of heat exchange systems for industrial applications, such as the boilers or other two-phase flow equipments. Chexal et al.[1] defined a map of instability from his experimental study with a single-channel natural circulation loop. When freon is used as the working fluid, an instability, indicated by periodical explosive vapor formations in the test tube, occurs at pressure 0.1 MPa, heat fluxes from about 3 kW/m^2 to 9 kW/m^2. This phenomenon is called the geysering. Other instabilities also occurred at lower heat fluxes. Casarosa et al.[2] showed experimentally the existence of the geyser effect in heat transfer process.

The geysering is a relaxation instability characterized by the periodic expulsions resulting from the sudden vaporization. This may occur in a vertical liquid column subjected to low heat fluxes[3]. Bezrodnny and Elekseyenko[4] pointed out that the phenomena occur at low pressures with large superheats. In these conditions the large specific volume of vapor results in the generation of large bubbles. Casarosa and Latrofa[2] showed that at low pressures the time intervals of bubble nucleations are large, which decrease when the heat flux is increased.

The aim of this work is to study experimentally the mechanisms of the geysering in a double tube closed thermosyphon, and to define the map of the silent phase (without bubble), the geysering and the steady boiling phase.

2. Experimental method

The experimental apparatus is shown in **Fig. 1**. This is a closed double tube ther-

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mosyphon which consists of a 8 mm inner dia. tube and a 18 mm outer dia. tube which has 1057 mm height. All parts of this apparatus: an evaporator, a condenser and an adiabatic part are made of glass. The outer tube of the evaportor is wound with a heater element heated by electricity to heat the fluid filled inside. Temperature was measured intermittently every 6 seconds at 15 points with a Yokogawa data acquisition system, and at the bottom, the middle and the top positions also were monitored continuously with a pen recorder. A pressure gauge was installed at the top end of the condenser and was connected to the pen recorder. To keep the inner tube at the center position a spacer was put at the upper part and a holding bed made of porous material was put at the bottom.

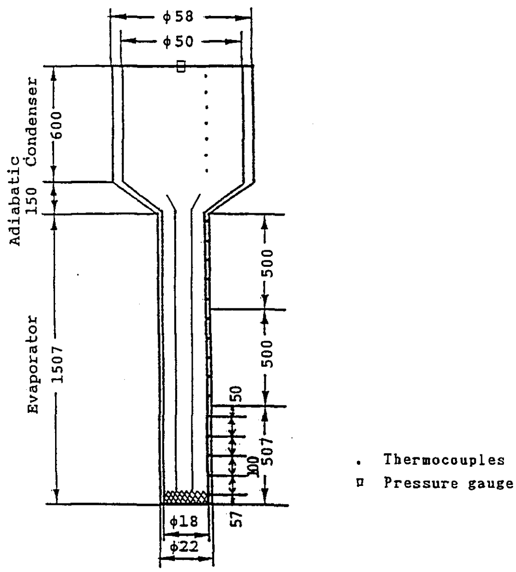

Fig. 1 Experimental apparatus.

In the experiment, the system was evacuated, then the evaporator was filled from the bottom with 852 ml Freon R 113 as the working fluid. The filling percentage or the volume percentage filled with liquid was 100%. A series of experiments was started by supplying heating power to the evaporator controlled by a regulator with condenser being inactive. The heating power was set up from 18 W (200 W/m^2) and was increased step by step up to 255 W (3000 w/m^2). When the condenser had reached the desired pressure, the cooling system began to be operated. Cooling water flow was controlled to keep the vapor pressure in the condenser at its silent condition constant. The pressure in the condenser was varied from 0.039 MPa to 0.083 MPa.

3. Experiment results and discussion

During the experiment the phenomena inside the thermosyphon were visually observed. Bubbles were observed to form at different levels depending on the heat flux and the pressure.

The phenomena observed in this experiment can be divided into three stages. The first is a silent stage or the one without formation of bubbles. In this case is heat absorbed by liquid with its internal energy being increased, then the energy is released at the top surface where the liquid evaporates. The energy is not large enough collected in the evaporator to increase the internal energy so that the maximum temperature reaches the saturation temperature or the temperature difference between liquid and the wall surface is lower than needed to produce bubbles. The second is the geysering. We define the geysering as a succession of intermittent boiling initiations followed by expulsions of the liquid to the condenser part. The third is a steady boiling phase. Based on this classification, a map is drawn in **Fig. 2** to discriminate these phases. It seems that a border lies at pressure 0.042 MPa, heat flux 544 W/m^2 and at 0.058 MPa, heat flux 296 W/m^2 which separates the silent phase from the geysering, and at pressure 0.051 MPa, heat flux 1866 W/m^2 and at pressure 0.075 MPa, heat flux 411 W/m^2 which separates the geysering from the steady boiling phase. In this figure, it is shown that the geysering occurs at lower heating powers for higher pressures.

A sketch of the phenomenon observed inside the thermosyphon at a heat flux 676 W/m^2, pressure 0.043 MPa is shown in **Fig. 3a**. First, a bubble is formed at the bottom inside the inner tube; it expands in like a cone shape which pushes the liquid in the inner tube upward and the liquid in the outer tube downward. Then after a short time, numerous bubbles are formed along the evaporator wall which rush to the evaporator. This stage continues during about 10 seconds. The ending of this process is a few bubbles rise in the outer tube.

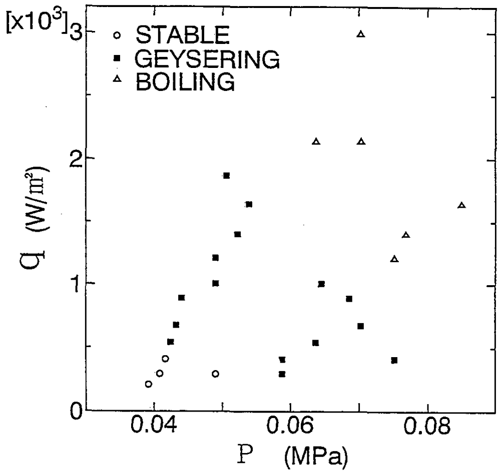

Fig. 2 Flow regime of geysering.

Fig. 3b shows an observation inside the thermosyphon at a heat flux 1007 W/m^2 and a pressure 0.049 MPa. A bubble is formed at about 400 mm from the bottom and while it moves upward the bubble expands upward and downward. Since the expansion is very fast the upper liquid is pushed upward strongly to the condenser to cause a phenomenon like an explosion. As a result the vapor pressure increases spontaneously. Then the temperature and the pressure in the condenser decrease as the liquid is cooled by the water cooler, and this process finishes followed by a silent condition. On the other hand the lower liquid is pushed downward, passes through the porous material in the bottom and flows into the inner tube in the upward direction. Before this liquid reaches the condenser, cold liquid from the condenser falls down to push the lower liquid downward.

The process of the bubble expansion can be described as follows. As the upper liquid

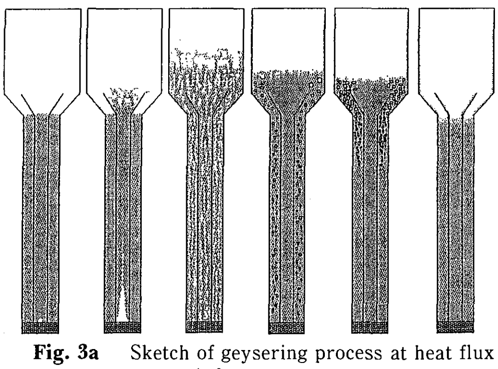

Fig. 3a Sketch of geysering process at heat flux 676 W/m^2 and pressure 0.0433 MPa.

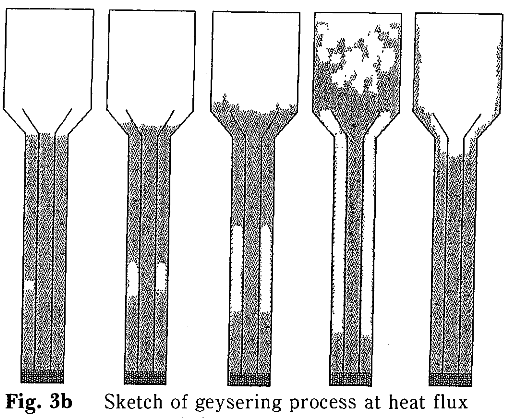

Fig. 3b Sketch of geysering process at heat flux 1007 W/m^2 and pressure 0.0490 MPa.

moves upward the static pressure decreases, which results in the bubble expansion[3]. At the same time, because of the upward movement of the bubble, the liquid around it flows downward to form a thin film attached on the inner wall. This condition improves heat transfter characteristics and makes bubble expansion faster. At lower heating powers the phenomenon is similar but the time period becomes longer.

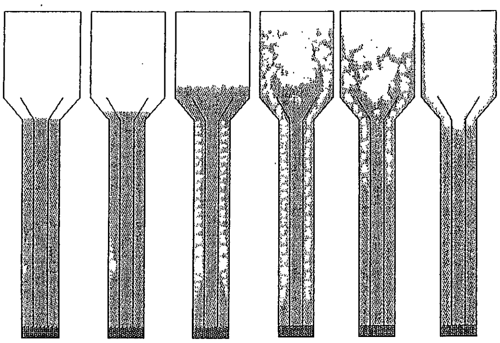

Fig. 3c Sketch of geysering process at heat flux 1866 W/m^2 and pressure 0.0507 MPa.

A sketch of the phenomenon inside the thermosyphon for a heat flux 1866 W/m^2 the pressure 0.051 MPa is shown in **Fig. 3c**. Formation of a bubble initiates at around a position a little lower than the middle. But almost at the same time bubbles form along the upper part and the lower bubble does not expand as shown in **Fig. 3b**. A little movement of the first bubble accelerates the production of the next bubble near above and this new bubble accelerates the production of the next bubble, and so on. Some new bubbles are also observed to form at the lower part. It seems that boiling begins spontaneously when the first bubble is formed.

The pressure in the condenser is in phase with the temperature in the condenser and is out of phase with the temperature in the middle part of the evaporator, whereas the temperature of the evaporator at the up end is little late than the condenser temperture. When the temperature around the middle part of the evaporator reaches its maximum, the first bubble outbreakes. The upward movement of this bubble increases heat transfer which causes the decrease of wall temperature. As the bubble expands, the pressure as well as the temperature in the condenser increases.

According to the Casarosa and Latrofa's experiment, a the heating power is increased with the pressure in the condenser kept constant, the frequency of the geysering increases but the intensity or the amplitude of the fluctuation of the mean wall temperature is almost unchanged. Nakanishi et al.[5] studied on the characteristics of a loop type thermosyphon and reported that when the heating power was increased the amplitude of the pressure oscillation in the evaporator increased.

In this study it is found that the amplitude of the pressure fluctuation in the condenser is not constant when the heating power is increased. Between the cases of heat flux 1007 W/m^2 and 1211 W/m^2 the difference of amplitude of the pressure fluctuation is about 20%. As was described before, at high heating powers bubble did not expand but at low heating powers boiling started soon after the initial bubble was formed. This is the reason why the pressure fluctuation is smaller in higher heating powers. When the heat flux is kept constant the condenser pressure fluctuations become smaller as the condenser pressure at silent condition is increased. If the pressure in the condenser is increased, with the heat flux in the evaporator kept constant, the fluctuation of the wall temperature becomes bigger.

Fig. 4 shows the temperature distribution for the cases of heat flux 1007 W/m^2 and heat flux 1211 W/m^2. It is shown that the maximum temperature occurs at about the same

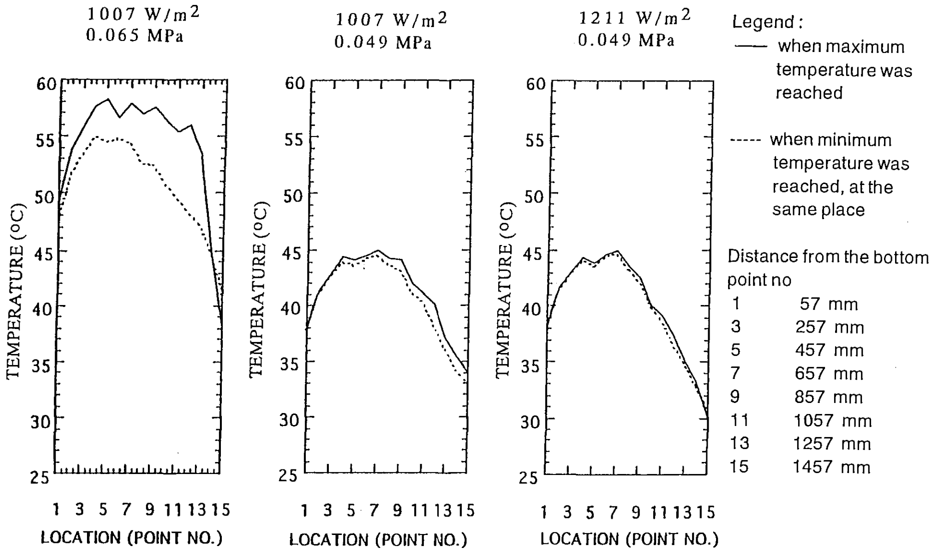

Fig. 4 Comparison of temperature distributions for various pressure and heat flux conditions.

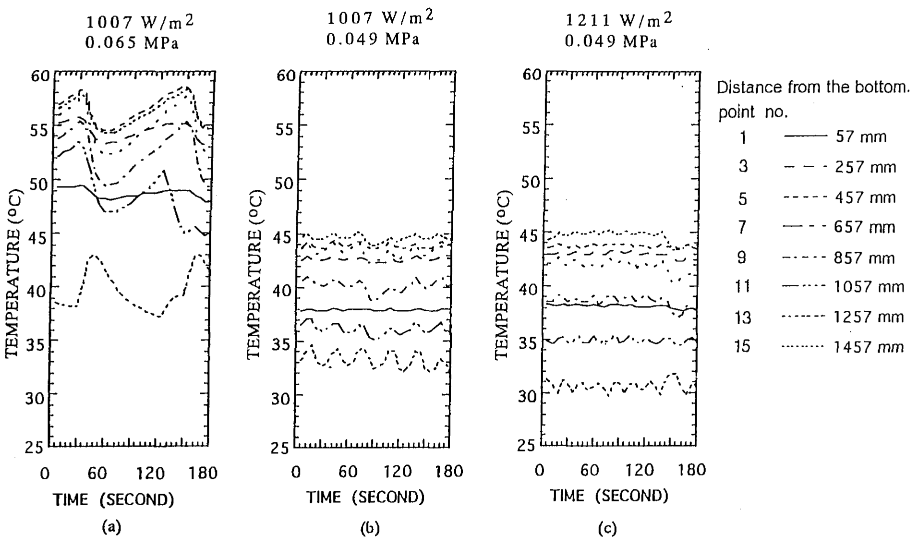

Fig. 5 Comparison of temperature fluctuations for various heat flux and pressure conditions.

place in both cases. Some difference in temperature distribution appears at the upper part. The temperature at the upper part at heat flux 1211 W/m^2 is lower than that at heat flux 1007 W/m^2. If we neglect the energy losses from the wall, energy from the evaporator is assumed to be transferred to the condenser through the up end of the evaprator only. The incrase in heat flux to the evaporator will cause the incrase in evaporation rate at the up end of the evaporator. The rate of cooled liquid which falls down along the wall of the condenser to the evaporator will increase also. This will cool the adiabatic parts as well as the upper part of the evaporator wall. At the same pressure, the rate of evaporation will be higher if the liquid temperature is higher. From these reasons it is considered that at higher heat fluxes, the temperature difference between the evaporator wall and the liquid at the upper part becomes smaller. If the condenser pressure is increased the maximum wall temperature increases and its position moves to the lower location, but the point of the geysering initiation is unchanged. At pressure 0.0646MPa, heat flux 1007 W/m^2 the wall temperature attains its maximum at about 457 mm while the geysering began at 657 mm from the bottom. From **Fig. 5a** the phase of the temperature oscillation at the point of the geysering initiation is opposite to that at the top. When the geysering occurred hot fluid from the middle part flows upward which heats the upper part. **Figures 5b** and **Fig. 5c** show the phase of temperature at the point where the maximum temperature occurs, which is out of phase with that at the top, and their bottom temperatures are almost constant. Although temperature at the top higher heat fluxes is lower, the amplitude of it's oscillation is smaller. According to **Fig. 5a** and **Fig. 5b**, the period of oscillation is longer when the pressure is higher. At higher pressure the temperature fluctuations of the evaporator at about the middle part are larger.

It is interesting to show the characteristics of the geysering at near the border. As shown in **Fig. 6**, when the geysering occurs at heat flux 1866 w/m^2 and pressure 0.0507 MPa, the temperature between points 357 mm and 757 from the bottom decreases, while at other points it increases.

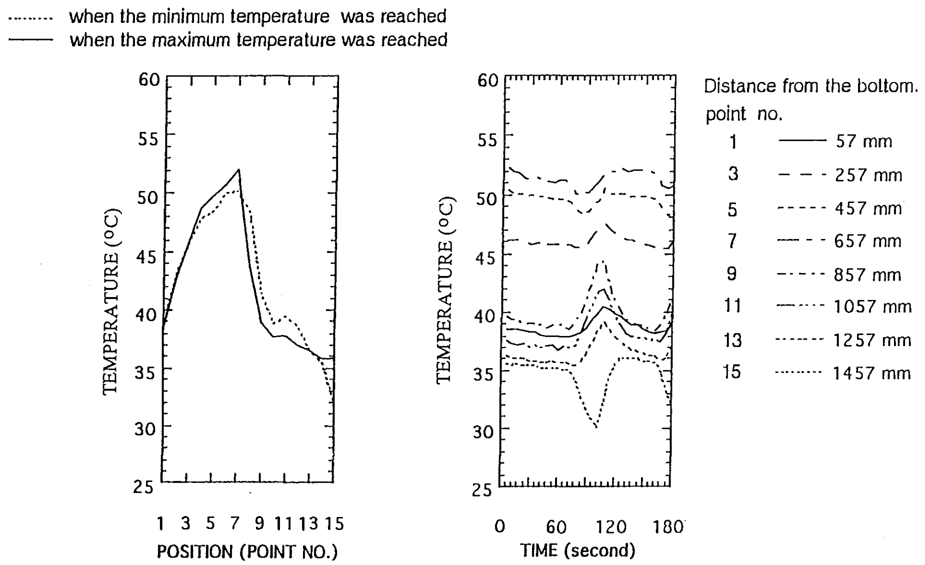

Fig. 6 Temperature distribution and its fluctuation near the border condition, heat flux 1866 W/m^2 pressure 0.0507 MPa.

4. Conclusion

The geysering in a closed double tube themosyphon working at low pressure and low heat flux is studied. Both the heat flux and the pressure tend to change the characteristics of the bubble development in the evaporator that is very important in the process of the geysering. At low heat fluxes a bubble is generated which then expands along the evaporator spontaneously to increase the condenser temperature and the pressure. At high heat flux conditions bubble forms at a position little lower than the middle and almost at the same time bubbles form along the upper part and the lower bubbles do not expand well.

References

1) Chexal, V. K., Bergles, A. E., Heat Transfer, AIChE Symposium Series, **69** No. 131, 37-45.
2) Casarosa, C., Latrofa, E., and Shelginski, A., Int. J. Heat Mass Transfer, (1983) 933-941.
3) Hands, B. A., Cryogenis, **28** (1988), 823-829.
4) Bezrodnyy, M. K., Elekseyenko, D. V., Heat Transfer Sov. res., vol. **9**, no. 5, Sep.-Oct., (1977), 14-20.
5) Nakanishi, S. et al, Nihon Kikai Gakkai Ronbunsyuu, **44** (1987) 4252-4262.