# LABORATORY MODEL OF GEYSERS: SOME PRELIMINARY RESULTS

N. SAPTADJI and D.H. FREESTON

Geothermal Institute
University of Auckland

**SUMMARY** - This paper discusses the results of an experimental study of three laboratory models of a geyser. The processes occurring within the system and the mechanism which cause an eruption to occur are observed in detail. The effects of a constriction at the top end of the channel on the model geyser performance are discussed.

## 1. INTRODUCTION

Geysers are natural surface features that discharge hot water and steam into the atmosphere intermittently and violently. Many observations have been made to study their performance; among others, the geysers at the Steamboat Springs, USA (White, 1967); Yellowstone Park, USA (Allen and Day, 1935; Rinehart, 1980; Bryan, 1986); Wainui, New Zealand (Benseman, 1964) and Whakarewarewa, New Zealand (Lloyd, 1975; Cody and Simpson, 1985) Geysers have unique performance characteristics, particularly in terms of the interval of eruption, the duration of water play and the height of eruption. Some geysers erupt at regular intervals whilst the majority will erupt irregularly. The performance characteristics can also change significantly with time; some active geysers, far example, have become inactive.

Geysers are associated with geothermal systems. A number of conceptual models have been proposed for the subsurface geyser system. It is generally accepted that the system is located near the surface, probably within 1 metre to 25 metres (Anderson et al., 1978) or perhaps to more than 70 metres (White, 1967). It consists of a reservoir (chamber) and a channel (Allen and Day, 1935; Benseman, 1964; White, 1967; Rinehart, 1980; Anderson, 1978; Steinberg, 1981; Bryan; 1986). Rinehart (1980) suggests that a geyser can be formed from a single stand pipe or shaft without a chamber. The rock can be fractured, porous and permeable (White, 1967; Fournier, 1969; Bryan, 1986); or it can be a cavity open to the atmosphere (Rinehart, 1980; Steinberg et al., 1981). The channel could be narrow (White, 1967), have a number of sharp bends (Bryan, 1986) and a constriction along its length (Anderson et al., 1978; Bryan, 1986).

The heat some is usually magmatic and is transported by steam or hot water fiom the bottom or from the side wall (Allen and Day, 1935; Rinehart 1980). Apart from an influx of hot water or steam, there is also an influx of cooler water into the system (Hallock, 1884, from Allen and Day, 1935; Steinberg et al., 1981; Bryan, 1986).

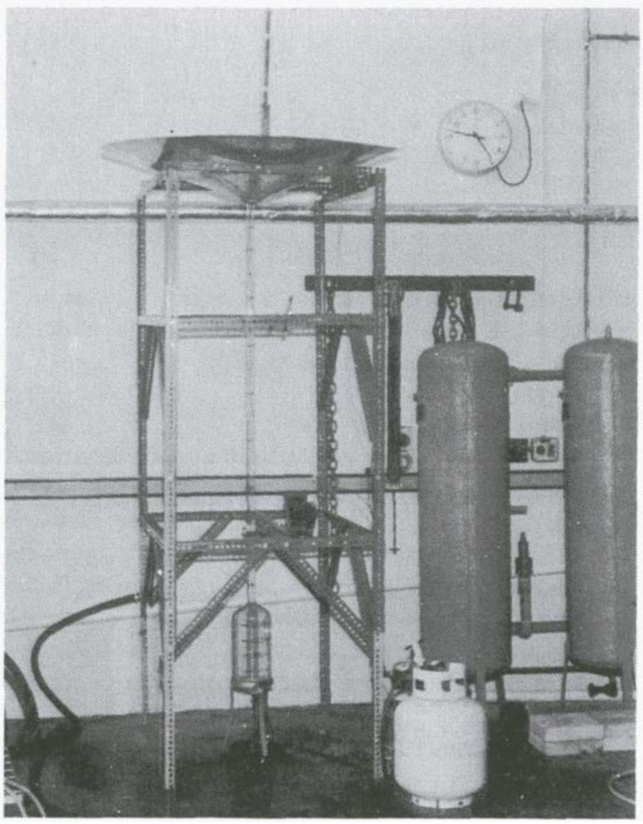
Aspects of geyser performance have been investigated using laboratory models (Allen and Day, 1935; Forrester and Thune, 1942; Anderson et al., 1978; Ozawa et al., 1979; Steinberg et al., 1982). The configuration and dimensions of the models built vary, but basically they have the four main components of a geyser system: a chamber, the channel, a working fluid and a heat source. In addition to these components, some models are completed with one or more of the following: a catch basin, a continuous water supply, a return leg to the chamber, and instrumentation' including flow meters, thermocouples and manometers. The experiments have not attempted to model natural conditions geometrically; nevertheless, they have assisted in the understanding of geyser characteristics such as the process occurring within the system, the mechanism of the eruption, and the effects of various geometric and flow parameters on the performance of geysers. One of the laboratory models of Steinberg et al. (1982) has successfully validated their proposed mathematical model.

In this paper the authors, as part of a much wider study, investigate the performance of three simple laboratory models of geysers. The models used are similar to the design used by Anderson et al. (1978), who found that eruptions were produced only with models that had constriction in the channel. Modifications of Anderson's model were chosen because they were comparatively simple to make for this preliminary study. The present experiments were undertaken to obtain a better understanding of the geysering process and to provide experimental data to validate a number of analytical models that have been produced.

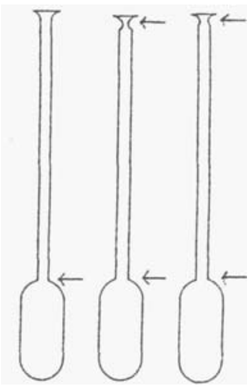
## 2. CONFIGURATION OF THE MODELS

The configuration of the models used is shown in Figure 1. Three laboratory models were tested, each consisting of a chamber and a channel. The dimension of each model is as follows :

| Model No | 1 | 2 | 3 |
|---|---|---|---|
| OD channel (cm) | 2.45 | 2.0 | 2.0 |
| Length of the channel (cm) | 150 | 152 | 150 |
| OD chamber (cm) | 10 | 10.1 | 10.1 |
| Length of the chamber (cm) | 24 | 25 | 25 |
| Total Volume (ml) | 2200 | 2150 | 2130 |



1-a



1-b 1-c 1-d

Figure-1 Laboratory model of a geyser.

The configuration of geyser model-1 (figure 1-b) is similar to that of Anderson et al. (1978). It has one constriction at the intersection of the chamber and the channel, as indicated by the arrow. The two other models used have an additional constriction at the top end of the channel. The diameter of this constriction for model-2 (figure 1-c) is 1 cm, and for model-3 (figure 1-d) is 1.5 cm. The chamber and the channel are made of pyrex glass to make visual observation of the processes possible. While in operation, a catch basin is attached to the model at the top end of the channel, as shown in Figure 1-a The catch basin is made of aluminium with a diameter of 1 m. A one-metre-long ruler installed vertically at the catch basin allows estimation to be made of eruption height. A thermocouple was inserted into the system at selected positions to measure temperatures during the experiments. One of the problems of these laboratory models is that there is no continuous water supply; hence, the water discharged during eruption will flow back to the system through the same channel and some is lost due to evaporation during the eruption, giving a reducing system mass flow.

Experiments were conducted by filling a known volume of water into the the tube. The system is then heated at the bottom of the chamber using a gas burner. The processes occurring within the system were observed, the temperatures at three different levels were measured, and the times when the eruption occurred and the volume of the water after each eruption were noted.

The possibility of meassuring temperatures at three different level simultaneously has been tried but due to instrument problems the present results were taken using a Fluke-77 multimeter for temperature measurement which, with time, were recorded manually. Recently, measurements have been made using a single channel HP3421A data acquisition unit connected to an HP-85. It is hoped to fit multiplexer to this unit to allow measurement of temperatures at different levels simultaneously.

## 3. EXPERIMENTAL RESULTS

### 3.1. Model-1

A series of experiments were performed to observe the process occurring within the system and to measure temperatures at the centre of the chamber, the centre and the upper part of the channel. The geyser system is filled with 2100ml of cold water. Temperatures were measured using K-type thermocouples lowered to selected levels. Since the diameter of the thermocouple wire was of a significant size when compared to the channel diameter, some tests were conducted without the thermocouple in the system.

The process occurring in this geyser model was observed visually. The model shows that, as the chamber is heated, the temperature increases and convection occurs. Simultaneously, the water expands and the water level increases slowly. After several minutes, small bubbles start to form. Initially, they adhere to the bottom of the chamber. They then rise to the upper part of the chamber where they become attached, especially at the neck of the chamber. When they become numerous, some of them separate from the wall and rise up the channel. Two phase flow then occurs in the system, obviously starting with the bubble flow (see figure 2-a). The water level continues to rise at a faster rate until it overflows into the catcher. After a few minutes, a large vapour bubble (figure 2-b) appears to enter the channel but it collapses as soon as it enters the bottom of the channel, consequently only small bubbles continue rising to the surface. This occurs several times, the vapour bubble collapsing at the bottom of the channel, although at a slightly higher 'position than the previous bubble. Once vigorous boiling occurs in the chamber (temperature in the chamber is then 103.8 deg.C), a vapour bubble rises into the channel without collapsing, followed by some water slugs from the chamber, which forces rapid movement of the water in the channel discharge water and steam out of the channel to a height about 50-70 cm for a few seconds. The flow in the channel at the time of the eruption is annular flow (figure 2-d).

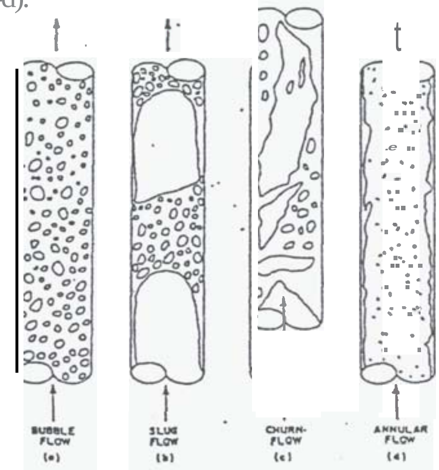



Figure-2 Flow regimes for vertical two-phase flow

The rapid flow of fluid ejected causes a sudden increase in temperature in the channel as indicated by line B-C in figures 3-b and 3-c. The temperature in the chamber when the first eruption occurs is 103.8 deg.C. This indicates that the water in the chamber is at the saturation temperature associated with a full column (hydrostatic pressure associated with full column is 1.1542 bar and the corresponding saturation temperature is 103.7 deg.C). The highest temperature in the centre of the channel is about 102.3 deg.C while in the upper part it is 100 deg.C. After an eruption, the ejected water falls into the catch basin and is immediately sucked into the channel, accompanied by audible 'booming'. The temperatures decrease rapidly as indicated by line C-A. Boiling in the chamber is suppressed, and the temperature in the chamber drops to 90 deg.C. At the centre and upper part of the channel, temperatures are 65 deg.C and 60 deg.C respectively.

After an eruption the ejected water returns to the system, hence the geyser system contains the residual water with the cooler, returned water. Because of evaporation and water losses during the eruption, the total volume of water is reduced. The process as described above is repeated, with the exception that it is started at higher temperature and lower water level than previously (point A in figs.). The water begins to heat up again, as indicated by the increase in temperature in the chamber (curves A-C of figure 3-a). Temperatures in the centre of the channel remain constant until the next eruption occurs (curves A-B in figure 3-b) while, at the upper part of the channel, temperatures are decreasing. Temperatures at the upper part of the channel represent temperatures above water level, i.e. in air, since after the second eruption the thermocouple is no longer immersed in the water. We observed that boiling always occurs in the chamber before an eruption. An eruption is always initiated after the vapour bubble is foxmed and rises into the channel without collapsing, while the water in the chamber is boiling vigorously.

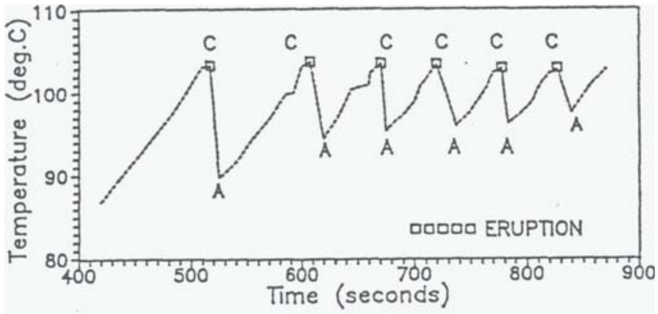



Figure 3-a Temperature in the chamber

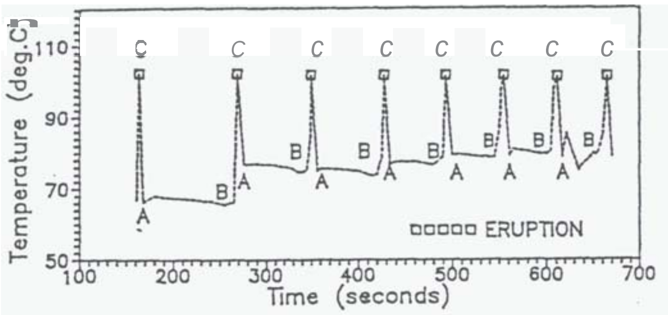



Figure 3-b Temperature at the centre of the channel

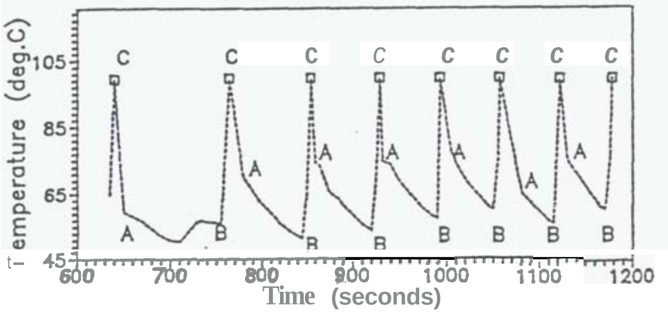
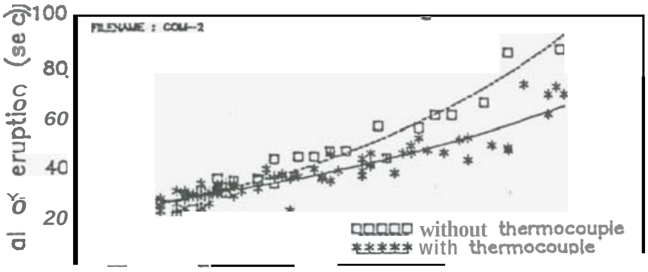



Figure 3-c Temperature at the upper part of the channel.

This model erupts about 15 times. The interval of eruption varied from 25 to 90 seconds. The inconsistency in the internal of eruption is due to the decrease in the water volume (level) after an eruption. The relationship between the water volume and the interval of eruption is shown in figure-4. As the volume of water or the water level decreases, the height and the interval of the following eruption is shorter; eventually, water is ejected below the catch basin and only steam flows to the catch basin, while the water in the chamber is still boiling vigorously. Figure 4 also shows that installing the thermocouple has quite a significant effect on the interval of eruption. In effect, it reduces the diameter of the channel.

In a system where there is a recharge into the chamber, the interval before the next eruption is the time required to



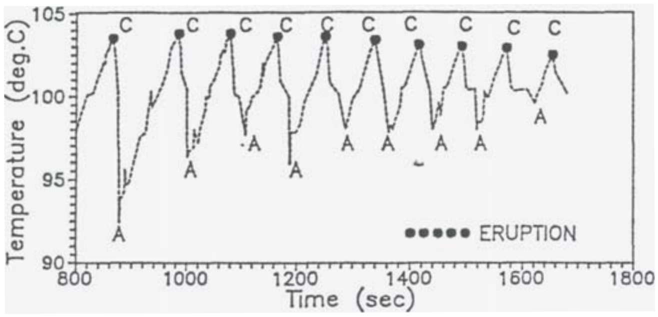

In some respects, this model works similarly to that observed by Anderson et al. **(1978). Similar** processes and the description of the mechanism of eruption *are* shown by **our** model; however, we did not experience the vibration that occurs either before or after the eruption **as** described by Anderson et al. (1978), probably due to differences in materials and methods of construction. Anderson did not describe the dimensions of his model, **and** some of the differences may be attributed **to** dimensional effects.

## 4.2. Model-2

This model has a constriction of 1 cm diameter **at** the top end of its channel (figure 1-c). The Same volume of water is used in **the** system. Temperatures were measured using a T-type thermocouple and HP3421A **data** acquisition unit and recorded by the HP-85; accordingly the temperature-time **data** obtained is more accurate. However, since the control unit at present has no multiplexer assembly, single point temperatures only were measured, multiple **runs** being **necessary** to obtain the temperature distribution through the system.

This model **also produces an** eruption, with water **ejected** to a height about **40-50** cm, which is slightly lower than that in the previous **model.** The process occurring within the system is much the same **as** that described above except that, after an eruption, the ejected water is not immediately sucked into the channel. The constriction **at** the top end of the channel apparently obstructs the **flow;** consequently a pool of water is formed in the catch basin. When this occurs, boiling is more vigorous in the chamber, resulting in steam rising up to the channel in counterflow to the **flow** of the water **from** the catch basin moving down the channel. Accordingly the ***steam,*** which fills the channel, is condensed from the top by the cooler water moving down. After some time the ejected water is sucked back rapidly into the channel accompanied by audible "booming", which is louder than before and accompanied by a transient vibration wave.

A series of experiments have been conducted **to** measure temperatures **at** the centre of the chamber, and at the centre and upper **part** of **the** channel (below the constriction) and the catch basin. The changes in the temperature are illustrated in Figure-5. Points C represent temperatures when the eruption occurs. The temperatures in the chamber when the eruption **occurs** are about 103-104 deg.C. The points C-D represent temperatures when the ejected water remains ***at*** the catch **basin** and the channel is mostly filled by **steam.** Temperature in the channel ***are*** about 100 deg.C. At the catch basin **the** water is **cooled** by **air,** hence temperatures after **eruption** decrease quite rapidly **as** shown in figure **5-d. The** curves **D-A** represent temperatures when the water at the catch basin is sucked **into** the tube. Point A represents the temperature after all the ejected water **returns** to the system.



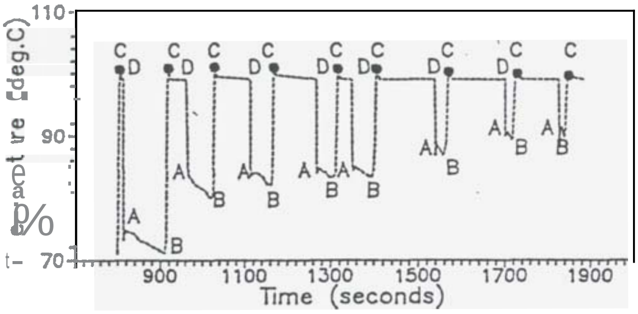




Figure 5-b Temperature *at* **the** centre of the channel

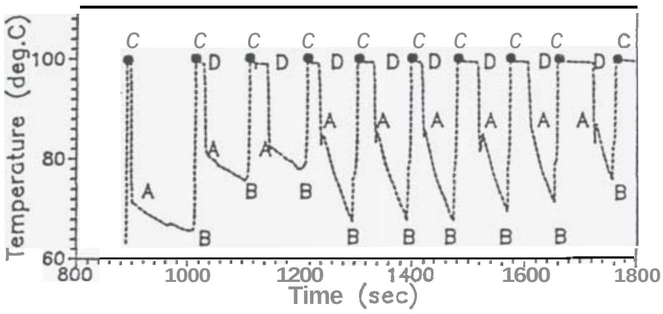



Figure 5-c Temperature at the upper **part** of the channel

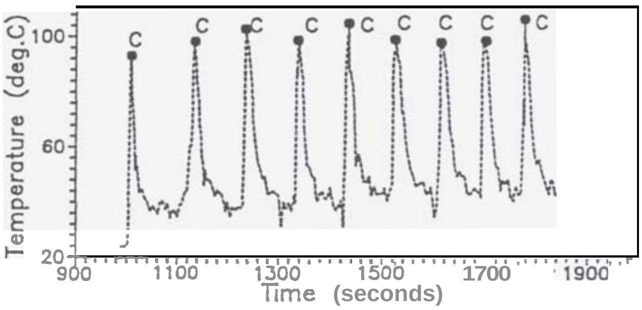



Figure 5 d Temperature **at** the catch basin.

It was reported by Anderson et al. (1978) that in a model with two constrictions, like this model, the large steam bubbles must rise up to the higher of the two constrictions before an emption occurs. Our model does not exhibit this behaviour; the vapour bubbles, as observed in the previous model, only rise up to the bottom of the channel before an eruption.

The constriction at the top end of the channel, as described previously, causes the ejected water to take a longer time to flow back down the channel. The time required, as shown by curves C-D in figures 5-b and 5-c, is variable. The corresponding intervals of eruption are plotted against the volume of water in figure-6. It appears that this time period is influenced by the local environment, as after an eruption the water remains in the catch basin and is cooled by the air. The intervals of eruption, which are equal to the time required to reheat the water until it is boiling vigorously plus the time required by the ejected water to return to the system, become irregular: they do not become shorter as the water volume or level decreases (figure-6).

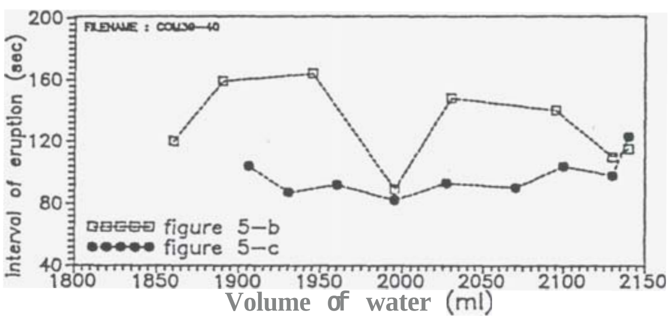



Figure-6 The relationship between the water volume and the interval of eruption.

### 4.3. Model-3

This model has a constriction of 1.5 cm in diameter at the top end of the channel and it performed similarly to the first model. After the eruption the ejected water is sucked immediately into the tube. The temperature changes in the system are shown in Figure-7. Points C represent temperatures when the eruption occurs; points A are the temperatures after the ejected water returns to the channel, and points B are just before the next eruption.

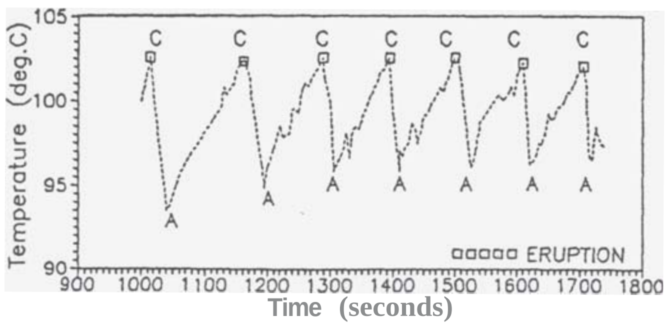



Figure 7-a Temperature in the chamber

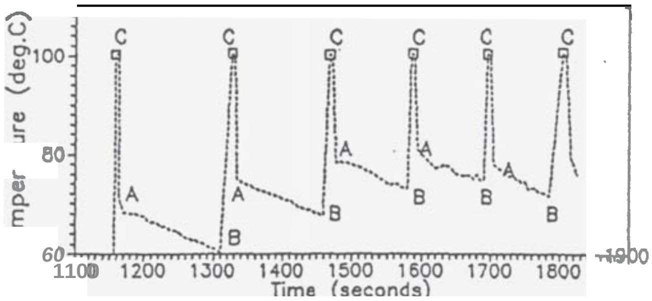



Figure 7-b Temperature at the centre of the channel

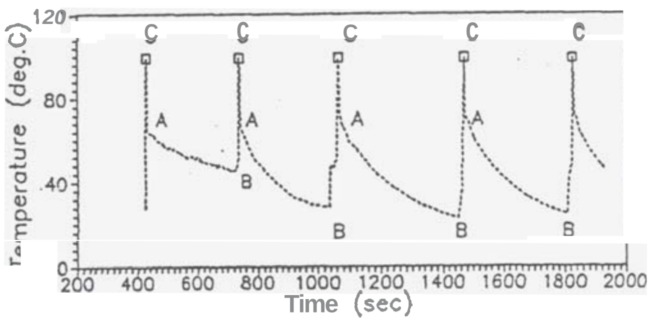



Figure 7-c Temperature at the upper part of the channel

## 4. DISCUSSION

All the laboratory models studied here produced eruptions. The same mechanism of eruption was shown throughout all the tests, that is, an eruption occurs immediately after the large vapour bubble rises into the channel without collapsing, which lifts the water out of the channel while the water in the chamber is boiling vigorously. Temperature data indicate boiling in the chamber at saturation temperature.

In our models, an overflow did not always occur prior to an eruption. An overflow occurs only when the water level is high. When the water level is low, the first vapour bubble that rises to the channel without collapsing lifts the overlying water up the channel but does not overflow into the catch basin; it then subsides. This occurs several times before an eruption, demonstrating a characteristic of some natural geysers which never overflow, while others overflow prior to eruption.

Although the same mechanism of eruption was shown by all the laboratory models, and the models are very similar in configuration and size, the geyser models performed differently. Each discharged water and steam to different heights. The highest eruption was about 70 cm in the geyser model that had no constriction at the top end of its channel. Those models that have smaller channel diameter and were constricted erupted to lower heights of about 40 to 50 cm. Many natural geysers erupt to heights of less than one metre. The geysers at the Steamboat Springs, USA, for example, as reported by White (1967), are mostly small and inconspicuous, typically erupting to heights of only 0.3 to 1 metre.

The very distinct difference between the performance of a geyser with and without a constriction at the top end of its channel is in the surface expression, which in the laboratory model occurs in the catch basin, and in the interval of eruption. A pool of water is formed at the catch basin for model-2 (constriction in the upper part of the channel), when the ejected water remains in the catch basin and reacts to changes occurring in the channel. This model performed much as the fountain or pool geysers which, in nature, are characterized by pools of hot water.

The effect of the constriction on the interval of eruption is also significant. The intervals of eruption of the geyser with no constriction are shorter as the water level is decreased. For the model with a constriction, the inconsistency in the eruption intervals did not correspond to the water level. The constriction apparently causes irregularity in the interval of eruption, which is much influenced by the surroundings.

## ACKNOWLEDGMENT

We acknowledge the helpful discussions during the writing of this paper with Associate Professor M.J.O'Sullivan, and we thank Pan Hesong, who spent considerable time helping in the construction of the laboratory model. Thanks are also due to Ashley Franklyn and Greg Bignall for their help with the experiments.

## REFERENCES

Allen, E.T. and Day, A.L. (1935): Hot Springs of the Yellowstone National Park, Carnegie Institution of Washington, 1935, pp 171-231.

Anderson L.W., Anderegg, J.W. and Lawler J.E. (1978): Model Geysers, American Journal of Science, Vo1.278, pp. 725-738.

Benseman, R.F. (1964): The Components of a Geyser, N.Z.J.Sci. 8, pp 24-44.

Bryan, T.S. (1986): The Geysers of Yellowstone. Colorado Associated Press, Boulder, Colorado, 1986.

Cody, A.D. and Simpson, B. (1985): Natural Hydrothermal Activity in Rotorua. The Rotorua Geothermal Monitoring Programme 1982-1985, Oil and Gas Division Ministry of Energy, pp 227-273.

Forrester, J.D. and Thune, H.W. (1942): A Model Geyser. Science, V. 95, No. 2460, pp. 204-206.

Fournier, R.O. (1969): Old Faithful : A Physical Model. Science, 17 January 1969, pp. 304-305.

Lloyd, E.F. (1975): Geology of Whakarewarewa Hot Springs. A.R. Shearer, Government Printer, Wellington-New Zealand, 23 pp.

Ozawa, M., Nakanishi, S., Ishigai, S. (1979): Flow Instabilities in Boiling Channels, Part 2. Geysering. Bulletin of JSME, Vol. 22, No. 170, August 1979, pp. 1119-1126.

Rinehart, J.S. (1980): Geysers and Geothermal Energy. Springer - Verlag New York Inc, 223 pp.

Steinberg, G.S., Merzhanov A.G. and Steinberg A.S. (1981): Geyser Process: Its Theory, Modelling and Field Experiment. Part 1. Theory of the Geyser Process. Modern Geology, Vol 8, pp 67-70.

Steinberg, G.S., Merzhanov A.G., Steinberg A.S. and Rasina A.A. (1982): Geyser Process: Its Theory, Modelling and Field Experiment. Part 2. A Laboratory Model of a Geyser. Modem Geology, Vol. 8, pp 71-74.

Steinberg, G.S., Merzhanov A.G. and Steinberg A.S. (1982): Geyser Process: Its Theory, Modelling and Field Experiment. Part 3. On Mestability of Water in Geysers. Modern Geology, Vol.8, pp75-78.

Steinberg, G.S., Merzhanov A.G. and Steinberg A.S. (1982): Geyser Process: Its Theory, Modelling and Field Experiment. Part 4. On Seismic Influence on Geyser Regime. Modem Geology, Vol.8, pp 79-86.

White D.E. (1967): Some Principles of Geyser Activity, Mainly from Steamboat Springs, Nevada. American Journal of Science, Vol 265, pp 641-684.