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A DYNAMICAL MODEL OF A GEYSER INDUCED BY BOILING: AN APPLICATION OF THE DYNAMICAL MODEL OF A GEYSER INDUCED BY INFLOW OF GAS

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Abstract

We have proposed a static model, a dynamical model and a modified dynamical model of a geyser induced by inflow of gas based on observation and model experiments of it and have also proposed a combined model combining above two models. And numerical simulations of the modified dynamical model or the combined model reappear spouting dynamics of a geyser induced by inflow of gas and it becomes possible that parameters (volume of the underground space, depth of spouting hole and so on) under a geyser are estimated due to comparison between results of simulation and those of observation. Moreover we proposed a dynamical model which assumed more than two underground gas supply sources by extension of above-mentioned usual dynamical model. As a result, irregular spouting dynamics of a geyser induced by inflow of gas could also be reappeared by the modified model. As a result, spouting mechanism of all kinds of geysers induced by inflow of gas, that is, that of not only regularly spouting geysers but also irregular spouting geysers has been clarified. However, in general, geysers are classified into two types dependent on inducer. That is, one is a geyser induced by inflow of gas and the other is a geyser induced by boiling. The latter is more popular and many ones exist all over the world. Though qualitative spouting models of a geyser induced by boiling have been proposed, its dynamics has not been discussed sufficiently. Therefore, in this study, we derive a dynamical model of a geyser induced by boiling applying the above-mentioned dynamical model of a geyser induced by inflow of gas. Then we try to estimate underground parameters of a geyser induced by boiling by comparison of results of numerical simulation of the model and those of observation of a geyser induced by boiling. Moreover, this study also provides concrete and effective information based on which we take measures to protect geysers whose spouting dynamics (spouting period, reachable height during spouting and so on) have been gradually declining. If the declining geyser is dealt with suitably and the former spouting dynamics of it is maintained through effective use of this study, this will protect not only local people supported by tourists who visit there so as to see or use the geyser but also the precious environmental resources for us.

Keywords: dynamical model, geyser induced by inflow of gas, geyser induced by boiling, estimation of underground parameters, numerical simulation, environmental protection

1.INTRODUCTION

A geyser is defined as a natural spring that sends hot water and steam intermittently into the air from a hole in the ground. Geysers are classified into two types dependent on inducer. That is, one is a geyser induced by boiling and the other is a geyser induced by inflow of gas. The former is popular and many ones exist all over the world. And some theories about its mechanism have been proposed[1, 2]. And their application to other phenomena was also tried[3]. Similarly, there are some studies about observation of the former[4]. Though qualitative spouting models of the former have been proposed, its dynamics has not been discussed sufficiently. On the other hand, the latter is not popular very much and there are few ones and only a few studies about its mechanism have been proposed[5].

We have proposed a static model, a dynamical model and a modified dynamical model of a geyser induced by inflow of gas based on observation and model experiments of it and have also proposed a combined model combining above two models. And numerical simulations of the modified dynamical model or the combined model reappear spouting dynamics of a geyser induced by inflow of gas and it becomes possible that parameters (volume of the underground space, depth of spouting hole and so on) under a geyser are estimated due to comparison between results of simulation and those of observation[6 - 9]. Moreover we proposed a dynamical model which assumed more than two underground gas supply sources by extension of above-mentioned usual dynamical model. As a result, irregular spouting dynamics of a geyser induced by inflow of gas could also be reappeared by the modified model[10, 11]. As a result, spouting mechanism of all kinds of geysers induced by inflow of gas, that is, that of not only regularly spouting geysers but also irregular spouting geysers has been clarified.

Therefore, in this study, we try to derive a dynamical model of a geyser induced by boiling. In case of a geyser induced by boiling, the trigger of spouting is boiling and hot water near the boiling point spouts. Among many studies about geysers induced by boiling, two theories are well-known. One is the cavity theory which was thought by Mackenzie[12] and extended by Honda and Terada[1, 2, 13] and the other is the perpendicular tube theory which was proposed by Bunsen and Descloizeaux[14] and Bunsen[15].

In case of the former, structure of the mechanism is similar to that of the dynamical model of a geyser induced by inflow of gas. Therefore, if it is assumed that gas supply rate increases rapidly after boiling begins, the dynamical model of a geyser induced by inflow of gas can be applied to a geyser induced by boiling. However, if the dynamical model of a geyser induced by inflow of gas is applied to a geyser induced by boiling, lukewarm water packed in the spouting pipe spouts. This is inconsistent with the fact that hot water near the boiling point spouts. Therefore the former is not suitable to a geyser induced by boiling.

On the other hand, in case of the latter, ground water packed in the spouting pipe is gradually warmed by geothermy subterranean heat. Then the lower part of water packed in the spouting pipe reaches the boiling point. Then boiling begins there and bubbles of steam begin to rise in the spouting pipe. Then many bubbles of steam push water packed in the spouting pipe and spouting begins on the ground. In this mechanism, since an underground cave is not needed, the dynamical model of a geyser induced by inflow of gas cannot be applied to this. On the other hand, in this theory, if volume of underground hot water is not sufficient, hot water cannot be dominant as spouting water.

2.MODEL

In order to solve the above-mentioned difficulty of the perpendicular tube theory, we consider a model such as the following. That is, it is assumed that volume of the underground boiling area is sufficiently large so that boiling in this area affects spouting dominantly. Concretely it is assumed that there is an area of the cylindrical shape as the underground boiling area and a narrow spouting pipe grows from there and reaches a spouting vent on the ground. In case of this shape, when underground water is heated sufficiently in the area of the cylindrical shape and boiling begins, hot water can spout on the ground through the narrow spouting pipe.

It is assumed that when boiling bubbles of steam grow only in the area of the underground cylindrical shape and growth of bubbles of steam in the narrow spouting pipe is ignored for simplicity. And it is also assumed that nuclei of bubbles occur only from the bottom of the underground boiling area and bubbles grow keeping spherical bodies.

Plesset-Zwick solution as a grow equation of a bubble when boiling is well known written as[16, 17];

$$R(t) = 2\sqrt{\frac{3}{\pi}} Ja\sqrt{a_L t} \tag{1}$$

where $R(t)$ represents radius of a bubble after a lapse of time t from occurrence, a_L represents temperature conductivity of liquid, Ja represents Jacob number written as;

$$Ja = \frac{\rho_L c_L \Delta T_{sat}}{\rho_V L} \tag{2}$$

where ρ_L represents density of liquid, ρ_V represents density of gas, c_L represents specific heat of liquid, L represents evaporative latent heat and ΔT_{sat} represents degree of superheat of liquid.

Therefore volume of a bubble after a lapse of time t from occurrence is written as;

$$V(t) = \frac{4}{3}\pi R^3(t) = 32\sqrt{\frac{3}{\pi}} J_a{}^3 a_L{}^{3/2} t^{3/2} \tag{3}$$

And the rising rate equation of a bubble when boiling is derived by Peebles-Garber and written as18;

$$Um = 1.18(\sigma g g_0 / \rho_L)^{1/4} \tag{4}$$

where σ represents surface tension, g represents gravitational acceleration and g_0 represents conversion factor.

Now it is assumed that occurrence rate of nuclei of bubbles per unit area per unit time from the bottom of the underground cylindrical boiling area represents p, area of the bottom of the underground cylindrical boiling area represents S, height of it represents h. Then sum of the volume of all of the bubble after a lapse of time t from occurrence of boiling is written as;

$$V_T(t) = \int_0^t V(t) pS dt = \frac{64}{5}\sqrt{\frac{3}{\pi}} J_a{}^3 a_L{}^{3/2} pSt^{5/2} \tag{5}$$

Here since bubbles of steam grow only in the area of the underground cylindrical shape, maximum increasing rate of $V_T(t)$ is written as;

$$V_{TM} = \left.\frac{dV_T(t)}{dt}\right|_{t=h/U_m} \tag{6}$$

Now we assumes that cross-sectional area of the spouting pipe represents s and z direction is vertical upward over the ground. Then spouting rate is written as;

$$\frac{dz}{dt} = \frac{1}{s}\frac{dV_T(t)}{dt} \tag{7}$$

This spouting rate $\frac{dz}{dt}$ can be consider as an index that represents the height of eruption.

3.RESULTS OF NUMERICAL SOLUTION AND DISCUSSION

An example of results of numerical solution of above basic equations is shown in Fig. 1. Time variation of $\frac{dz}{dt}$ from the beginning to the peak depends on above-mentioned parameters. We can estimate underground parameters through comparison between results of numerical solution and results of real observation of a geyser induced by boiling.

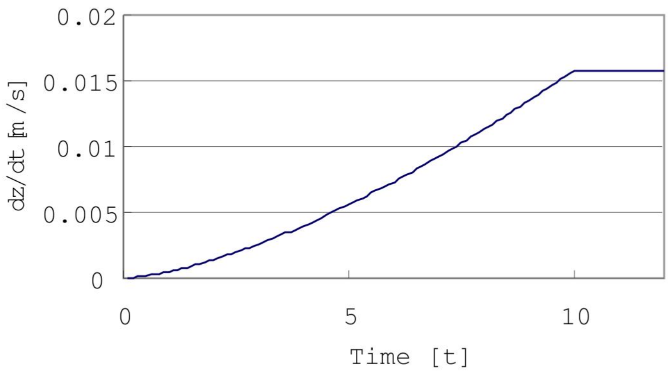

Fig. 1 An example of results of numerical solution of a model of a geyser induced by boiling

4.CONCLUSION

A dynamical model of a geyser induced by boiling was derived based on the consideration of the nature of the dynamical model of a geyser induced by inflow of gas and actual conditions of a geyser induced by boiling. It is suggested that we can estimate underground parameters through comparison between results of numerical solution of the model and results of real observation of a geyser induced by boiling.

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