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DEVELOPMENT OF A TWO-PHASE FLOW METERING SYSTEM

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ABSTRACT

Accurate measurement of geothermal production fluids is of vital importance for both reservoir management of geothermal resources and for production utilization of available geothermal fluids. The metering of two or more flowing phases in a pipeline is inherently complex. Considerable research effort spanning decades has searched for a solution that has been elusive.

The New Energy and Industrial Technology Development Organization (NEDO) has initiated a research program titled " Development of Technology for Reservoir Mass and Heat Flow Characterization." As a part of the research project, Japan Petroleum Exploration Company, Ltd. (JAPEX) has contracted to carry out a research project titled " Development of the Two Phase Metering System".

At present, a system using separator is the most popular to meter steam and hot water volume continuously, but this system is so expensive that we can not set up at each well. Therefore, the purpose of this study is to measure of steam and hot water volume in two-phase flow line of geothermal pipelines with high accuracy and low cost.

In the beginning, we had conducted a feasibility study of the two-phase metering system for low cost and easily maintenance. As the result of the feasibility study, it became clear that a vortex shedding flow meter (VFM) combined with a dielectric steam quality sensor (DSQS) was the most useful and effective for two-phase metering system. To clarify the usefulness of this system in a geothermal pipeline, we had carried out some field experiments at the Okuaizu geothermal field. Data collected by these experiments were compared with data obtained by tracer dilution method (TFT) which was accurate as same as the separator measurement. As the result of the experiments, we could confirm that DSQS and VFM could work in a two phase flow so well. Also, the results of DSQS/TFT measurement were agreeable on two of three test runs, even when operated in a transitional annular and wavy stratified flow regime. From these experiments, the usefulness and effectiveness of this system were demonstrated in geothermal field. However, another new technique will be required to protect scaling on these devices. To correspond to the scale issue, we will propose a scanning method by using a laser flow meter as a future work.

1. INTRODUCTION

In two-phase flow measurement, most methods including those incorporating ultrasonic, capacitance, microwave, volumetric, differential pressure and nuclear devices incur difficulties due to problems associated with flow regime, interference, distortion and limited range (Rajan et al., 1993, Fueki, et al., 1997, Griston et al., 1998). Representative ratio sampling is complicated by the flow regime and distribution patterns. There may be a time in the future when an improved, compact, stand-alone pipeline device is developed and it may resolve these difficulties.

Outside of the test separator metering system, the orifice meter for well-flow monitoring has been the only continuous monitoring method in widespread geothermal use. This technique requires knowing the total enthalpy, and in normal field use. It also incurs an error of plus or minus 20%. The Jamestube and TFT require blowing the total flow to the atmosphere or using specialized equipment for precision chemical injection. On the other hand, it is difficult for the test separator to be installed on every production well: because of the high expense and complexity associated with its use. Some fields are equipped with separator stations for a group of production well, while others depend on periodic, portable, test separator updates normally performed annually (Daniel et al., 1997).

The VFM, DSQS and TFT method to measure two phase volume were applied in our experiments. Brief explanation for these methods will be given in the following paragraphs.

The VFM can measure a superficial vapor rate. This device is extensively used in the steam flood projects at California. Hundreds of such flow meters have been used successfully. Since the hot water fraction takes up volumes, a higher pseudo rate is usually measured. A correction factor is often applied to offset this effect.

The DSQS is a device to measure a art steam quality currently on the market (Sims et al., 1997). The DSQS device was tested for steamflood projects (Griston,1998). It is used extensively in heavy oil steam flood projects numbering over 100 installed satisfactory. These units in steam flood application have an operating range from 20% to 90% steam quality. For the geothermal use, its application is very new. The device has been installed on only the Coso geothermal field in California. The DSQS has been identified as promising method for two phase measurement.

Recently, a tracer dilution technique called TFT has been developed to provide an acceptable means to measure two-phase flowing wells without the use of costly separators (Hirtz 1995). In operating, liquid and vapor tracers are injected into the pipeline and mixed with the geothermal fluids. At that time, a downstream dilute sample yields a ratio proportional to the injectant. The primary drawback to TFT is its inability to continuously monitor flow. The TFT method, however, can have important synergistic effects by being used to periodically calibrate less accurate but continuously operating two-phase flow metering methods. The TFT system can be synergistically used to calibrate and fine-tune a DSQS system, thus providing an interim two phase flow meter that continuos monitors the wells with improved accuracy . We had carried out the field experiments for the DSQS combined with the TFT

By using these devices, higher accuracy, lower pressure drop, higher turndown, and lower cost methods were being researched.

2. OPERATING PRINCIPLE

2.1 Vortex Flow Meter (VFM)

The vortex flow meter is a velocity measurement tool. The shedding frequency that is measured is a function of the flowing velocity divided by essentially the diameter of the probe. The relationship between velocity and vortex frequency is showed as the following equation.

$$St = (f \cdot d)/v \qquad (1)$$

where

St: Strouhal number
f: vortex frequency
d: vortex width
v: velocity

Since Strouhal number has a constant value in extent of $10^{3.5}$~$10^{5.5}$ of Reynolds number, the vortex flow meter can be applied for under this condition. Reynolds number (Re) can be expressed as,

$$Re = (v \cdot d)/\nu \qquad (2)$$

where ν is kinematics viscosity coefficient

Since a liquid volumetric component is relatively small in comparison to the steam fraction, the reading value gives an approximate indication of the steam rate under moderate steam quality measurements. If the steam quality is known, the hot water can be backed out from the mixture to give each rate.

2.2 Dielectric Steam Quality Sensor (DSQS)

The DSQS is a device for impedance measurement. The measurement tool behaves like a cylindrical capacitor. It takes into consideration the dielectric strength of the hot water and steam blend, including the conductivity of the hot water fraction. Since breakdown voltage of the hot water is significantly lower than the vapor, the phase shift is used to determine the steam quality. Measured impedance (conductance or capacitance) of a two-phase fluid depends on the sensor geometry and the liquid volume fraction. A capacitance transducer consists of two parallel conduction plates separated by a dielectric medium such as water. The capacitance is proportion to the area of the plates, and inversely proportional to the distance between them. The constant of proportionality for the area of the plates is given by the product of the dielectric constant. This equation can be expressed as follows:

$$C = \kappa \cdot \varepsilon \cdot A/d \qquad (3)$$

where

C : capacitance
κ : dielectric constant
ε : dielectric constant in a vacuum
A : plate area
d : distance of the plate

The change in capacitance is directly proportional to the change in the dielectric constant of the medium between the plates.
Hence,

$$\kappa = (1-\lambda)\ \kappa_G + \lambda\ \kappa_L \qquad (4)$$

λ : liquid volume fraction
κ_G: dielectric constant of the gas phase
κ_L :dielectric constant of the liquid phase

Generally speaking, the DSQS device measures the capacitance of deionized water steam and liquid. However, geothermal water contains dissolved solids that make the liquid phase conductive. Consequently, the DSQS device measures impedance, which is the vector resultant of capacitive reactance and resistance.

$$Z_{Total} = (X^2 + R^2)^{1/2} \qquad (5)$$

Z_{tota} : total impedance
X : reactance
R : resistance

Two-phase impedance is calculated by subtracting background impedance from total impedance

$$Z_{TP} = Z_{total} - Z_{sensor} \qquad (6)$$

where

Z_{TP} : two phase impedance
Z_{sensor}: inherent impedance of the device

The liquid volume fraction is then determined from vapor impedance, the vapor pressure, the hot water resistivity, and the impedance of the two phase.

$$\lambda = K(\rho_W \cdot P)^{1/2} Log(Z_v/Z_{TP}) \qquad (7)$$

where

K : constant
ρ_W: hot water resistivity
P : vapor pressure
Z_V : vapor impedance

Finally, steam quality can be calculated from the following equation.

$$SQ=\{1+(V_V/V_L)\cdot\lambda/(1-\lambda\}^{-1} \quad (8)$$

where

V_V: vapor specific volume
V_L: liquid specific volume
SQ : steam quality

2.3 TFT (Total Flow Test)

A tracer dilution method is a two phase metering system developed by Paul Hirtz of Thermochem company to measure flow volume by dilution ratio (Hirtz 1995). This technique requires precisely detection of liquid-and vapor-phase tracers injected into the two-phase flow line.
The mass flow rate of each phase is determined by the following mass-balance equations:

$$Q_V=Q_{TV}/(C_V-C_B) \quad (9)$$
$$Q_L=Q_{TL}/(C_L-C_B) \quad (10)$$

where

Q_V : vapor mass flow rate
Q_L : liquid mass flow rate
Q_{TV} : vapor tracer mass injection rate
Q_{TL} : liquid tracer mass injection rate
C_V : tracer concentration in vapor sample
C_L : tracer concentration in liquid sample
C_B : background concentration of tracer in each phase

3. FIELD EXPERIMENT

3.1 Experimental procedure

A field experiment was conducted on Well 87N-16T in the Okuaizu geothermal field, Japan. The purpose of the field experiments was to evaluate the performance of a commercially available the DAQS and the VFM device installed at variable steam quality in the geothermal fiele. A small amount of flow was extracted from one inch top port of the two-phase line and flowed into a test apparatus. The outline of the Okuaizu field test set-up is illustrated in Figure 1. As shown in Figure 1, the VFM and DSQS were installed on the two inches line, in turn, from upstream; especially, the DSQS was set at a corner of the line to get a homogeneous flow condition. The tracer for the TFT was injected at the top of the two inch line. During the experiments, the condition of two phase line were as follows;

Well Flow Rate: Steam: 11t/hr, Hot Water: 11t/hr
Steam Quality: 50%
Line Pressure: 0.8 MPa
NCG: 10%
Hot water Conductivity: 37,000 μMho/cm

The fluid passed each device was introduced into mini-separator, and then released to the atmosphere. The measurement were carried out at three flow rates, Run 1 (20%), Run 2 (50%) and Run 3 (12%) ; 0~100 percent of the VFM is corresponded to 0~500 kg/hr. Also, the pressure for measurement was assumed to 0.4 MPa because of having to install a previous scheduled pressure before measurement
The TFT was, simultaneously, conducted to measure real flow rate.

3.2 Results of experiments

Vortex Flow Meter (VFM)

Figure 2 shows the stability of VFM with time. From these diagrams, the result of each run demonstrates that the operating condition had been a stable. Table 1 summarizes the results of the measurement for VFM and TFT. In this table, the average velocity of TFT was calculated from steam qualities. Judging from these experimental results, the data collected by VFM are in good agreement with TFT data (± 10%). From these experiments, we could affirm that the velocity measurement by VFM was available in two phase line.

Dielectric Steam Quality Sensor (DSQS)

Figure 3 shows the frequency distribution diagrams against the steam quality. As shown in these diagrams, run 1 and run 2 test result demonstrate good sorting, but the frequency distribution of the run 3 data shows a broad and skewed sharp. This cause will be discussed in later section. Next, the results of DSQS and TFT are given in Table 2. There is a big difference of the result between DSQS and TFT. This is a reason why the initial setting value for steam impedance and hot water conductivity was different, comparing to real these values. Consequently, we had to perform a correction of hot water conductivity and steam impedance to know the real steam quality. Also, noncondensible gas (NCGs) effect must be considered to calibrate the steam quality. The correction was carried out by the following methods

Conductivity of the hot water significantly effects the output of the steam quality. Although the hot water conductivity with and without TFT injection changed considerable, this would effect the measurement by the uncorrected DSQS. The DSQS had an E-Prom programmed with the Okuaizu specified 37,400 mho/cm hot water conductivity. However, measured pressure and hot water conductivity were as follows:

Run 1: 0.8 MPa, 7,000 μ mho/cm
Run 2: 0.6 MPa, 12,500 μ mho/cm
Run 3: 0.85 MPa, 13,500 μ mho/cm

To know the real impedance for two phase, we calculated the value by the vapor pressure and conductivity measured in the field. Then, real vapor impedance was calculated from the two phase impedance.

In general, geothermal vapor impedance is not so different at each geothermal field. However, the impedance of the Okuaizu geothermal steam was different due to a considerable amount of noncondensible gases (NCGs): more than 10%. This NCGs effect contributes to the DSQS steam quality shift but the exact amount is unknown. Since 100% dry steam could not be provided at various working pressures, the gas effect could not be determined with certainty. Knowing the effects of mixed geothermal gasses entrained with the produced steam is required to calibrate a DSQS system. Real steam impedance was calculated by following steps.

At first, we decided λ value by inserting the steam quality value measured TFT method in the equation (8). Then, λ value calculated by the equation (8) was inserted in the equation (7). By these steps, we could calculate the real vapor impedance for the Okuaizu field. The average vapor impedance was about 19,400Ω. The steam quality was finally calculated by using this impedance,

As a result of recalculation, two out of three of the runs were very close to the TFT results. Run 1 was within 1.7 percent, and Run 2 was within 2.5 percent in steam quality point from the calibration source, which was considered very respectable. Whereas, the data of Run 3 showed the higher steam quality than that of the TFT result. This cause will be discussed in the later section.

4. DISCUSSIONS

4.1 VFM

The vortex flow meter can measure a volumetric flow rate, but is not commonly used in geothermal two-phase flow measurement. This measurement must be corrected for the vapor and liquid volumetric contributions and other effects, but gives a first order approximation of the vapor rate. The VFM was able to provide stable measurement under the conditions encountered and provide a steam mass rate variation of 7.6 to 4.4 percent from TFT measurements. In considering the uncalibrated nature of the flow meter and other instrumentation, the results are acceptable under the conditions encountered.

4.2 DSQS

Generally, the measurement of two-phase flow using the DSQS requires a stable annular flow regime, with a steam quality range between 30 percent to 90 percent. This would not present problems with normal geothermal producing wells. However, the testing required a slipstream sample from one inch port on the main ten inch pipeline. Phase splitting and low steam flow created difficulties for the test. Stratified flow can create a layer of fluid on the bottom of the pipe essentially inducing a short circuit across the DSQS.

To check the cause of the different steam quality between DSQS and TFT (Run 3), the superficial steam velocity and hot water velocity were plotted on Taiel & Dukler diagram (Fig. 4). On this diagram, the data taken from run 2 was plotted on the near annular area, and the run 3 data was on near a stratified area. Run 1 data was plotted on the intermediate area. It is estimated that the third run had a very low steam quality and operated at very low superficial velocities in a complete stratified region. This operating point may just be outside the meter range.

5. FUTURE WORKS

It was found that the scale issue was unavoidable in the continuos monitoring. For the resolution of scale issue, the development of new device will be required installation of a device which can remove easily.

In general, a liquid area to the cross section of the pipe is much smaller than that of steam in the horizontal pipeline of the geothermal field. As a consequent, the regime of two phase flow may be restricted at the horizontal pipe; stratified flow, stratified wavy flow, and semi-annula flow. Hence, we propose a new two phase metering system by a laser velocity meter. This device can , directly, measure each phase velocity by scanning from upside of pipeline to bottom.

6. CONCLUSIONS

The following conclusions were obtained from field experiments.

1. DSQS and VFM can work in a two phase flow, but the DSQS does not work in a stratified flow regime.
2. The results of DSQS/TFT measurement agreed on two of three test runs, even when operated in a transitional annular and wavy stratified flow regime.
3. In the case of setting DSQS and VFM on the pipeline, scale issue is unavoidable for a long term monitor.
4. To correspond to the scale issue, we recommend a laser velocity meter for two phase metering.

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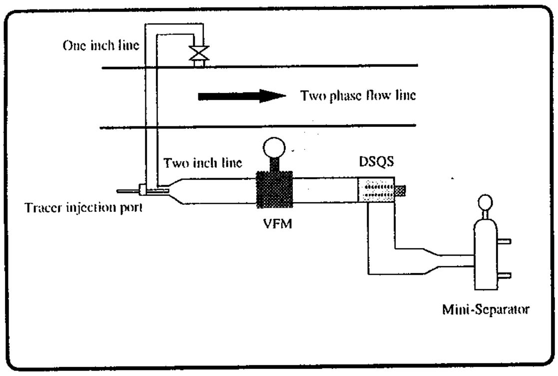

Figure 1. Overview of the field experiment for two phase metering.

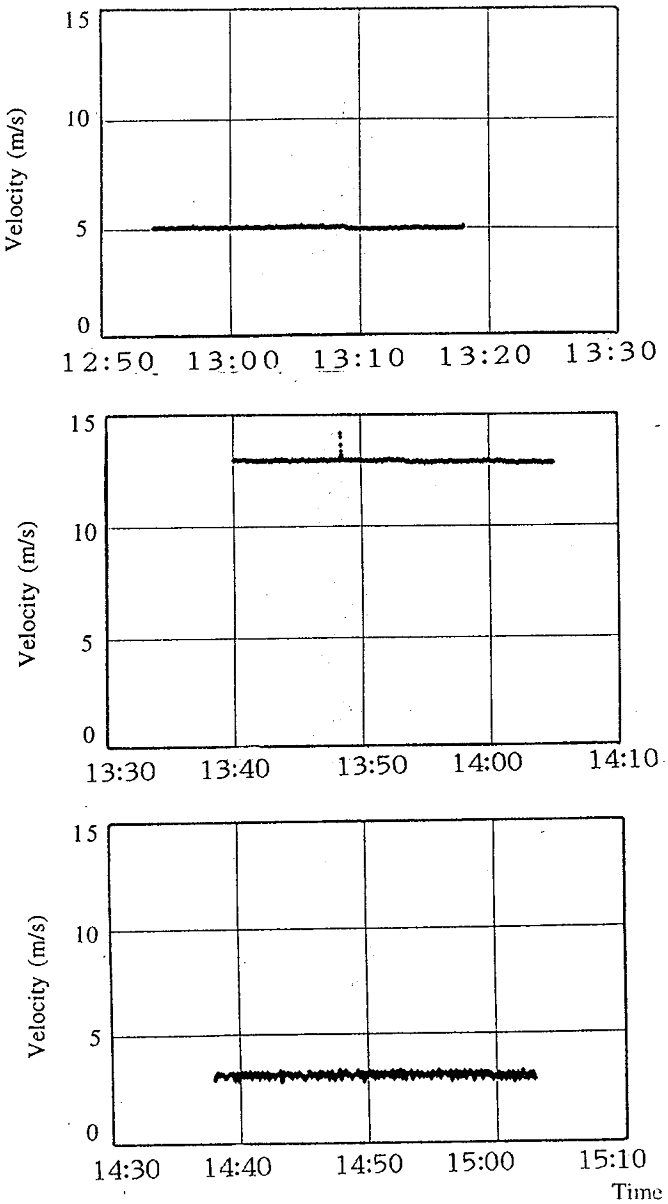

Figure 2. Results of the VFM field experiments.
(Top: Run 1, Middle : Run 2, Bottom : Run 3)

Table 1. List of the velocity results for VFM and TFT

	VFM Reading Value (%)	VFM Velocity (m/s)	TFT Velocity (m/s)
Run 1	19.60	5.04	5.62
Run 2	50.02	12.86	13.81
Run 3	12.04	3.09	3.65

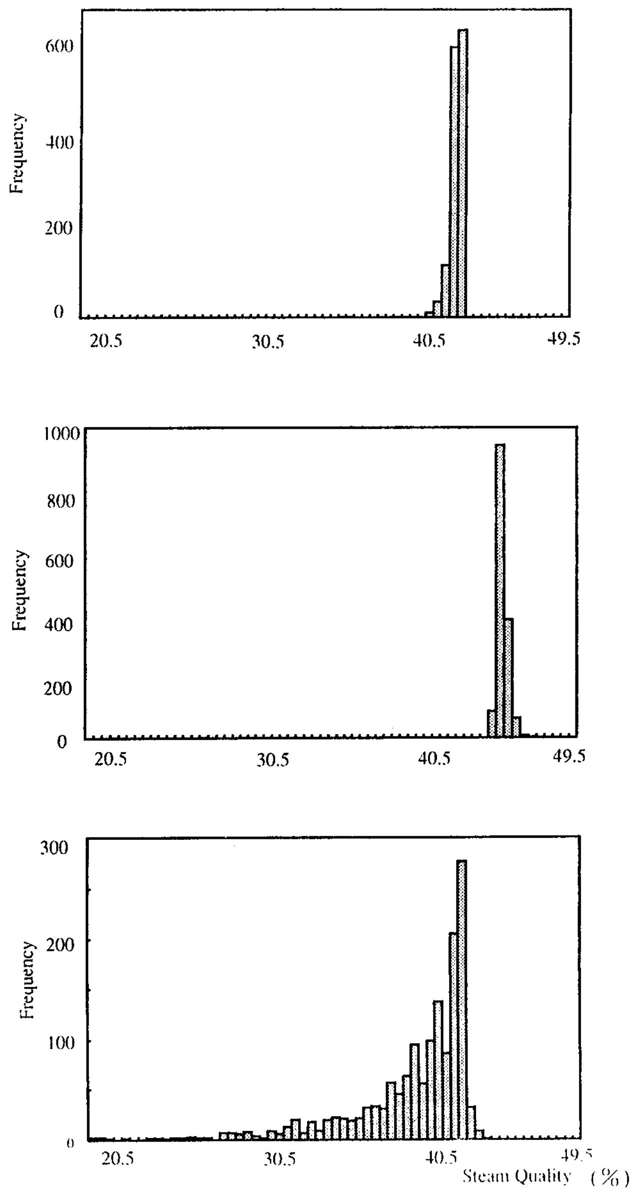

Figure 3. Frequency histogram of the steam quality by DSQS
(Top: Run 1, Middle: Run 2, Bottom: Run 3)

Table 2. List of the steam quality obtained by DSQS and TFT

	Steam Volume (kg/hr)	Hot Water Volume (kg/hr)	Corrected Steam Quality (%)	Steam Quality Obtained by TFT (%)
Run 1	168	126	58.8 (42.9*)	57.1
Run 2	324	95	74.8 (45.4*)	77.3
Run 3	116	301	54.7 (39.6*)	27.8

* ( ) : Data before correction

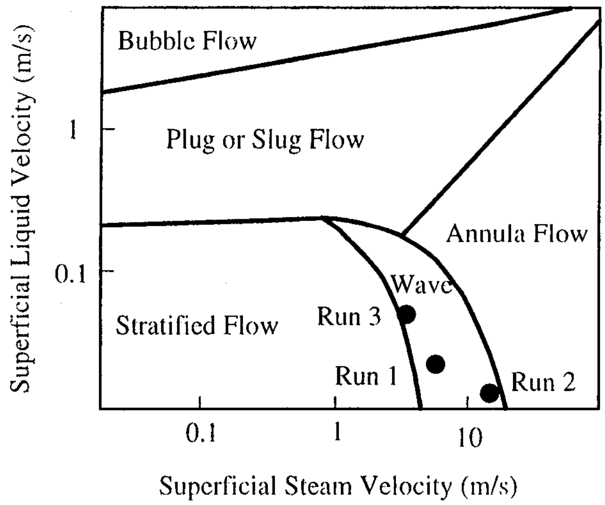

Figure 4. Flow patterns for the horizontal range of a pipeline