PROCEEDINGS, Thirty-Fifth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 1-3, 2010
SGP-TR-188

DEVELOPMENT OF MEASUREMENT METHOD OF STEAM-WATER TWO-PHASE FLOW SYSTEM USING SINGLE FREQUENCY WAVES

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ABSTRACT

The measurement method of steam and water flow rates by using several single frequency waves has been carried out. The measurement apparatus consists of transmitter, receiver, mixer, sound card, and laptop. The transmitter is clamped on the pipe and used for emitting the sound which will be absorbed by the fluid. The receiver is used for capturing the signal. In order to magnify and to make the signal softer, the mixer is required. Due to the number of input signals, the sound card is utilized for recording the signals. Software Cool Edit Pro Version 2.0 is chosen for generating frequency signal where locked frequencies of several values are selected. Installing all hardware, several measurements of different mass flow rates are performed to obtain the correlation between mass flow rates and the amplitudes of the signals. The study showed that the correlation between measured flow rates and the response amplitudes may depend on the flow rate and the fraction of each phase.

INTRODUCTION

A production test of a new geothermal well is normally carried out after drilling operation has been completed. The data gathered during the test are mass flow rates of total fluid, steam, water, wellhead pressure, and enthalpy of fluid. Then, deliverability and output curves are obtained for predicting the well performance. From this information, we can further decide the optimum operation of the production well and the scenario for future development.

There are two methods for measuring steam and water flow rates; (a) lip pressure method and (b) the orifice and weir method. In the lip pressure method, the fluid is discharged from the well directly to the atmosphere. The lip pressure is then measured at the extreme end of the discharge pipe using a liquid-filled gauge to damp out pressure fluctuations (Grant et al., 1982). In the latter method, the orifice is used for steam flow rate discharged from the separator and the weir for the water flow rate leaving from the separator (Lindeburg, 1992). The wellhead pressure is usually measured using a bourdon gauge. In order to avoid any thermal and chemical contaminations on surface soil and vegetations near wellbore by discharging fluids to the atmosphere, the latter method is preferable for flow measurement.

However, due to the complexity of the equipments in the second method and there is a desire that the quick information on mass flow rates is required, this preliminary study proposes an alternative method for quick and simple mass flow rate measurement by utilizing the audible single frequency wave. The simplicity of this method is that we just clamp the main sensors on the pipe surface without destroying the pipe installation and disturbing the fluid flow inside the pipe. Some calibrations with field data are, of course, required for reliable measurement results.

THEORY

The basic principle of the developed sonic flow meter method is by calibrating the recorded parameter shown on the meter and the fluid flow rate obtained by the standard flow meter. When water and steam flow in a pipe and the portion of water is larger than that of steam or the area occupied by the water is larger than that of steam, the water velocity becomes higher. The larger the area occupied by the water in a pipe, the higher the wave amplitude is absorbed by the water. The analysis is performed by determining the highest amplitude for a single generated frequency. Having known the maximum amplitude, then it must be corrected by a factor for the respective flow rate.

Sound Wave

Sound is a mechanical compression or a longitudinal wave which travels through a medium formed by the particle of medium from a vibrated source. The audible sound is one that has a frequency ranging from 20 to 20,000 Hz.

Energy

The fluid particle that has certain acceleration will produce force or energy and the wave as well. The wave brings energy to everywhere. When the wave travels in the medium, the energy is transferred as the vibration energy from the particle to the medium particle. The amount of energy brought by the wave can be expressed as,

$$E = 2\pi^2 m f^2 p^2 \tag{1}$$

where E, m, f, and p are wave energy, particle mass in medium, wave frequency and wave amplitude, respectively. From Eq. (1), it can be seen that the energy produced by the sound wave is proportional to the square of amplitude. This correlation may be utilized as the basic concept for the measurement design.

Sound Wave Generation

In this method, the sound wave is generated by the use of crystal piezoelectric. When a crystal is placed in an electrical magnetic field of alternating current, the molecules will vibrate and produce the wave with high frequency. The generated frequency may reach 50 kHz.

Sound Wave Propagation

The traveling velocity of sound is faster in solid medium than in liquid and gas. Because the sound velocity is proportional to the frequency, the medium that has denser atomic structure must use higher frequency to transmit the wave. The maximum ability of frequency in propagating the wave is applied as the parameter for flow meter design.

Beside the wave can propagate in solid, liquid and gas, the wave can also be reflected or absorbed by medium. When the wave hits a medium, part of the wave is reflected and other part may be transmitted or absorbed. The ratio between the pressure amplitude of transmitted wave to that of reflected wave depends on acoustic impedance. Mechanically, impedance means the ratio between force amplitude and velocity amplitude. It can also be defined as the ratio between potential amplitude and current amplitude. Due to the partial absorption of the wave by the medium, the wave amplitude may be reduced.

Wave Propagation with Constant Frequency

The sound wave is said to be propagating with constant frequency if it oscillates as a sinusoidal wave and as a function of time. The acoustic pressure P_{acs} is defined as,

$$P_{acs} = P_{peak} \cos(\omega t - \varphi) \tag{2}$$

where P_{peak}, ω and φ are pressure peak, angular frequency and constant phase, respectively.

<u>Sound Intensity</u>

The amount of energy that is transferred through an area of medium is said to be sound wave intensity. The larger the amplitude of vibration of particles in medium, the larger the energy transferred through the medium is. Consequently, the sound wave intensity becomes larger as well. The unit of the sound intensity is in decibels (dB). It can be expressed as,

$$I = \frac{E}{tA} \tag{3}$$

$$I = \frac{P}{A} \tag{4}$$

where I, E, t, and A are sound intensity, energy, time and area, respectively.

<u>EQUIPMENTS AND APPARATUS</u>

The schematic diagram of the experiment is shown in Fig. 1. The equipments and apparatus required in the experiment consist of the following items.

1. Boiler (steam generator)
2. Water flow breaker
3. Rotameter for steam
4. Steam-water mixer
5. Acrylic pipe
6. Flange (pipe connector)
7. Plexiglas pipe
8. Transmitter
9. Receiver
10. Paper screen
11. Lamp
12. Separator
13. Water Tank
14. Pump
15. Valve 1
16. Valve 2
17. Rotameter for water
18. Mixer
19. Signal analyzer
20. Note book

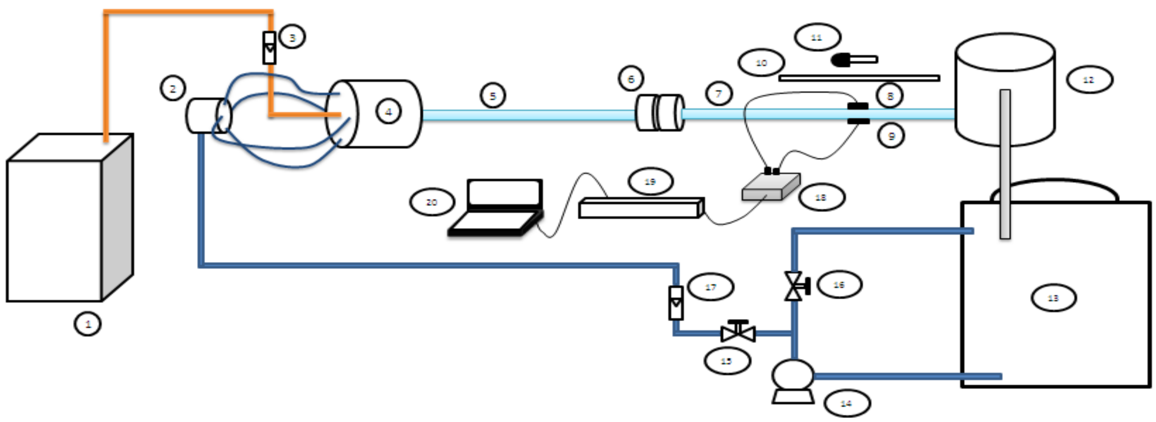

Figure 1: The pipe installation and the equipment and apparatus arrangement for experiment.

FLOWMETER DESIGN

The block diagram of the flow meter and the transducers mounting are shown in Figures 2 and 3, respectively.

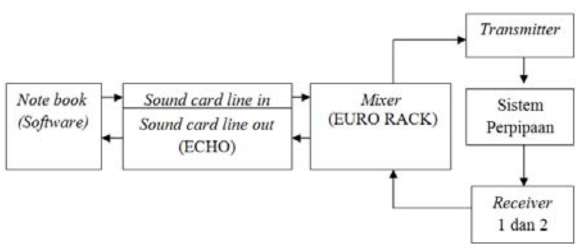

Figure 2: Block diagram of the hardware.

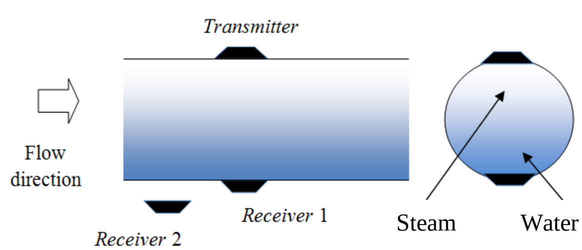

Figure 3: The transducer mounting.

Transmitter is used for generating the signal. The speaker flat type with the frequency response of 18,000 - 21,000 Hz is used in this experiment. It is made of circled thin aluminum with diameter of 2.5 cm and thick of 1 mm. The transmitter is clamped on the upper pipe surface and the thin aluminum vibrates when generating signals.

Receiver is used for receiving the signals generated by the transmitter. The piezoelectric type is used in the experiment and has frequency response from 0 - 44,000 Hz. The shape is similar to that of transmitter but it has diameter of 1.5 cm and thick of 1 mm. It is made of piezoelectric materials that can vibrate when receiving input signal. It is clamped on the opposite pipe surface with the transmitter position. Receiver 1 is used for capturing the signal from fluid flow and the environment, while receiver 2 is for environment only. The difference between the two represents the signal from fluid flow only.

Mixer is used for amplifying and softening the output signal leaving from line out sound card to be transmitted to the transmitter. After the signal is generated by the transmitter to the flowing fluid medium, it is received by the receiver. It is necessary to adjust the signal level by the mixer before entering the line in sound card in the laptop.

Because of the limited capability of the laptop available where only one line for input signal, the sound card ECHO with 12 I/O and sample rate of 192 kHz is utilized. In order to generate the frequency signal, the software of Cool Edit Pro v 2.0 that is already installed in the laptop is utilized. It is the software that is capable for recording, editing and mixing the sound. The recorded parameter that has been edited and mixed is saved in wav format. Once the hardware is ready, the locked frequency signal is selected as the generated signal. The signal is sent to the transmitter to be generated and received by the receiver and then the frequency is analyzed by Cool Edit.

RESULTS AND DISCUSSION

Locked frequency signal or single frequency and sometimes called as tone frequency is defined as a generated signal for one frequency only. In this experiment, the locked frequencies are selected to determine the most visible signals to be analyzed.

Determination of locked frequencies

Before utilizing the selected locked frequencies, they must be analyzed using method and one of them is white noise signal. It is the signal where only on that signal all frequencies are generated simultaneously with the same amplitudes. The signal may represent the real situation for all measurement conditions. The results of the responses due to white noise signal are presented on Figures 4 and 5.

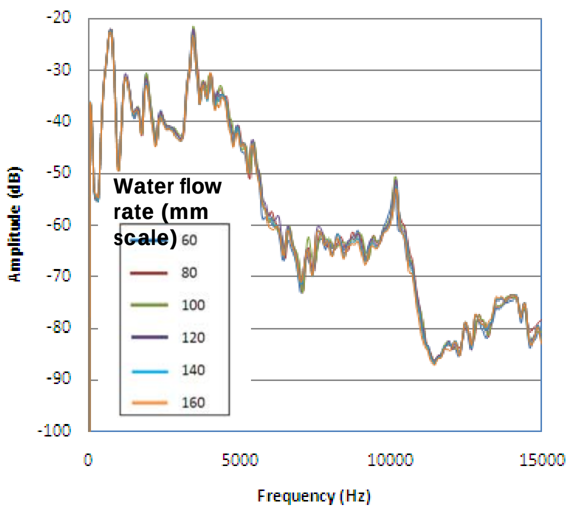

Figure 4 : Amplitude responses with the frequencies due to white noise signal on the varied water flow rates.

From Fig. 4 it can be seen that the responses of the system lie between the frequencies of 0 to 7,000 Hz. The flow rate variations do not show significant difference. This can be indicated by no specific order of the frequency responses due to various flow rates.

The similar situation can be observed on amplitude responses on the varied steam flow rates which are shown in Fig. 5. The responses of the system lie between the frequencies of 0 to 7,000 Hz. However, there is a slightly different response due to various flow rates for the frequency of 1,900 Hz.

From these results, the single frequency will be determined for further measurement. There are three ways how to determine the single frequency. The first one is just by determining the middle frequency, i.e. the difference between the two frequency responses. In this case the value is (7,000-0)/2=3,500 Hz. The second way is by determining the peak of frequency responses. This indicates that the frequency wave which produces resonant phenomenon with the white noise frequencies is the only one, i.e. one causes the maximum amplitude.

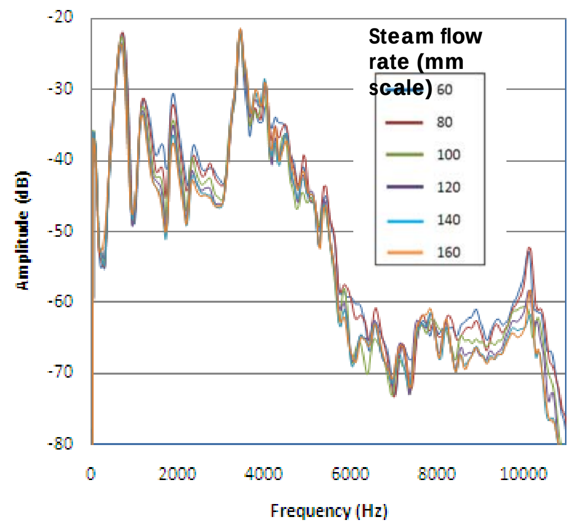

Figure 5 : Amplitude responses with the frequencies due to white noise signal on the varied steam flow rates.

From the observation it can be found that the peak response of the frequency can be determined to be about 3,500 Hz as can be seen in Figures 6 and 7.

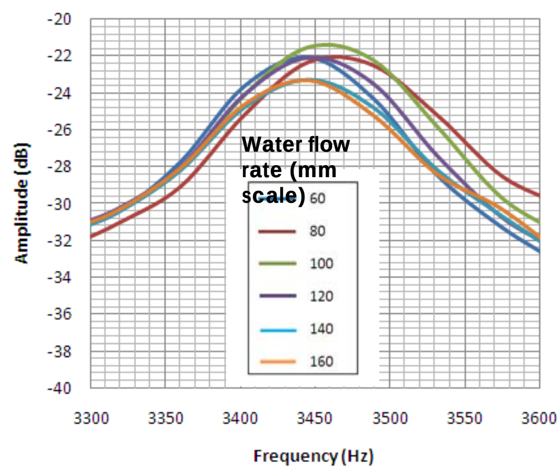

Figure 6 : Amplitude responses for the frequency of 3,500 Hz on the varied water flow rates.

And the third one is by determining the frequency in which the amplitude responses have good order with the corresponding flow rates. From the observation in this experiment, the variation of water flow rates did not show significant differences in the values. On the other hand, the variation of steam flow rates showed relatively clear differences in the value, i.e. at 1,900 Hz as shown in Figures 8 and 9.

From these results, we can understand that the choice of which frequency that will give good readings is based on many factors, such as the total flow rates, the fraction of each phase and flow patterns that were beyond this study.

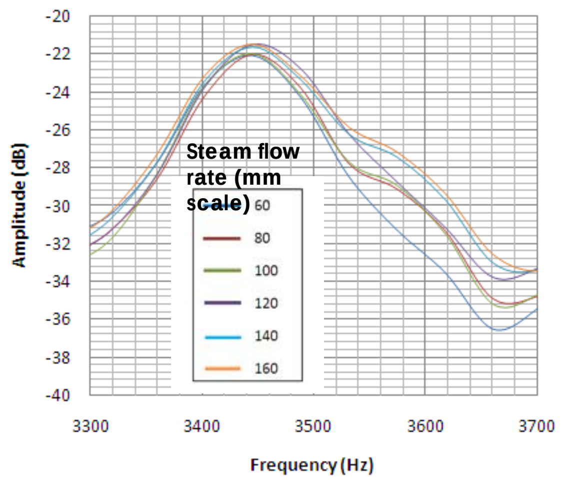

Figure 7 : Amplitude responses for the frequency of 3,500 Hz on the varied steam flow rates.

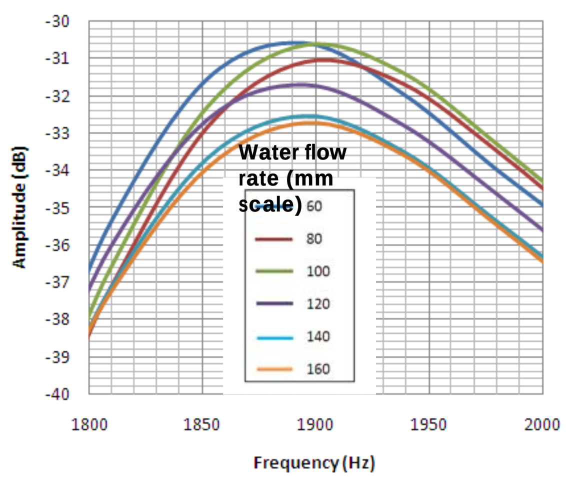

Figure 8 : Amplitude responses for the frequency of 1,900 Hz on the varied water flow rates.

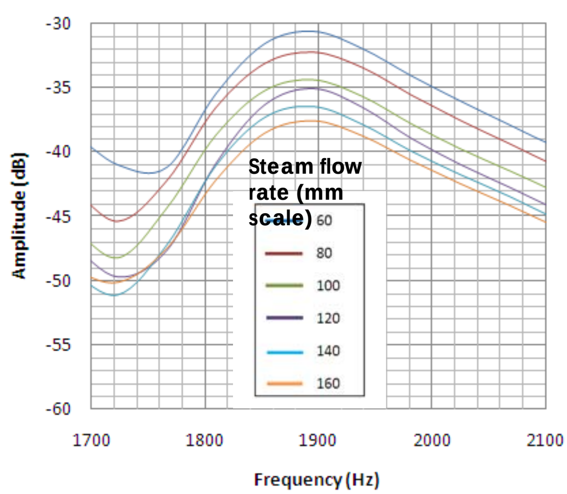

Figure 9 : Amplitude responses for the frequency of 1,900 Hz on the varied steam flow rates.

Flow Rate Calibration

The calibration of mass flow rates was carried out by utilizing two rotameters for each phase. The accuracy of measurements is much dependent on the readings by the observer. The measurement of each flow rate value was conducted three times. The calibrated water flow rate was carried manually by flowing water from the pump then stored into volumetric beaker for a specified time. While the steam flow rate was calibrated by assuming that it has similar properties with ideal gas. So, the air from the compressor was used for calibration of steam flow rate. The correlation between the calibrated flow rates and the height of the float in rotameters can be seen in the Figures 10 and 11.

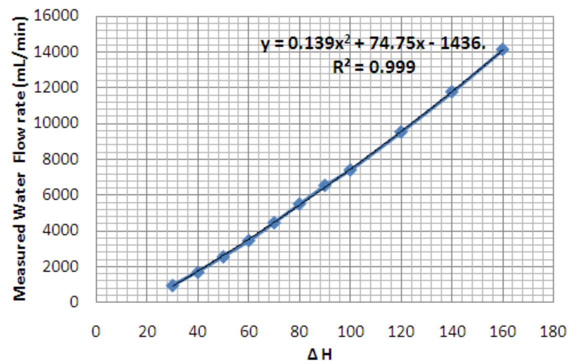

Figure 10 : Result of calibration for water flow rates.

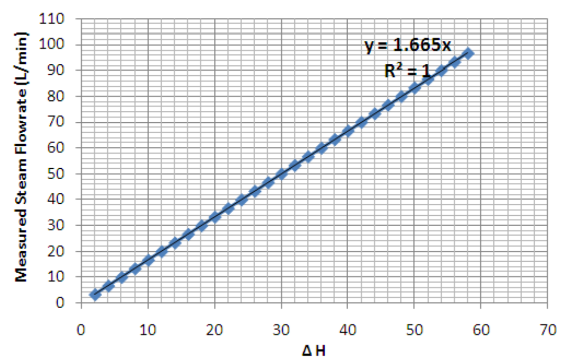

Figure 11 : Result of calibration for steam flow rates.

Measured flow rates

In this study, only the measured flow rate that is obtained by using the single frequency of 1,900 Hz will be presented because of its ease of reading. Table 1 shows the measured flow rate data with corresponding RMS amplitude. The similar result is presented in Figure 12. The RMS amplitude is used because its value fluctuates due to the fluctuation of the system response. The average value is obtained by scan function of the Cool Edit software. The range of duration for averaging is 60 seconds for 1 value.

Table 1 : The correlation between total mass flow rate vs RMS amplitude for various steam rate.

Exp.	∆H Water	∆H Steam	Total Mass Rate (kg/s)	RMS Amp. (dB)
1	60	60	3.481	-12.7812
2	80	60	5.320	-13.1203
3	100	60	7.268	-12.4847
4	120	60	9.324	-12.7483
5	140	60	1.488	-12.7483
6	160	60	13.761	-12.6596
7	60	80	3.492	-12.4344
8	80	80	5.331	-13.0317
9	100	80	7.279	-12.1263
10	120	80	9.335	-12.7380
11	140	80	11.500	-12.4426
12	160	80	13.773	-12.5602
13	60	100	3.504	-12.4869
14	80	100	5.3432	-13.2978
15	100	100	7.290	-13.6496
16	120	100	9.346	-12.7241
17	140	100	11.511	-13.0177
18	160	100	13.784	-13.4126
19	60	120	3.515	-13.5653
20	80	120	5.354	-13.8269
21	100	120	7.302	-12.9712
22	120	120	9.358	-13.8808
23	140	120	11.522	-14.6592
24	160	120	13.795	-14.3646
25	60	140	3.5269	-12.7769
26	80	140	5.3658	-13.7287
27	100	140	7.3133	-15.6983
28	120	140	9.369	-14.4738
29	140	140	11.533	-14.8083
30	160	140	13.807	-15.7569
31	60	160	3.538	-19.1705
32	80	160	5.377	-21.1813
33	100	160	7.324	-19.6963
34	120	160	9.380	-19.8954
35	140	160	11.545	-19.9577
36	160	160	13.818	-21.0044

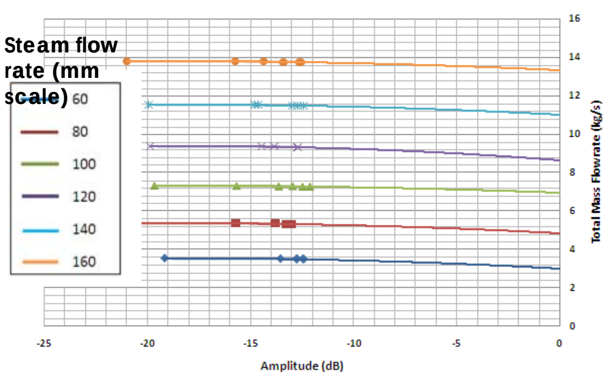

Figure 12 : The correlation between total mass flow rate vs RMS amplitude for various steam rate at the frequency of 1,900 Hz.

In a digital system, the scale used is dBFS (Decibel Full Scale). The value of 0 dBFS is the highest level that can be expressed by the personal computer, so the measured values are always negative below the maximum value as shown in Fig. 12.

The change in the amplitude is affected by the flux of each phase. So, each curve shown in Fig. 12 may basically represent the mass flow rate of the steam in the two-phase flow. If the rate of one phase changes it will cause the rate of each phase passes through the cross sectional area of the pipe also changes. The change in the rate per area of the pipe will affect the generated signal velocity. This will result in the change in the amplitude and sound intensity. The more water flow will cause the larger the pipe cross sectional area that will be occupied by the water. This implies the reduction of the amplitude received by the transducer. This is because that most of the energy is brought by the water flow. On the other hand, when the large amount of steam flow occupies the cross sectional area of the pipe the amplitude response received by the transducer becomes larger. However, the velocity of each phase should also be taken into account for better results which is beyond the study.

Future development

There may be a possibility to apply this measurement method in the fields. There was an opportunity to test the method for a production well at Dieng geothermal field, Central Java, Indonesia. The test just was aimed to know the signal response of the system due to several valve operations. The photograph of the testing is shown in Figure 13.

Figure 13 : The field testing of the developed method.

However, in order to implement the method for flow rate measurement in geothermal application the method must be calibrated with many wells using standard flow rate measurement methods. The idea is to use other parameters, such as pressure at wellhead and then to correlate them with the amplitude response and the measured flow rates from the standard methods. The more wells used for calibration the more accurate the method will be.

CONCLUSION

1. The measurement of steam-water two-phase flow can be performed by utilizing single frequency wave.
2. The selected single frequency should be chosen because of the ease of readings of the response.
3. The correlation between measured flow rates and the response amplitudes may depend on the flow rate and the fraction of each phase.
4. It is required to calibrate the developed method with many wells for further application in the fields.

ACKNOWLEDGEMENT

The authors would like to acknowledge Gadjah Mada University for financial support on this research through UGM-RUSNAS Program. Thanks are due to Luthfi and Irfan for installing equipments and apparatus and collecting experimental data.

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