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FIELD TESTS OF CONDUCTANCE CROSS-CORRELATION FLOWMETER IN MEASUREMEANT OF OIL/WATER TWO PHASE FLOWS IN HIGH WATER PRODUCTION WELLS [1]

**Xing-Bin, L.; *Jin-hai, H.; **Ling-an, X.; *Zhi-hui,Y.; *He-tang,Q.; **Xiao-ping, L.*
**Yu-hui Zh.; *Chun-hui H.; *Jia-qiang, Zh; *Zhuor Q.; *Hai-jun, Zh.*
*Daqing Production Well Logging Institute, China; **Tianjin University, China

Abstract: A new type of conductance cross-correlation flowmeter based on two conductance sensors has been designed to measure the velocity of oil/water two-phase flow in a borehole. This flowmeter is capable of measuring the flowrate in a production well with high water cut. Experiment results carried out in a multiphase flow loop demonstrated that the flow velocity measuring range is from 0.0368 to 3.68 m/s, and the relative deviation is 2.3%. Field tests have been performed with the flowmeter in Daqing oilfield. The total flowrates measured with the flowmeter in the well are very closed to the flowrates metered at surface.

Keyword: Conductance Sensor, Cross Correlation Flowmeter, Two-phase Flow, Production Logging

1 INTRODUCTION

Production profile logging, which is to determine the individual flowrates of multiphase fluid entering from each production zone at different depth in an oil well, is very important for oil well production. For oil/water two-phase producing wells, the downhole logging tool is usually a combination of flowmeter and water holdup meter. Spinner flowmeter and capacitance holdup meter are widely used in downhole measurements. Although the spinner flowmeter has the feature of simple structure, low pressure loss, and good linearity between rotation of spinner and flowrate, the instrument constant of the flowmeter is liable to be affected by long-term working and being mended after logging, which decreases the measuring accuracy. Besides these, the producing sand moving with the fluid may also clog the spinner.

The cross-correlation flowmeter, which performs measurements by using intrinsic fluctuations of the fluid, is suitable for measuring flowrate in multiphase flow conditions. As there is not possibly any movable sensitive element, this meter can avoid the main shortcoming of spinner flowmeter, i.e., it has an unstable instrument constant caused by friction. During the past decades, many kinds of correlation flowmeter based on the capacitance sensor, conductance sensor, and ultrasonic, thermal, and radioactive sensors had been presented, however, up to now there is not yet a report on the application of a commercialized cross-correlation flowmeter to oil industry.

Lucas [3] [4] proposed the method of correlation flowmeter based on the ring-type electrode impedance sensor for measuring the flowrates of two-phase in one-dimensional, vertically upward bubbly oil/water flows. It provides a valuable idea for measuring the flowrates in an oil/water two-phase flow.

Liu et al [5][8][9][10] have been working in this area since the early 1990s. As the oil reservoirs in Daqing oil field are composed of multi zone-developed sandstone, and, at present, the oil field has already been at the late stage of development with a high water cut. In producing fluid, the water becomes the continuous phase, and the oil is the dispersed phase. Furthermore, in most cases, bubbly flow is the dominant flow regime existing in borehole. In order to determine the production profile under the condition of high water cut, Liu Xingbin et al [5][6][7] proposed the method of measuring water holdup by using the conductance sensor. The holdup meter has been put into use in practical logging in Daqing oilfield. Liu et al [5][8][9][10] also suggested the method measuring the flowrate of each production zone at different depths in a borehole by using a correlation flowmeter based on the conductance water holdup sensor. This flowmeter has no movable and no flow-disturbing parts, and therefore is free of some borehole problems. On the basis of the theoretical and experimental researches mentioned above, the prototype flowmeter for field logging has been developed at present. After being calibrated, the flowmeter has been tested successfully in a sucker

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rod pumping well with high water cut in Daqing oilfield, and the testing results are optimistic.

2 PRINCIPLE AND STRUCTURE OF THE FLOWMETER

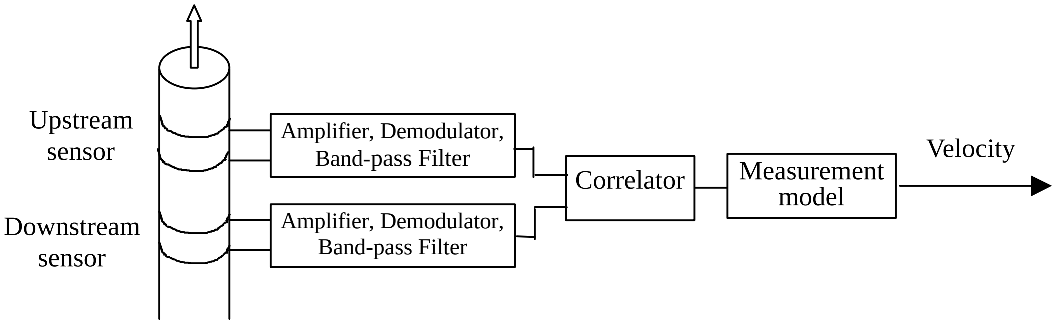

Figure 1. Schematic diagram of the conductance cross-correlation flowmeter

The principle of the conductance cross-correlation flowmeter is shown in Fig. 1.The sonde of the flowmeter consists of two conductance sensors, each sensor consisting of ring-shaped electrodes [6] which are mounted flush on the inside wall of the insulator pipe through which the fluid flows. The two sensors sense the conductance of the fluid flowing through the sensor. The variation of the oil/water mixture conductivity causes the variations of the output signals from the two sensors. The signals from the sensors are transmitted into electronic cartridge, where the signals are amplified, demodulated, and band-pass filtered. The output flowing signals from the electronics are cross-correlated by data processing unit and the transit time of the fluid flowing from upstream sensor to downstream sensor can be derived. After being calibrated in multiphase flow loop, the flowmeter can be used for measuring downhole flowrates.

Cross-correlation function, $R_{xy}(\ )$, with the time delay as its variable can be obtained through random flowing signals $V_x(t)$ and $V_y(t)$

$$R_{xy}(t) = \frac{1}{T}\int_0^T V_y(t)V_x(t-t)dt \qquad (1)$$

Given the distance between the two sensors L, the correlation velocity V_{cc} can be derived with the transit time $\ _0$

$$V_{cc}=L/\ _0 \qquad (2)$$

and the measured flowrate Q can be derived from Eq. (3)

$$Q=V_{cc}A \qquad (3)$$

where A is cross section area of the sensor' flow channel. For practical applications, the flow meter should be calibrated in a multiphase flow loop.

The prototype flowmeter for downhole testing consists of measuring sensors, electronics, and diverter, with 28mm I.D, as shown in Fig. 2. In Daqing oilfield, most production wells yield very low production rates.

Commonly, daily production rate in a single well is within 100m^3/d. In a casing of 125mm I.D, flow velocity is below 0.1 m/s. It is difficult for a flowmeter to measure such a low velocity accurately with the tool inside the casing. To solve this problem, a diverter should be used to increase the velocity of the measured

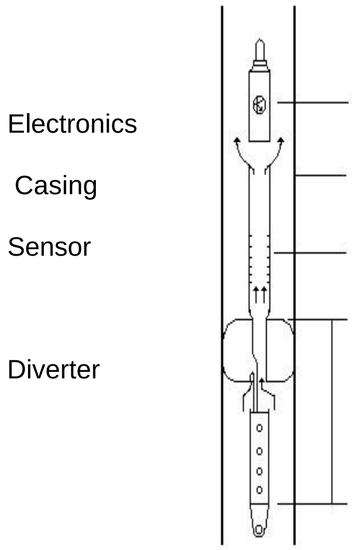

Figure 2. Schematic diagram of the structure Conductance Cross-Correlation Flowmeter

fluid passing through a measuring channel inside the flowmeter. A diverter installed in the upstream above the sensors is capable of being open and closed. In the courses of up and down logging runs, the diverter keeps closed, which ensures that the flowmeter can move smoothly in the casing. When the flowmeter being located at the desired depth in the wellbore, the diverter will open and seal the annulus between the tool and the casing. Therefore the producing fluid from below is funneled into a narrow sensing channel inside the flowmeter, and discharged back into the casing through the outlets above the diverter. The fluid velocity in sensing channel is increased by near 50 times, which leads to a more accurate measurement. This technique proved to be the good method of measuring the flowrate in a low production rate well.

In a low production well, the flow velocity of the oil exceeds the velocity of the water, due to the difference between the densities of the oil and the water. This leads to the water holdup, which is defined as the volumetric concentration of water in the wellbore, is higher than the water cut, which is the ratio of water flowrate to the total flowrate. The difference between the water holdup and the water cut increases with the decreasing of average velocity. And therefore in low velocity condition, even if water cut is very low, the water is likely to be the continuous phase. For instance, when the flowrate is less than 5 m^3/d in a pipe
of 20mm I.D, and the water cut ranges from 0 100%, the water is still the continuous phase. When the flow velocity is high enough, compared to the average velocity, the difference between the velocities of the oil and the water is negligible, and the water holdup is almost equal to the water cut. Therefore the flowmeter can work under the condition of water cut above 50% at high velocity and under the condition of water cut below 50% at low velocity.

3 EXPERIMENTS IN A MULTIPHASE FLOW LOOP

The prototype flowmeter was calibrated in the flow loop in Daqing Production Well Logging Institute. The test facility consists of a transparent perspex pipe of 8m long and 125mm I. D., an overhead flow-stabling tower of 45m high, standard flow meters, and three interconnecting separation tanks. The flowing media in the loop are water and diesel oil. The flowmeter was positioned inside the pipe, and the diverter was opened to force the fluid from below to flow into measuring channel inside the flowmeter. The total flowrate ranged from 1 m^3/d to 100m^3/d. At first the flowrates were set at 1m^3/d, 2m^3/d, 5m^3/d and 10m^3/d respectively. After the flowrate was above 10 m^3/d, each increment of 10m^3/d was set, until the total flowrate reached 100m^3/d. For each total flowrate, the water cut was adjusted to a desired value. The signal waveforms from the flowmeter were recorded and processed by a signal analyzer DATA 6500. With known flowrate and water cut, the correlation velocity V_{cc} was calculated based on Eq.1 and Eq.2. In repeat measurements, a more accurate average correlation velocity was obtained.

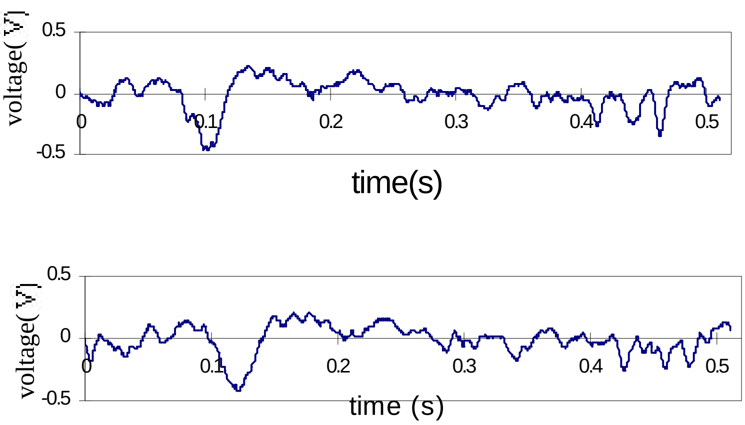

Figure 3. Typical flowing signals from the two sensors. flowrate=40 m^3/d, water cut=80%

Typical flowing signals from the two sensors are shown in Fig. 3. From the figure, we can see clearly that the two sets of signals are very similar. The typical normalized cross-correlation functions are shown in Fig. 4. The relationship between the correlation velocity and the standard flowrate with different water cuts is shown in Fig. 5. In the figure, we can see that the flowmeter has responses to the flowrates, which range from 1 100m^3/d.
When the total oil/water flowrate is above 5 m^3/d, there is a good linearity existing between the correlation velocity and the standard flowrate, and the correlation velocity is independent of water cut.

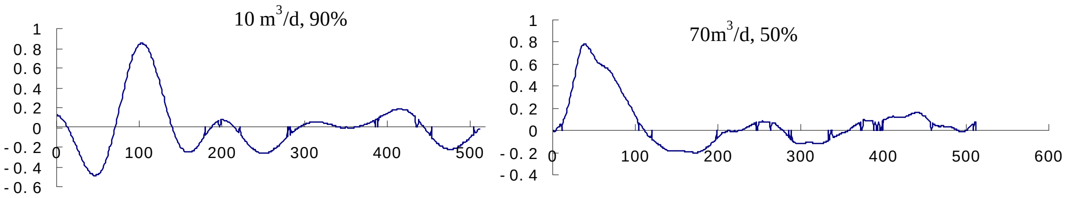

Figure 4. Typical normalized cross-correlation functions

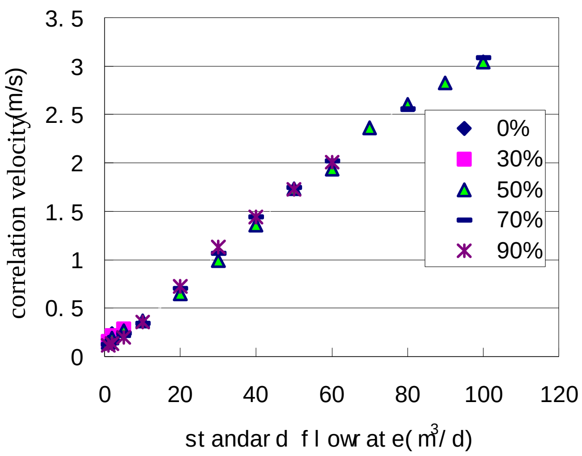

Figure 5. The correlation velocity *vs.* the standard flowrate at different water cuts

The experimental data are fitted with least square method when the flowrates are equal to and exceeding 5m^3/d. The linear correlation coefficient is 0.9988, and the standard deviation is 0.072 m/s. Considering the correlation velocity corresponding to maximum standard flowrate (100m^3/d, and the standard flow velocity is 3.68m/s in a measuring channel of 20mm I.D.) is 3.09m/s, the relative deviation is 2.3%. When flowrates are lower than 5m^3/d, the correlation velocity has a tendency of increasing. This is caused by the difference between the flowing velocities of the oil and water. The oil bubbles flow upward faster than the water, which may lead to a large measured correlation velocity.

The repeated experiment was taken with the flowmeter, and another calibration chart was obtained. The maximum of relative differences between the corresponding measured correlation velocities in the two charts is less than 3%, which indicates the good repeatability of the flowmeter.

4 FIELD TESTS IN OiI WELLS OF HIGH WAER CUT

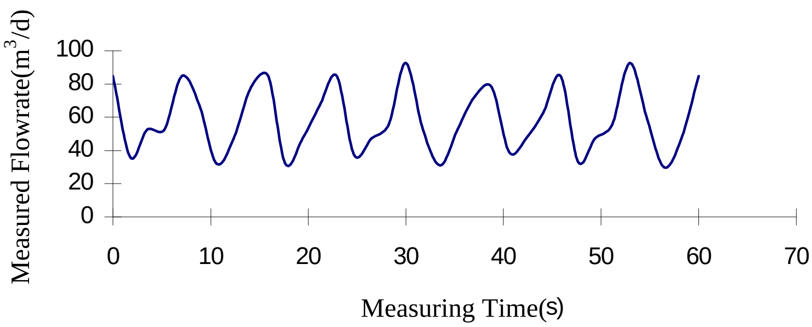

Figure 6. The measured flowrates varied with time at depth of 906m in Well N2-J4-441.

After being calibrated in multiphase flow loop, the prototype flowmeter was run in 11 pumping wells with high water cut in Daqing oilfield. When tested at well site, the downhole flowmeter connected with the armored logging cable was run into the wells by the winch drum installed on a winch truck. Armored triple cable was used in tests. One of the 3 conductors powers the diverter to be opened and closed, and the other two conductors were used to transmit the flow noise signals from two conductance sensors. When the tool was lowered at the top of given production zone, the diverter was opened and the measurements were taken. After finishing the measurements at the depth, the diverter was closed and then the tool was removed to the top of another production zone to be logged. The flowing signals from the downhole flowmeter were acquired and processed by a signal analyzer. The sampling size was 1024, and sampling period was between 0.1ms and 2 ms, according to the flowrates to be measured. The measured transit times between the two conductance sensors were converted into the flowrate by using the calibration chart obtained in multiphase flow loop. The flowrates varying with time were recorded, and the average values were taken.

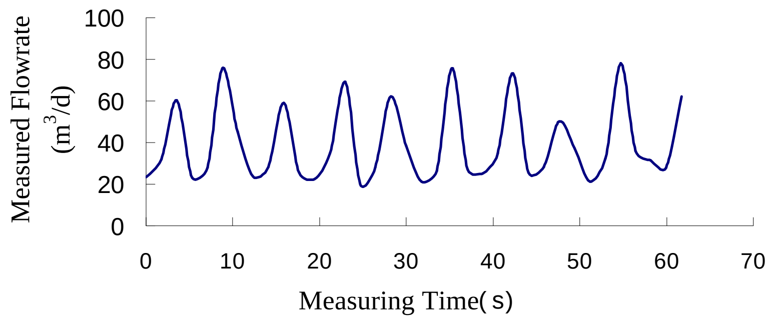

Figure 7. The measured flowrate varied with time at depth of 1041.3m in Well N3-10-C246.

The average flowrate is 57.9 m^3/d, the frequency of strakes of the pump was 8.5 strokes /min.
The average flowrate is 40.3 m^3/d, and the frequency of strokes of the pump was 8.5 strokes/min.

Fig.6 and Fig.7 show the measured flowrate curves at the given depths in the Well N2-J4-441 and the Well N3-10-C246 respectively. The flowrates varying with time are accord with the frequencies of strokes of the pumps. This shows that the flowmeter is suitable for measuring the transient flowrate in multiphase pulsating flows. The average value of the flowrate is stable, which shows that the measuring results are reliable.

Table 1 lists the total flowrates measured by using the flowmeter at the depths where all the produced fluid passing through in 11 oil production wells and the flowrates metered at the wellheads. In Table 1,we can find that the two flowrates measured in wellbore and at the wellhead in a well are very near, except for the Well N1-40-521. In this well, plenty of natural gas was produced, which caused that the flowrate measured in the well was much higher than that metered at the wellhead. The large difference between the two flowrates indicates that the flowmeter is not suitable for running in a well with high gas production.

Table 1. Comparisons between the flowrates metered at wellheads and the flowrates measured by the conductance cross correlation flowmeter

Series number	Well Number	Depths of the Measured Stations m	Measured Flowrates m3/d	Flowrates Metered at Wellheads m3 /d	Differences Between the Flowrates m3/d
1	N3-2-C77	1136	78.6	77	1.6
2	N3-10-C246	1039	57.3	54.7	2.6
3	N4-60-C255	1085	18.6	15.5	3.1
4	N1-40-521	964	55.6	37	*
5	N2-J4-441	906	57	52	5
6	N3-1-P56	1145	94.5	91.6	2.9
7	N2-J6-420	958	36.1	33	3.1
8	O268-76	1090	4.6	5.1	0.5
9	F128-60	1480	10.9	9.1	1.8
10	S8-31-642	1016	40.2	36	4.2
11	L6-1738	1060	104.9	112	7.1

*plenty of gas was produced from the well.

5 CONCLUSIONS

The conclusions are drawn from the above analysis as follows:

1. The developed conductance cross-correlation flowmeter is suitable for measuring flowrate of oil/water two-phase flow while the water is the continuous phase. The tool has no movable and no flow-disturbing element, and therefore has a stable instrument constant.
2. The experiments carried out in multiphase flow loop show that the flowmeter has wide measurement range of flowrate, good repeatability, and acceptable precision.
3. The results of the field tests carried out in 11 pumping wells show that the flowmeter is not only used for measuring the flowrate in an oil/water two-phase steady flow with high water cut, but also suitable for measuring the flowrate in a transient multiphase flow in pumping wells.
4. The flowmeter is not suitable for measuring an oil/water/gas three-phase flow, single-phase flow, and oil/water two-phase flow while the oil is the continuous phase.

After being further improved, the flowmeter will be found wide use in production profile logging in oil field with high water production

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AUTHORS: *Dr Liu Xing-bin, Daqing Production Well Logging Institute, Fengshou, Shartu District, Daqing City -163153, Heilongjiang Province, P R China. Phone number: 086-459-5821905, E-mail:* liuxb@cjs.dq.cnpc.com.cn. *Prof. Dr. Xu Ling-an, Tianjin University, P. R. China. Phone number: 086-022-27404197, E-mail:* Laxu@public.tpt.tj.cn