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Inexpensive and Accurate Measuring Device for Water Constitute in Oil

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جهاز اقتصادي و دقيق لقياس كمية الماء في الزيت

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الخلاصة: هذه الورقة تقدم جهاز قياس اقتصادي ودقيق لمعرفة كمية الماء في الزيت. هذا الجهاز الجديد يعتمد على العلاقة بين كمية الماء في الزيت و الضغط من عينه من الزيت. النتائج المعملية اظهرت ان الجهاز يمكن ان تصل قدرتة على التمييز الى ٠,٤٪-/+ و يمكنه ايضا لان يستعمل لجميع الحالات من (٠-١٠٠٪) ماء. بالاضافة الى هذا فان النتائج المعملية قورنت بالنتائج النظرية و اظهرت موافقه جيده.

المفردات المفتاحية : نسبة الماء، زيت، ضغط، اقتصادي.

Abstract:This paper presents an inexpensive and accurate measuring device for water constitute in oil. The new device is based on the relationship between the water constitute in oil and the pressure of a sample from the oil. Experimental results show that the device can attain a very high resolution that can reach up +/- 0.4% and it can be used to measure a full range of water percentage levels (0-100%). Experimental results showed good agreement with theory.

Keywords: Water percentage, Oil, Pressure, Inexpensive measuring device

1. Introduction

Oil wells, in general, produce oil, water, and gas. Knowing the percentage of water in oil is very important for oil production. Oil from nearby wells is carried via pipelines into a collection station. Basic Sediment and Water (BS & W) devices are usually used to determine the percentage of the water in the produced oil. Conventional BS & W devices are based on measuring the capacitance or impedance characteristics of the oil (Smit, *et al*. 1998; Lucas, 1994). However, such devices cannot be used in a full range of water percentage (0-100%). Other devices such as radioactive and microwave (Shaofan, 1994; Beckwith, *et al*. 1981) are harmful and require a special operation procedure. Fiber optic sensors (Betta, *et al*, 1993; Giallorenzi, *et al*. 1986; Grattan, 1987) are also available. However, these devices are expensive. In this paper we are reporting experimental results for a new, user friendly, and accurate off-line device that can determine the water constitute in oil. The experimental results show that the device can attain a very high resolution up to +/- 0.4% and it can be used to measure a full range of water percentage levels (0-100%). In addition, the experimental results were compared with the theoretical ones and showed a good agreement.

2. Proposed Water-Cut Measurement Method

The proposed measurement method of the water-cut in a mixture of oil and water is based on the pressure of a sample from the mixture. Consider the system in Fig. 1. The system consists of an apparatus where the pressure of a liquid sample can be measured. The needed sample from a liquid is of a fixed quantity of height H_s. In principle, for a water and oil mixture, the mixture sample will consist of heights H_o and H_w, respectively:

$$H_o + H_w = H_s \tag{1}$$

where,
H_o = height/level of water
H_w = height/level of oil

The pressures of the oil and water are:

$$P_o = \rho_o H_o g \tag{2}$$

$$P_w = \rho_w H_w g \tag{3}$$

where,
P = pressure, kPa
g = gravitational acceleration, m/s^2

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H = height/level, m (Pressure Head);
ρ = density, kg/m^3

The subscripts (*o*, *w* and *s*) stand for oil, water and sample, respectively.

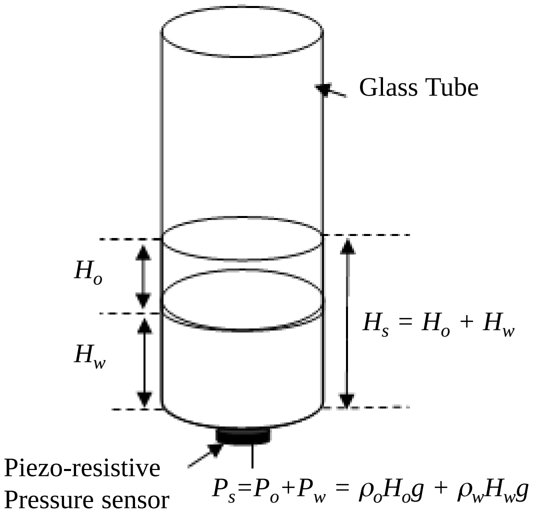

Figure 1. A pressure measuring apparatus

The total pressure P_t at the bottom of the container is equal to:

$$P_t = P_o + P_w + P_a \tag{4}$$

where P_a is the atmospheric pressure. Subtracting P_a from (4) yields:

$$P_s = P_o + P_w \tag{5}$$

P_s is the pressure of the mixture sample which reflects the heights or the fractions of both oil and water in the sample. This system can be used to indicate the fractions of water and oil for different mixtures.

Substituting Eqs. (2) and (3) in Eq. (5) yields:

$$P_s = \rho_o H_o g + \rho_w H_w g \tag{6}$$

Equations (1) and (6) are two independent equations with two unknowns, H_o and H_w.

The sample quantity H_s in Eq. (1) is known and fixed. On the other hand, the sample pressure P_s in Eq. (6) is the measured pressure. For known ρ_o and ρ_w, it is possible to solve Eqs. (1) and (6) for H_o and H_w as:

$$H_o = \frac{\frac{P_s}{g} - \rho_w H_w}{\rho_o} \tag{7}$$

and

$$H_w = H_s - H_o \tag{8}$$

This device can also be used to find the densities of the oil and water samples ρ_o and ρ_w, respectively, from the pressures of two samples of known heights. For example, Eq. (6) can be written for the first sample as:

$$P_{s1} = \rho_o H_{o1} g + \rho_w H_{w1} g \tag{9}$$

Similarly, for the second sample, Eq. (6) can be written as:

$$P_{s2} = \rho_o H_{o2} g + \rho_w H_{w2} g \tag{10}$$

Equations (9) and (10) can be solved for:

$$\rho_w = \frac{\frac{P_{s2}}{g} - \rho_o H_{o2}}{H_{w2}} \tag{11}$$

and

$$\rho_o = \frac{\frac{P_{s1}}{g} - \frac{H_{w1}}{H_{w2}} \frac{P_{s2}}{g}}{H_{o1} - \frac{H_{w1} H_{o2}}{H_{w2}}} \tag{12}$$

It should be noted that this device is an off-line measuring instrument. In order to determine the water-cut in a flow, a sample from the flow is needed. This can be taken automatically from a side pipe through a valve that can close and open automatically by a switch or from a base station computer command. From the pressure of a known amount of the flow, we can determine the percentage of water in oil.

3. Experimental Setup

The experimental setup consisted of a piezo-resistive pressure sensor. The sensor was attached to the bottom of an apparatus to measure the pressure of a sample. The output of the sensor was connected to an amplification circuit as shown in Fig. 2. The sample height, H_s, for all experiments was set to 25 cm. The pressure sensor that was used in the experiments was a differential type, *i.e.* the output of the sensor indicates P_s as in Eq. (5).

Figure 3 shows a photo for the experimental setup. The experimental samples were prepared using tap water and motor oil.

4. Experiments

A number of experiments were conducted to test the accuracy and the capability of the device. In the first experiment, a full range test was conducted starting from a 25 cm water level and no oil and ending with no water

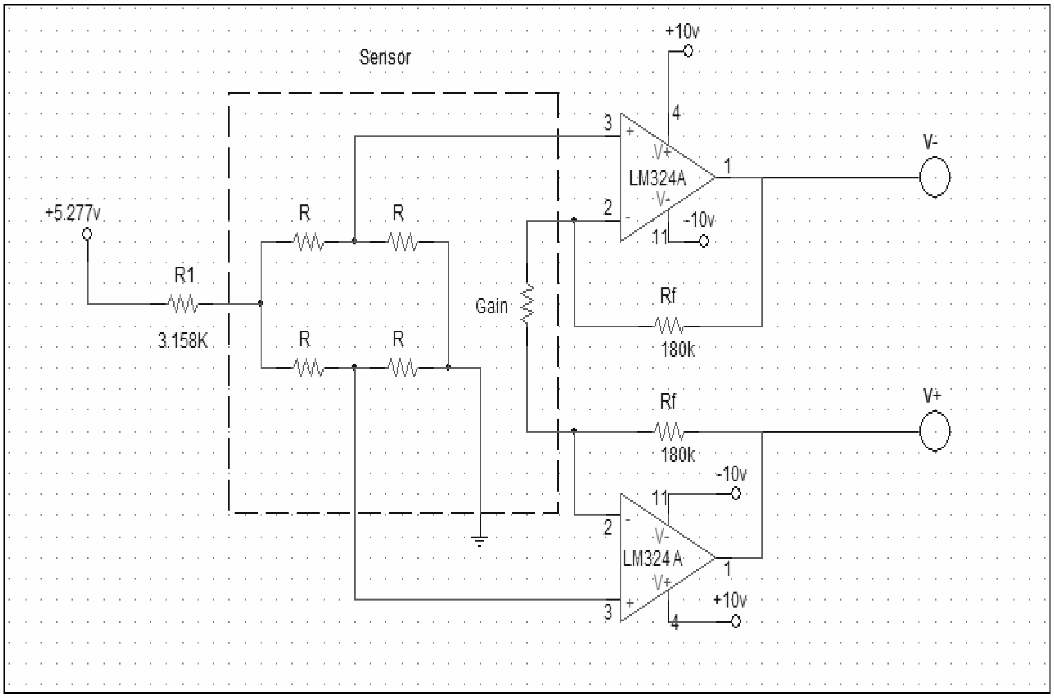

Figure 2. The piezo-resistive pressure sensor and its amplification circuit

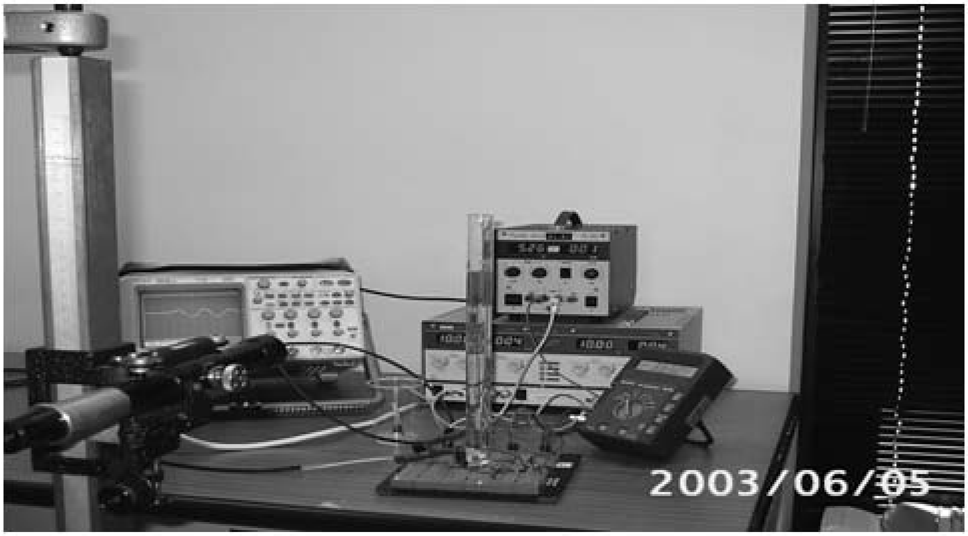

Figure 3. Experimental set up

and a 25 cm oil level with 1 cm increments. Theoretical results were deduced from the equations presented in Section 2.0 and compared with the experimental results. For the theoretical analysis, an oil density of ρ_o=0.87 gm/cm^3 and a water density of ρ_w=1.104 gm/cm^3 were used. Figure 4 shows both the theoretical and experimental results. The data indicate that since oil has a less density, the pressure dropped as the oil level increased. The results show almost a linear relation between the oil level and the voltage.

The second experiment was designed to test the accuracy of the device and if it can detect small changes in the mixture. This experiment began with a 25 cm water level and no oil. The oil in the mixture was then increased from zero to 0.8 cm using 0.1 cm increments. The results of measurements are shown Fig. 5. From these results, it is clear that the device can detect the 0.1 cm change in the 25 cm mixture. The 0.1 cm step is equivalent to +/- 0.4% change in the oil concentration in the mixture. Therefore, it is possible to deduce that the device has a resolution of at least +/- 0.4%.

A third experiment was conducted and aimed also to test the accuracy of the device within another range of oil and water mixture. The range taken was from 20 cm water and 5 cm oil mixture to 19 cm water and 6 cm oil mixture in increments of 0.1 cm. The results are shown in Fig. 6. In the fourth experiment, another mixture range was taken

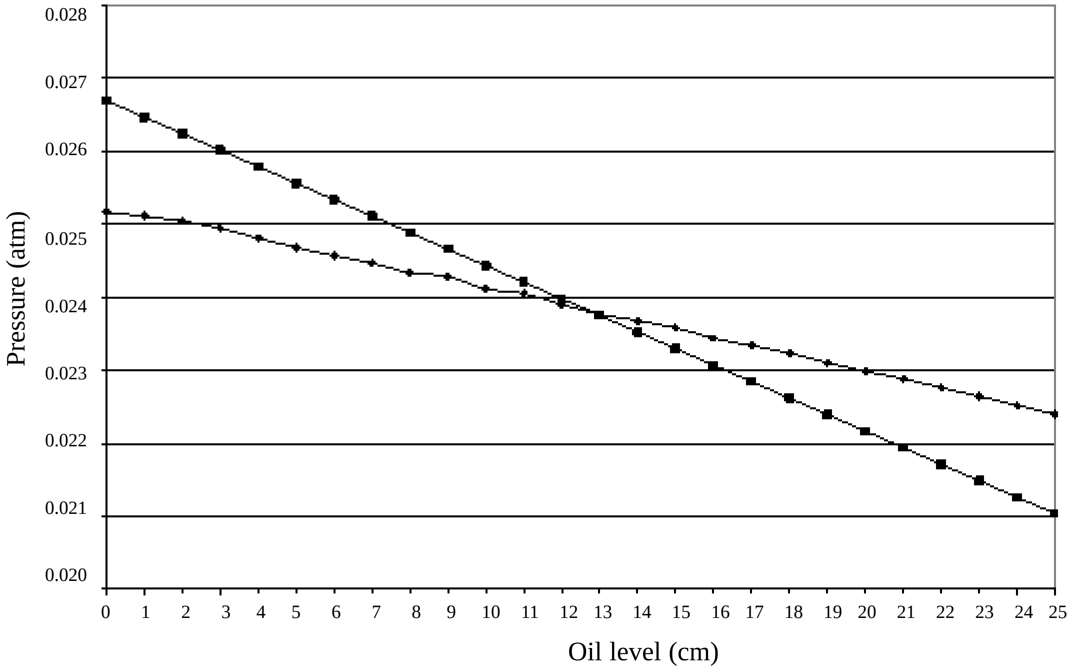

Figure 4. Oil level versus pressure for both the theoretical and experimental results (■ Theoretical, ♦ Experimental) for full range of oil

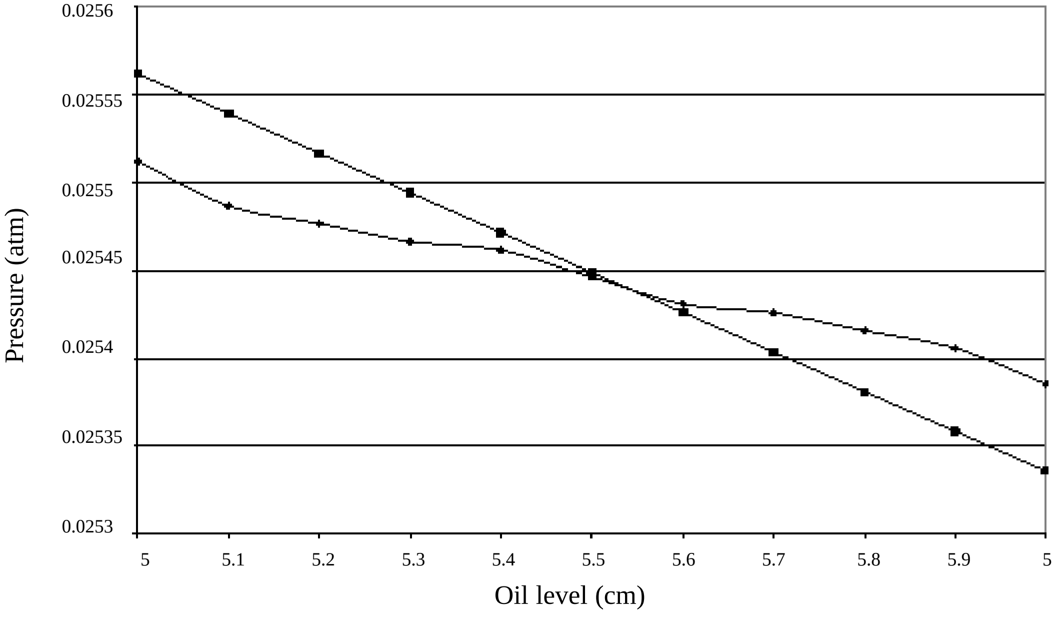

Figure 5. Oil level versus pressure for both the theoretical and experimental results (■ Theoretical, ♦ Experimental) for 5 to 6 cm range of oil

from 5 cm water and 20 cm oil stand to 3 cm water and 22 cm oil stand in increments of 0.1 cm. The obtained results are shown in Fig. 7.

The experiment was conducted using four trials in order to determine the standard error and precision of the system. As an example, Table 1 displays the measurement results of the first experiment alongwith the average and standard error. The overall average precision on the pressure measurement was determined to be approximately 0.083 mAtm.

5. Analysis of the Experimental Results

Based on the experiments conducted, it was concluded that the device can be used and trained to detect water-cut in an oil and water mixture. The results of the first experiment showed a clear change in the output voltage as the percentage of the oil increased in the mixture. The other three experiments showed that the device can detect small changes at different oil level ranges. In all the ranges considered, the device was able to clearly detect 0.1 cm

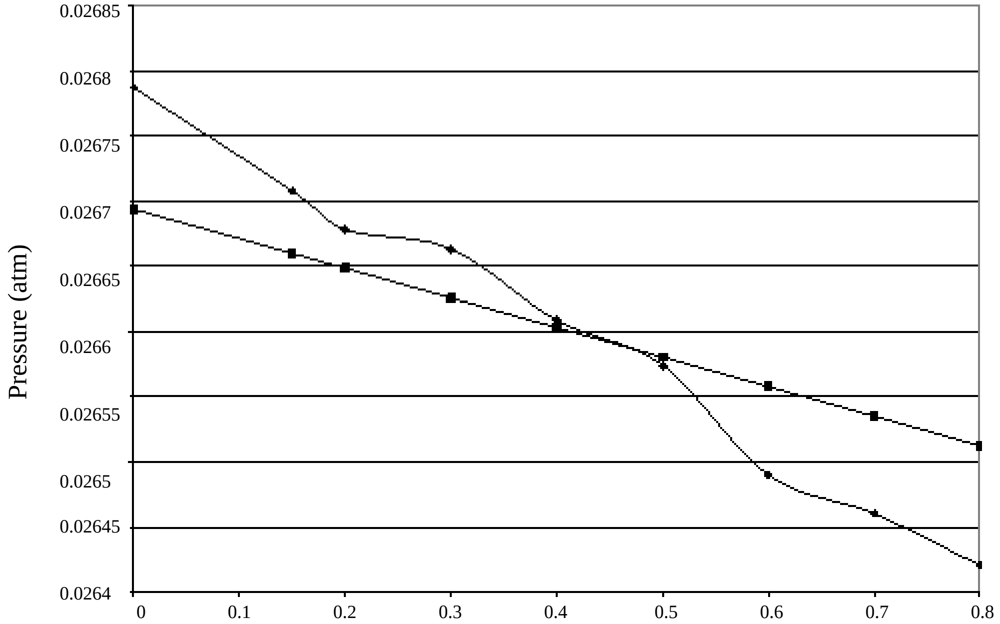

Figure 6. Oil level versus pressure for both the theoretical and experimental results (■ Theoretical, ♦ Experimental) for 0 to 0.8 cm range of oil

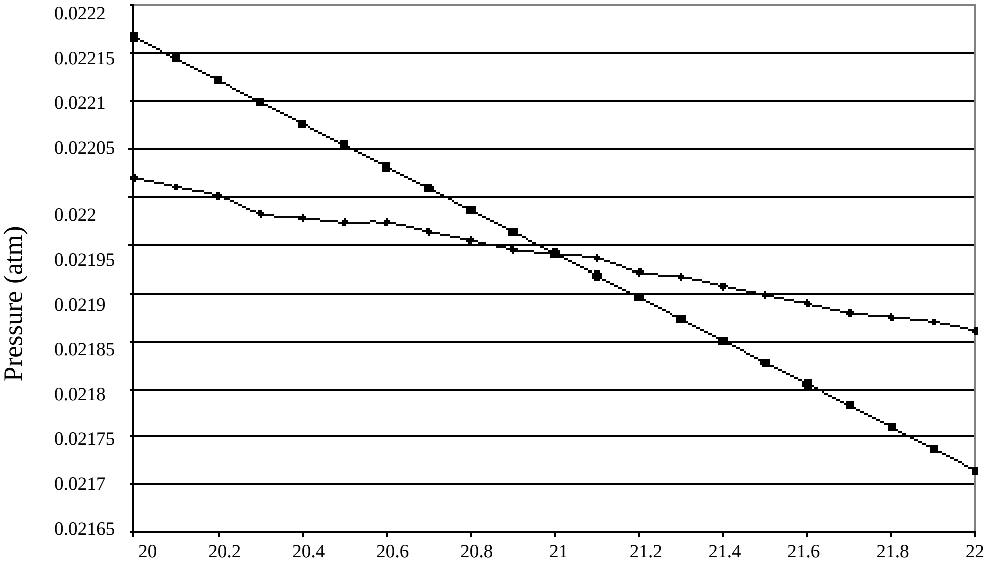

Figure 7. Oil level versus pressure for both the theoretical and experimental results (■ Theoretical, ♦ Experimental) for 20 to 22 cm range of oil

change of oil in the mixture. The 0.1 cm change in a 25 cm level is equivalent to a measurement resolution of +/- 0.4%. One other very important observation is that the device can operate over a full range of water-cut from 0-100%.

6. Conclusions

A number of water-cut measurement devices were evaluated, which included capacitance and conductance devices. Other devices such as microwave, radioactive and fiber optics sensor were either unsafe or expensive cannot be used in the whole water-cut range. The proposed technique, which is based on the relationship between the water-cut in an oil and water mixture and the pressure of a sample from the mixture, is to be very cheap compared to the existing devices. This device is robust, user friendly and can operate in the whole water-cut range.

Table 1. Measurement results of the first experiment along with the average and standard error values

Oil (cm)	Pressure (mAtm)					Std Error
	Trial 1	Trial 2	Trial 3	Trial 4	Average	
0	25.258	25.156	25.342	25.529	25.321	0.079
1	25.202	25.034	25.286	25.408	25.233	0.079
2	25.137	24.932	25.184	25.305	25.140	0.078
3	25.034	24.857	25.109	25.230	25.058	0.078
4	24.904	24.773	25.025	25.146	24.962	0.080
5	24.773	24.717	24.969	25.090	24.887	0.087
6	24.661	24.577	24.829	24.950	24.754	0.084
7	24.559	24.493	24.745	24.866	24.666	0.085
8	24.428	24.428	24.680	24.708	24.561	0.077
9	24.372	24.344	24.596	24.642	24.489	0.076
10	24.204	24.288	24.540	24.540	24.393	0.087
11	24.139	24.148	24.400	24.428	24.279	0.078
12	23.989	24.064	24.316	24.288	24.164	0.081
13	23.859	23.905	24.157	24.111	24.008	0.074
14	23.775	23.840	24.092	23.989	23.924	0.072
15	23.672	23.737	23.989	23.887	23.821	0.072
16	23.532	23.625	23.877	23.812	23.712	0.080
17	23.430	23.467	23.719	23.728	23.586	0.080
18	23.327	23.402	23.653	23.672	23.514	0.087
19	23.196	23.299	23.551	23.532	23.395	0.088
20	23.075	23.187	23.439	23.448	23.287	0.093
21	22.972	23.047	23.299	23.290	23.152	0.084
22	22.851	22.870	23.122	23.224	23.017	0.093
23	22.730	22.748	23.000	23.122	22.900	0.096
24	22.608	22.646	22.898	23.010	22.791	0.097
25	22.487	22.571	22.823	22.870	22.688	0.094
					Average	0.083

Experimental results showed that the new, inexpensive, and simple measuring device for water-cut in oil can attain a very high resolution that can reach up +/- 0.4% and it can be used to measure a full range of water-cut levels (0-100%).

Acknowledgements

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