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Influence of temperature on the algorithm to define salty water-in-oil flow characteristics

Yu.P. Filippov, I.D. Kakorin *, K.S. Panferov

Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Russia

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ABSTRACT

A promised continuation of the previous paper by concerning determination of the volume fraction of water and the total volume flow rate of the salty water-in-oil two-phase flow is presented. The measuring system consists of an RF-sensor and a narrowing device. The RF-sensor responds to complex permittivity of the flow, whereas the pressure drop along the narrowing device depends on the flow rate. The results of the tests presented earlier were not perfect because the temperature effects had not been considered. In this paper an improved variant of the algorithm for the same measuring system and the same flows is offered. This algorithm takes into account the temperature dependence of physical properties of the flow as well as own temperature dependence of RF-sensor characteristics. Comparison of the errors of the previous and new algorithms is carried out. The improved algorithm makes the measuring system applicable under real conditions.

1. Introduction

There are several diagnostics problems in oil-producing industry. One of them is to determine flow rates of the components of the water–oil flow. The measuring system for this purpose based on the combination of the RF-sensor and a narrowing device, has been considered by Filippov and Panferov (2012). In this paper, the results of testing the measuring system on real oil-contained flows have been presented and a semitheoretical algorithm of data processing has been developed which allows one to calculate values of water cut, w, that is the ratio of the water volume flow rate compared to the total volume flow rate of oil and water, Q, from the measured values of the resonant frequency of the RF-sensor, f, and pressure drop along the narrowing device, ΔP. The errors of determining the w- and Q-values by means of this algorithm have been estimated by comparison with the experimental data. It has been noted that the total errors δw and $\delta Q/Q$ have nonzero systematic terms and the distribution of the error δw has two distinct peaks that is not an ordinary case. These irregularities were supposed to be caused by influence of temperature variations. It was also supposed that taking the influence of temperature into account could in principle reduce accidental error terms as well. One needs to note that the experimental data processed by the developed algorithm were obtained approximately at the same temperature. In practice, the temperature can vary for several dozens of degrees that leads to much greater values of the errors δw and $\delta Q/Q$, than the values presented in the paper mentioned above. Even for approximately stable temperature conditions the working temperature can differ significantly from the calibration temperature that causes rather big systematic errors. So taking the value of the temperature into account is obligatory to work under real conditions. It is worth noting that we have not found any investigations of this problem in accessible literature devoted to multiphase flow-meters based on the mentioned configuration of the flow-meter. As a rule, their operation is described at a constant value of temperature only.

The aim of this paper is to investigate how the temperature of the flow, T_f, and temperature of the body of the RF-sensor, T_b, affect on the readings of the measuring system, to improve the algorithm developed earlier taking the influence of the temperature into account, and to compare the errors of the previous and improved versions of the algorithm. Let us consider improvements of the new algorithm in detail.

2. Temperature updating of algorithm

All temperature influences can be combined in two groups: effects which cause a temperature drift of the RF-sensor's reading, and effects leading to a temperature drift of the value of pressure difference along the narrowing device.

The RF-sensor reading depends on two temperature effects. Firstly, the T_b-value influences the resonant frequency. Thus, the sensitivity of the empty RF-sensor at room temperature is about

* Corresponding author. Tel.: +7 49621 63627; fax: +7 49621 65767.
E-mail address: kakorin@jinr.ru (I.D. Kakorin).

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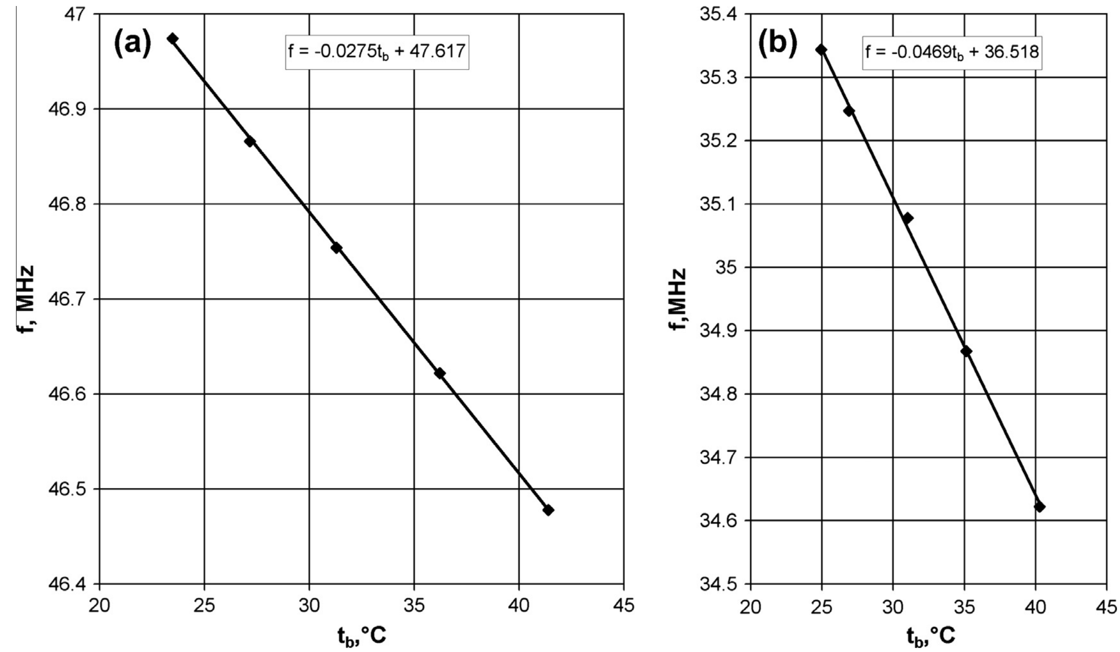

Fig. 1. Dependence of the resonant frequency, f, upon the sensor body temperature on the assumption of $T_f \approx T_b$ at different water cuts, w: (a) pure oil ($w = 0.005$), $s(w) = -0.0275$ MHz/°C and (b) emulsion "salty water-in-oil" ($w = 0.7$), $s(w) = -0.0469$ MHz/°C.

27 kHz/K, and at the temperature difference of 10 K, for example, the frequency shift is 270 kHz that corresponds to 25% of the signal range $\Delta f = f_{oil} - f_{air}$ when the sensor is filled with oil and air at the atmospheric pressure. Secondly, the readings depend on the T_f-value, since its changing leads to changing the dielectric permittivity of the flow. The experimental investigation has shown that if $|T_b - T_f|$ does not exceed several degrees, the both effects can be considered together and one can regard frequency as a function of T_b only. It has been found that in the temperature range from 20 to 50 °C the dependence $f = f(T_b)$ is almost linear, as it is demonstrated in Fig. 1, where the two experimental dependencies are presented corresponding to the minimum and maximum investigated w-values.

Analysis of the experimental data has shown that the temperature drift of the RF-sensor in the range of the investigated water cut from 0 to 0.7 can be taken into account by the following empirical formula:

$$f_{corr} = f + s(w)(T_b - T_0), \quad (1)$$

where f_{corr} is the adjusted value of the resonance frequency that is used instead of directly measured value f, T_b – the sensor body temperature, T_0 – the defined point within the range of the resonant frequency measurements $f(T_b)$ when the RF-sensor is filled with different media, and $s(w)$ – the experimental function dependent of the w-value. The value of T_0 can be taken at any suitable point within the range of $f(T_b)$, for example, $T_0 = 20$ °C. A function form $s(w)$ has been found experimentally by determining its values at several points w_i and by interpolating the obtained points (w_i; s_i) with a smooth curve.

As for the second temperature updating, related with the narrowing device, we studied the dependence of the ΔP-value on the T_f-value. This dependence is especially apparent for laminar flows, which occur for viscous emulsion with a high w-value, for example, for $w = 0.4$ as it is shown in Fig. 2.

The temperature drift of the ΔP-value can be taken into account by considering the temperature dependence of physical properties of the flow. The main of them are the average density and the average viscosity. The latter one is calculated by means of the previous

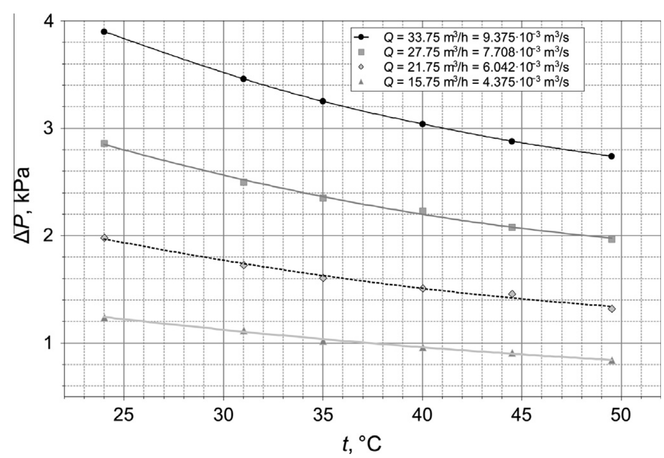

Fig. 2. Experimental dependence of the pressure drop along the narrowing device, ΔP, upon the flow temperature, $t = T_f - 273.15$, for oil–water emulsion at $w = 0.4$ and different Q-values.

algorithm from the values of water cut and the dynamic oil viscosity, μ_{oil}. To take into account the temperature dependence of the μ_{oil}-value, we have used a well-known equation, originally proposed by Walther (1931):

$$\log(\log(\nu_{oil} + 0.6)) = W(T), W(T) = A - B\log(T), \quad (2)$$

where $\nu_{oil} = \mu_{oil}/\rho_{oil}$ is the kinematic oil viscosity in cSt (or in 10^{-6} m^2/s), T – oil temperature in K, log – the common logarithm, $W(T)$ – the Walther function with unknown constants A and B, which depend on the kind of oil and are usually determined experimentally. The same equation is recommended by ASTM Standard 2004D 341-03 for liquid petroleum products. We have put $B = 3.5$ which is a typical value for many kinds of oils, as it is mentioned, for example, by Mehrotra (1990). Constant A can be excluded by comparison of two Walther functions: $W(T_f) = W(T_0) + 3.5\log(T_0/T_f)$, where $W(T_0) = \log(\log(\nu_{oil}(T_0) + 0.6))$. At last, knowing Walther function $W(T_f)$, one can determine the μ_{oil}-value: