Estimating the effect of instrument accuracy on the accuracy of mathematical modeling of quality indicators of oil treatment for transportation

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Abstract. This paper is dedicated to mathematical modeling of oil treatment quality indicators. The system developed by the authors uses the results of measurements done with the instruments that the oil treatment unit is equipped with as the initial data for the modeling. In this regard, the effect of instrument measurement accuracy on the accuracy of prediction of crude oil quality indicators is relevant. The coefficient values of the effect of instrument measurement accuracy on saturated vapor pressure of the crude oil were estimated using a mathematical model of a typical oil treatment unit. It was shown that the prediction accuracy was most affected by the accuracy of measurements of temperature and gas consumption at the last separation stage.

1. Introduction
At the moment, the introduction of mathematical models of processing units is one of the relevant topics in the oil industry [1-9]. As far as the oil treatment field is concerned, such models allow to solve both direct process tasks (selection and adjustment of parameters of the operating mode and equipment operation) and many other related issues (equipment condition evaluation, personnel training, etc.)

The mathematical model of an oil treatment unit makes a connection between crude oil quality indicators with the chemical composition of the initial liquid-gas mixture and the process equipment operating mode, i.e.

\[ p_s = f(Q, z_t, T_j, p_j) \]  
(1)

\[ x_{H2S} = f(Q, z_t, T_j, p_j) \]  
(2)

where \( p_s \) and \( x_{H2S} \) are the saturated vapor pressure and hydrogen sulfide content in the crude oil; \( Q, z_t \) are the flow and chemical composition of the raw oil; \( T_j, p_j \) are the temperature and pressure in the unit devices.

Said models can be built using modern software products such as "MiR PiA Process" [10-13]. They can be used to calculate the composition and properties of all material flows, as well as the parameters of the processing equipment for stationary operating mode of the unit.
2. Accuracy estimation technique

However, the oil treatment processes are characterized by constant change in volumes and composition of the raw material. Therefore, such models must be adapted to constantly changing operational conditions in order to obtain consistent results. The model receives data necessary for adaptation from regular instrumentation sensors of the oil gathering and processing system.

This brings up the question of the effect made by the measurement accuracy of the said sensors on the accuracy of the processed oil quality indicators prediction. It is suggested to estimate the modeling accuracy as follows

\[
\Delta p_s = \sum_{k} \left| \frac{\partial p_s}{\partial y_k}, \right| y_k
\]

(3)

\[
\Delta x_{H2S} = \sum_{k} \left| \frac{\partial x_{H2S}}{\partial y_k}, \right| y_k
\]

(4)

where \( y_k \) is the \( k \)-th instrumentation sensor reading.

In this paper, we analyzed the case of the prediction of saturated vapor pressure \( p_s \), where three different oils were to be treated with their flow \( Q_k \) measured by sensors of the gathering system measuring units. The treatment unit is also equipped with gas flow meters installed at three separation stages \( V_k \) and a temperature sensor installed at the hot stage \( T \). The modeling accuracy shall then be determined by the formula

\[
\Delta p_s = \sum_{k=1}^{3} \left| \frac{\partial p_s}{\partial Q_k}, \Delta Q_k \right| + \sum_{k=1}^{3} \left| \frac{\partial p_s}{\partial V_k}, \Delta V_k \right| + \left| \frac{\partial p_s}{\partial T}, \Delta T \right|
\]

(5)

Figure 1 shows the corresponding mathematical model of the oil treatment unit created with the MiR PiA Process software.
As stated above, the necessity to adapt the model is caused by the constant change in oil production volume. In this regard, a time range was chosen during which the production volume of oil from different fields varied significantly over time (see figure 2).

![Figure 2. Dynamics of change in oil production volume.](image)

Since the equations (1) and (2) were solved by numerical methods, the coefficients of the effect of sensors accuracy were estimated as follows

$$\frac{\Delta p_y}{\Delta y_k} \approx \frac{p_y(y_k + \Delta y_k) - p_y(y_k)}{\Delta y_k}.$$  

At each moment of time, a series of computing experiments were performed using the developed mathematical model in order to find the values of $p_y(y_k + \Delta y_k)$ and $p_y(y_k)$.

3. Accuracy estimation results

Figure 3 shows the influence coefficients of the accuracy of sensors of the measuring units installed in the oil gathering system for the specified time range. The analysis of the obtained data shows that:

- influence coefficients change over time and to a large extent depend on the ratio of volumes of oil produced at different fields;
- the higher the coefficients, the more different compositions of oils from different fields are;
- oils from one field can be characterized by both positive and negative influence coefficients over time.

Figure 4 shows the dependence of the influence coefficients for gas flow meters installed at three separation stages. It is shown that saturated vapor pressure is significantly more affected by the accuracy of gas flow meters, rather than by the accuracy of well flow rate measurements. Moreover, the accuracy of the sensor at the third separation stage has the biggest effect, while that of the sensor at the first stage has the smallest effect. An interesting (and an actually observed) fact is the positive coefficient value for the second separation stage.

However, the accuracy of the prediction of saturated vapor pressure is most affected by the accuracy of temperature measurement at the last separation stage (see figure 5). Wherein its value is practically constant over time.

Based on the effect of accuracy of all mentioned instruments, a total absolute accuracy of the prediction of saturated vapor pressure was determined (see figure 6).
In this example, the accuracy of measuring units for metering the produced oil is 2.5 %, the accuracy of gas flow meters is 1 %, and the accuracy of temperature measurements is 2.5 °C.

Figure 3. Time dependence of the influence coefficients of the accuracy of sensors of the measuring units installed in the oil gathering system.

Figure 4. Time dependence of the influence coefficients of the accuracy of sensors of the gas flow meters installed at separation stages.

4. Conclusions and recommendations
Thus, based on the study results, it can be concluded that the degree of effect of the instrument accuracy on the theoretical prediction of saturated vapor pressure of the treated oil decreases in the following sequence:
- temperature at the last separation stage;
- gas consumption at the last separation stage;
- gas consumption at the second separation stage;
• gas consumption at the first separation stage;
• produced oil flow rates.

\[ \frac{\Delta p}{\Delta t} \text{ kPa/K} \]

![Figure 5](image)

**Figure 5.** Time dependence of the influence coefficient of the accuracy of the temperature sensor installed at the last separation stage.

\[ \Delta P_{sat} \text{ kPa} \]

![Figure 6](image)

**Figure 6.** Time dependence of the total absolute accuracy of the prediction of saturated vapor pressure.

According to this, we can recommend to improve the accuracy of the temperature and gas flow measurements at the last separation stage of the oil treatment unit if a more accurate prediction is required.

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