Cognitive model application for automatic system of methanol supply to flowlines

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Abstract. The main problem during natural gas extraction is hydrating risk. The hydrates could be formed at every stage of extraction: from gas foundation to Central Processing Facility (CPF). The hydrating is quite unwanted process, because it decreases the efficiency of field operations and causes accidents. The process operating procedure of any production field provides some measures to prevent hydrating. Mostly different hydrate growth inhibitors are used to prevent hydrating, for example methanol or water-methanol solution. At this time the most important problem is evaluation of the optimal methanol flow rate or water-methanol solution concentration for current conditions. The cognitive model application for hydrating diagnosis is discussed in the article. It is based on real time analysis of head temperature and pressure, temperature and pressure in the entrance of the CPF and ambient temperature. In this case, current parameters and their dynamic are analyzed. The hydrating conditions are diagnosed by the algorithm, offered in this article. This algorithm includes the results of temperature and pressure dynamic analysis and the cognitive model, based on expert knowledge. This system was tested in the Yamburg gas condensate field. These tests approved real methanol saving.

Introduction
During development of West Siberia and the Far North reservoirs, the problem of hydrating in the gas formation, wells and flowlines, which connect gas well cluster with the gas treatment unit, arises [1]. They are formed by many natural gas forming components during interaction with water.

At the first stage of the field production, it is quite difficult to provide the non-hydrate mode because of high formation pressure and low gas temperature. At the final stages of the field production the pressure decreases, but water in flow increases. So favorable conditions for hydrating are constantly provided.

Hydrates settle on the inner pipe wall and decrease significantly the rate of flow. Hydrating inside section isolation valves leads to loss of its function.

Hydrate formation in the flowlines impedes all gas field technological processes and it can be the reason of an accident under unfavorable conditions. An emergency response contributes to gas production cost. That is why, the prevention of hydrate build-up is a statutory requirement of an every gas field technical specifications.

The urgency of an issue
Many different ways are used to prevent the hydrate formation [2-4]. The main factors, which influence hydrating, are gas composition, gas flow pressure and temperature conditions and water vapor.
saturation. So the main well-known ways of hydrate prevention are designed to correction or removal of these factors.

The technological methods are a maintenance unhydrate mode and gas drying. The unhydrate mode is provided by pressure decreasing and temperature increasing. The chemical methods are hydrate growth inhibitor injection in the gas flow. The physical method is based on the regulation of the gas flow temperature, which is over the hydrate formation temperature. It is made with the help of a local heating unit, heat insulation and the choice of operation conditions.

Hydrate growth inhibitor supply to the well and flowline is wide spread both in Russia and in other countries [3, 5]. The most widely used inhibitor is methanol and different concentration water-methanol solution (WMS) [6-7]. The complex problem is to quantify methanol for concrete pressure-temperature conditions. In Russia, methanol flow is calculated according to the department regulation document [8]. The calculation derived theoretic flow does not always coincide with the really required one. This difference is caused by two reasons. First, there is no ongoing monitoring of all technological parameters which are necessary for [8] calculation. Second, the calculation procedure does not take into account all factors which affect methanol flow, because some of them could not be measured at all [9]. Since insufficient concentration of WMS causes an inverse effect and accelerates the hydrate blockage growth, the technologists in the fields increase the calculated value by 20-25%. This leads to the redundant methanol flow, a decline in efficiency and an increase of expenses on water-methanol solution regeneration.

Thus, the development of the automatic system of the methanol supply, which provides a change of methanol flow depending on current operating conditions, allows not only increasing the gas field operational integrity but providing real methanol savings.

The theoretical part

The purpose of carried research is a development of the automatic system methanol supply (AS MS) to the gas flowlines based on the cognitive model. This system allows one to correct calculated gas hydrate formation point in real time and to provide required methanol supply to the gas flow line.

Methanol quantity depends on current parameters of pressure and temperature conditions and calculated hydrate formation point. Basic data accuracy is determined by the veracity and results integrity of temperature and pressure real-time measurements in the tangent points of the flowline and other factors such as a heat transmission coefficient. Other factors which influence representative results could not been measured. In the developed system, this problem is solved by increasing real time measurements and using the cognitive model. This cognitive model allows taking into account some immeasurable factors.

The main system functions are:
− continuous monitoring of flowline pressure and temperature conditions in order to diagnose hydrate conditions appearance in time;
− checking the plausibility of conclusion about possible hydrating;
− correction of the theoretical hydrate formation point. In case the conclusion is incorrect, the cognitive model is used to calculate a new hydrate formation point.

The flow diagram of the offered automatic system of methanol supply is shown in figure 1.

The main blocks of AS MS are a data base block, a cognitive model block and an information handling and design unit. The data base block consists of three submodules:
− a variable data submodule – the telemetry results from the wells (pressure and temperature measurements from the top of the well), pressure and temperature measurements in the flowline at the entrance of the CPF and also ambient temperature. These measurements come by the wireless data link from the recording device. These data come from the measuring means, which the automated control system of technological processes of CPF (ACS TP CPF) includes;
− a conditional constant data submodule includes the results of inhibitor concentration values, which are supplied to the top of the well, and the layer water quantity, which comes from the well and gas density. All these measurements are entered manually periodically. These values are determined in
the laboratory in some period of time, which is determined by the production field manufacturing instruction;

− a constant submodule includes the intake flow lines quantity, the theoretical meaning of the flow line heat transmission coefficient from the gas flow to the ambient, flow line length and others. If necessary, these data are uploaded.

![Figure 1. AS MS architecture](image)

The gas field is a typical example of a complex system. There is not enough quantity information about the system behaviour, its changes and also some factors, which influence this system. So it makes the researchers use quality analysis of this system processes. That is why, it is necessary to use cognitive models that describe such systems.

This model sets the correlation between the flow line heat transmission coefficient and the alignment sheet, the flow line isolation condition, the snow covering depth, the wind direction and its speed and others. The quantity evaluation of these factors influence on the heat transmission coefficient is very important. This coefficient is used in the formula of hydrate formation temperature calculation. This temperature determines the optimal methanol flow rate directly.

There is one fuzzy cognitive model in figure 2. This model is made for the gas flow line coefficient of heat transmission correction. It includes the following components:

− a gas heat transfer coefficient to the external environment;
− a ground type and its water intensity;
− pipe walls condition;
− heat insulation condition;
− a snow depth, its intensity, wind speed and its direction;
− a surface relief where the flow line is lain (depression area and its length), the way of its laying;
− gas moisture;
solid particles in the gas flow.

Figure 2. Cognitive model

This system runs optimal control according to the following algorithm.

At first, theoretical hydrate formation temperature $t_{gt}$ and nominal methanol flow rate $q_{nom}$ are calculated according to [8] for initial conditions of the field operation.

The control of the process of hydrating prevention in the flow line is made by pressure and temperature control at the entrance of the CPF ($P_2$ and $t_2$). These parameters are measured periodically and automatically in real time and put to the data base. This data base is the same for ACS of TP of CPF and AS MS.

In order to diagnose the probable beginning of hydrating in the flow lines and CPF, the temperature $t_2$ at the entrance of the CPF is continuously compared with the theoretical calculated temperature of hydrate formation $t_{gt}$.

While $t_2 \geq t_{gt}$, the nominal methanol flow rate is supplied to the flow line. If the measured temperature becomes lower than $t_{gt}$, it theoretically means that hydrating begins. But this situation could be caused by the fact that some factors were not considered in $t_{gt}$ calculations. These factors are the surface relief where the flow line lays, the flow line’s insulation condition, the snow covering depth and so on. All these factors influence the heat transmission coefficient. Therefore, later, pressure $P'_2$ at the entrance of the CFP is compared with pressure $P_3$, obtained in the previous measurement cycle. If the pressure increases by some value and this pressure difference stays for some period of time, one can say that hydrating begins. The pressure changing (for example, by 10%) and the time when this difference remains (for example, 30 minutes) are determined by the cognitive model. Then AS MS makes a decision that it is necessary to increase the methanol flow rate to destroy hydrate blockage.
The new value of the methanol flow rate is determined by CPF technology regulations. If the pressure does not change, the information-processing unit accesses the cognitive model and checks the reliability of the decision on the hydrating onset. In case hydrating does not begin, the theoretical hydrate formation temperature $t_{gt}$ is corrected according to the formalized knowledge from the cognitive model. In another case, the methanol flow rate is recalculated, and control action is formed for methanol supply subsystem (MSS).

**Practical implications**

The offered developed system of optimal control of methanol supplying to the gas flowline was probed in the flowline of the Central Processing Facility CPF-5 of the Yamburg gas-condensate field. The length of the pipe line is 5 km. The pressure of the top of the well is 2.8 MPa, the pressure at the entrance of the CPS is 0.9 MPa. The gas field is at the closing stage of exploitation. So the methanol is supplied to the flowline continuously with nominal flow rate $q_{nom}$.

The calculation of the gas hydrate formation point was made according to the procedure using data from table 1. The value of $T_{gt}$ is minus 16.6 °С. The WMS concentration according to this temperature is 40%.

| Table 1. Data for hydrate formation temperature calculation |
|-------------------------------------------------------------|
| **Value name**                                             | **Value**               |
| Ambient temperature, °C                                    | minus 10                |
| Temperature of the top of the well, °C                     | 12                      |
| Temperature at the entrance of the CPF, °C                 | 5                       |
| Head pressure, MPa                                         | 2.8                     |
| Pressure at the entrance of the CPF, MPa                   | 0.9                     |
| Gas mass rate, kg/h                                        | $600.65\times10^3$     |
| Gas specific heat, kcal/(kg·°C)                            | 0.83                    |
| Flowline length, km                                        | 5                       |
| Calculated value of coefficient of heat transmission of gas pipe line, kcal/(m²·hr·°C) | 1                       |

The registers of the technological parameters were set at the wells connected to the gas flow lines. These registers measured pressure and temperature and sent these values to the Computer-Aided Process Control System (CAPCS) of the CPF by the wireless data link.

There are pressure measuring results at the top of the well and at the end of the flowline in table 2. These measurements were obtained 10.02.2016 and 14.02.2016. As can be seen, in both these cases, the pressure has changed both at the top of the well and at the end of the flowline. And in these both cases, at least one pressure measuring changes by more than 10 %. That is why, repeated measuring was carried out in 30 minutes. In the first case (10.02.2016), pressure measuring showed that pressure has stabilized. It means that there were no hydrating conditions but one should correct the hydrate formation point according to the cognitive model up to minus 18.3 °С. In the second case (14.02.2016), pressure has not stabilized, and it means that hydrating conditions are satisfied, and it is necessary to increase the methanol feed.
Table 2. The analysis of pressure changing trends.

| Pressure meanings, MPa | 10.02.2016 | 14.02.2016 |
|------------------------|------------|------------|
|                        | 12.01      | 12.29      |
|                        | 12.58      | 20.40      |
|                        | 20.54      | 21.21      |
|                        | 21.46      |            |
| $P_1$, the top of the well | 2.78     | 2.83       |
| $\Delta P_1$, %        | 1.8        | 4.3        |
| $P_2$, gas flowline    | 0.9        | 0.75       |
| $\Delta P_2$, %        | 16.7       | 27.8       |

Conclusion.
The developed automatic system of methanol supplying to the gas pipeline allows improving accuracy of the theoretical hydrate formation point test owing to real-time pressure and temperature measuring at the top of the well and in the Central Processing Facility (CPF).

Diagnosis of the hydrating process beginning by two factors (gas temperature decreasing and pressure increasing at the entrance of the CPF during steady state conditions) allows one to improve the accuracy of the diagnosis and to use the methanol more efficiently.

Using the cognitive model allows one to pay attention to expert knowledge. All these factors have an effect on methanol supply optimization. It could be noticed that the coefficient of heat transmission of the gas pipe line has an effect on the hydrate formation point.

The research carried out in the Yamburg gas-condensate field suggests that the real coefficient of heat transmission changes according to the season and weather conditions. It changes in the range from 0.3 to 3 – 4 kcal/(m$^2$·hr·ºC). At the same time, the rated value for the moisture-free and undamaged heat insulator is 1 kcal/(m$^2$·hr·ºC). The calculation was made for the gas pipe line length – 5 km, ambient temperature – minus 20 ºC, the top of the well temperature – 12 ºC, the temperature at the entrance of CPS – 5 ºC, mass gas discharge – 172 thous. kg/hr. The hydrating formation point was counted by the cognitive model using the above-mentioned values. This point changes in the range from 14.5 to 17.3 ºC. The methanol concentration in the WMS, corresponding to these temperature values, is 43.67 up to 30.89% wt. This difference is the range optimization.

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