ENSURING STABLE OPERATION OF GAS COLLECTION SYSTEM IN CONDITION OF REDUCED WELL PRODUCTION

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Abstract. Any gas condensate field has an extensive gas collection system (GCS), through which gas is delivered from the wells to a Gas Processing Plant by means of reservoir energy. At the final stage of field development the GCS operating conditions undergo significant changes, in particular due to lower temperature of transported gas and increased water cut in the production fluid. In winter, simultaneous action of these factors may lead to formation of ice and hydrate plugs disrupting normal operation of the GCS. Gas stream velocity shall exceed so-called critical velocity to ensure that the flowlines operate in the liquid removal mode. Its value is determined by a pipeline diameter, ratio of gas and liquid density, thermobaric conditions, flowline slope and other factors. Ensuring necessary velocity at the final stage of operation is usually impossible, thus, complete moisture removal is problematic and the hazard of ice formation persists. This paper proposes an innovative technology providing stable GCS operation by preventing ice formation in the flowline. For that end, the gas-liquid mixture in the GCS gets additional heat from heat tracing located inside the GCS. The heat tracing is coiled tubing with constant circulation of liquid heat-transfer medium: methanol-water solution, heated by rejected heat when passing through the air cooler unit (ACU). The coiled tubing forms a closed loop with the methanol pipeline. Changes in heat exchange medium consumption are introduced with a VSD-driven pump, basing on the results of temperature measurement in the flowline. Application of the proposed technique allows not only providing emergency-free GCS operation, but recuperation of rejected heat from the ACU as well.

1. Introduction

When oil and gas condensate fields (OGCF) reach the final stage of their development, operation of GCS becomes significantly more complex. It is so due to several factors, such as reduction of reservoir pressure, lower well production and higher water cut. The issues are especially vexed during the cold part of year, when the ambient temperature is significantly lower than 0 $^{\circ}$C and the soil is freezing to negative temperatures. At the final stage, gas stream velocity values at the majority of GCS segments (not taking into consideration the joint sections) are usually at the level insufficient for liquid removal. Lowering of wellhead temperatures and reduced gas flow from the wells lead to the situation when the amount of heat coming from the reservoir with the gas is insufficient to keep water in the flowline from freezing on contact with the pipeline walls [1].

It shall be noted, that at the initial stage of OGCF development, influence of sub-zero temperatures is insignificant due to self-regulation of flowline operation. On the one hand, glaze ice on the pipe walls acts as additional thermal insulation, thus reducing heat losses. Besides, it leads to reduced section and increased gas stream velocity. On the other hand, the flowline resistance increases, as well as its pressure drop along the length, which especially affects increased winter flowrates. When well production is sufficient, such self-regulation creates an equilibrium state that provides normal operation of wells and the flowline alike. It is possible if the wells operate in a wide range of flowrates and wellhead pressures (without self-kill), providing liquid removal. However, during the final stage of development, when well production is reduced, the wells themselves start operating with liquid accumulation and even insignificant increase in wellhead pressure leads to self-kill. Thus, unlike earlier stages of development when equilibrium may be found providing enough clear opening for gas stream, at the final stage of development the gas flow rate and reservoir heat coming with it are insufficient to prevent total freezing of the pipelines.

The main hazard from combination of such factors as accumulation of liquid in flowlines and reduction of gas stream temperature lies in formation of ice and hydrate plugs, which not only impair the efficiency of gas field operation, but in some cases may lead to emergency [2]. Thus, analysis of existing operational conditions of GCS at Urengoy OGCF and its trends and further development of innovative technologies allowing efficiently operating GCS under the changed conditions is a pressing scientific and practical problem.

2. Analysis of progress to date

As a part of field development audit for additional development of Cenomanian deposit of Bolshoy Urengoy deposits regularly performed by Gazprom VNIIGAZ LLC, an efficiency analysis was performed on the current gas collection system operation and forecasts were made for its further operation basing on the GCS model. This model was developed from design premises and current measurements of field parameters obtained from the telemetry system on the basis of RPT-04 process recorders [3], which are currently installed on almost every well. GCS thermal conditions, amount of removed water and changes in well production were the objects of analysis.

Analysis of GCS thermal conditions has shown that at all fields there is a stable reduction in temperature of transported product [4, 5]. So, if in January 2004 the temperature at the inlet of Gas Processing Plant (GPP), that is, at the end of GCS, was on average 5.8 ºC, in some days of January 2013 this value was as low as minus 2 ºC while the ambient conditions were comparable (average ambient temperature of 0.9 ºC). Changes in temperature from 2014 to today and forecasts up to 2030 are shown in Fig. 1.

The obtained results bear record to increased risk of hydrate and ice formation in GCS pipelines as further reduction in production and wellhead temperature during the operation of the field will lead to further lowering of temperatures in the flowlines.

Water cut in GSC flowlines is assessed from the amount of water reaching the GPP separators. As the research shows, during the year daily and monthly volumes of liquid reaching the GPP vary significantly, as water ingress in non-uniform (Fig. 2). It is due to seasonal variability of gas extraction, water accumulation in GCS and its further massive removal when gas extraction increases or some other changes in GPP operation are introduced.

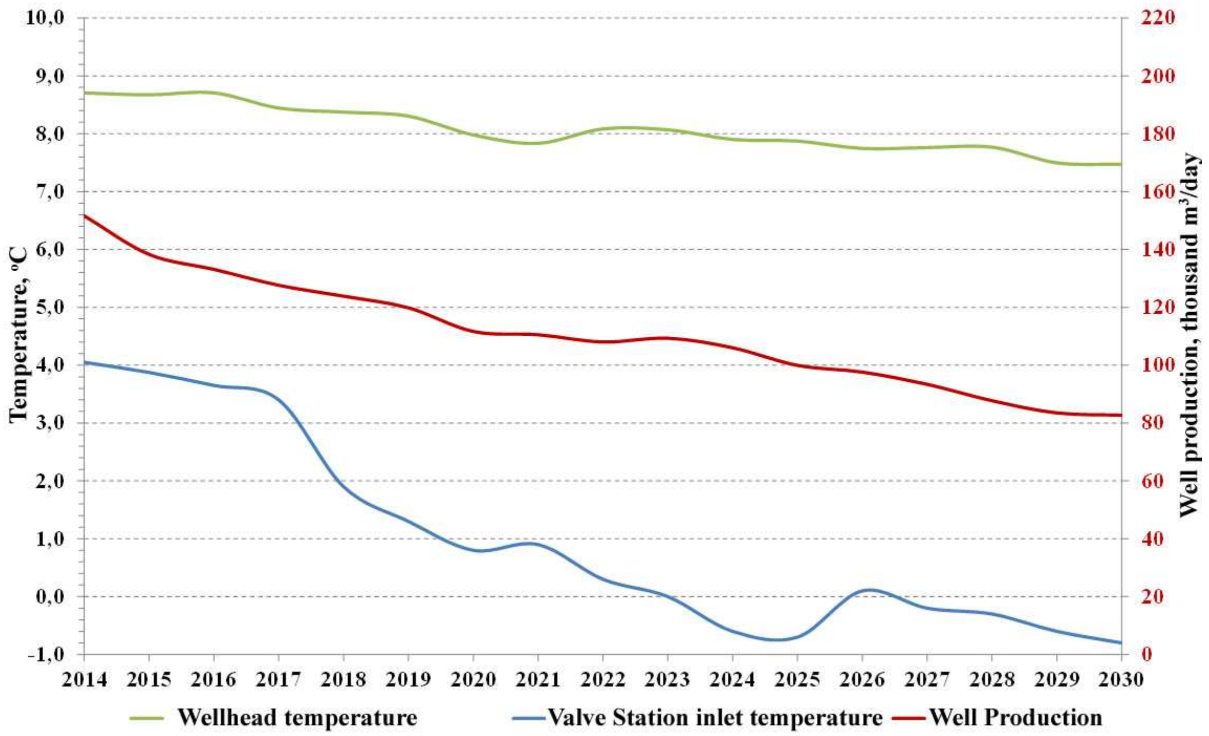

Figure 1. Dynamics of temperature and well production for wells connected to GPP-5

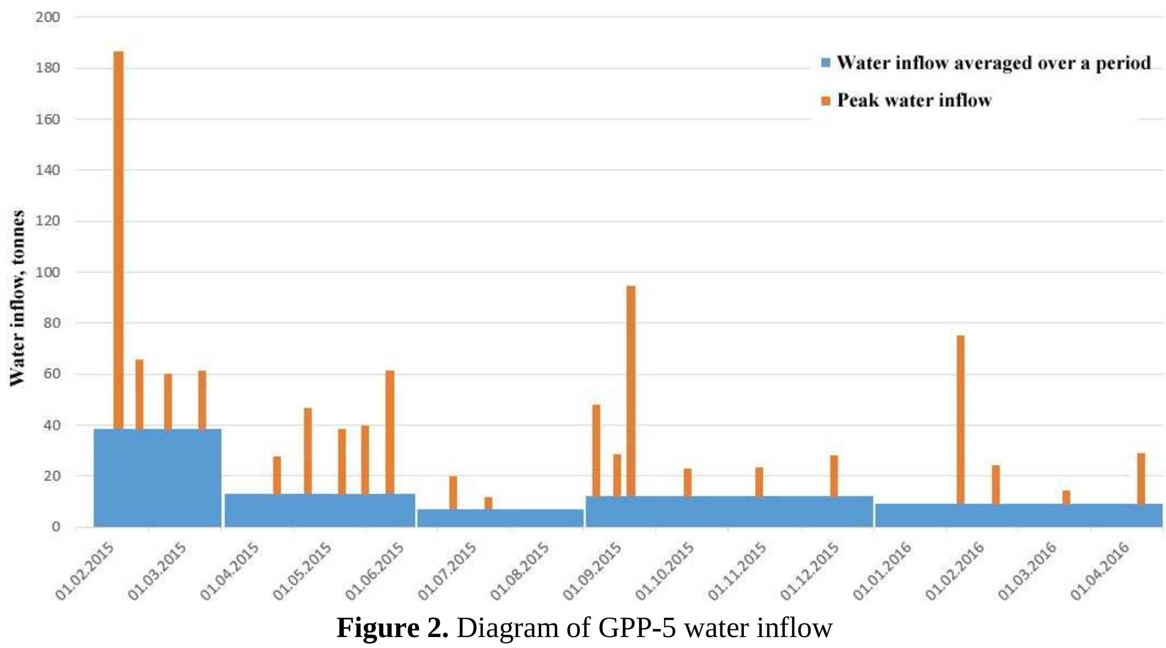

Figure 2. Diagram of GPP-5 water inflow

Water inflow from the gas collection system is of unstable nature, mainly due to some GCS sections operating in plugged mode. Inflow of liquid plugs depends on well and pipeline operating modes, cooling intensity, presence of low pockets where liquid is accumulated (such as ravine or river crossings). When a volume of accumulated liquid exceeds the critical value, it is removed by gas and transported to another section. This process repeats until the liquid reaches GPP in the form of a liquid plug.

Gas-liquid stream flow state in a three-dimensional pipeline is a function of many variables: pressure, slope, stream velocity, etc. Calculations usually use so-called critical velocity as a criterion; it is a velocity when for given thermobaric conditions and pipeline geometry there is a transition from liquid removal mode to liquid accumulation mode. In downslope pipeline segments a layered mode is actualized: liquid flows along the bottom of the pipeline, gas moves above it, at that, liquid velocity is quite close to that of the gas. In upslope pipeline segments, accumulation of liquid occurs, and when the liquid occludes the pipeline section, a plug flow is actualized (with generation of low frequency liquid flowrate pulses). At that, the liquid accumulation mode arising in the upslope segment leads to a significant reduction in effective flow velocity of the liquid phase with respect to that of the gas.

Under current operating condition of Cenomanian wells production collection, one of the most important limiting factors to efficient operation of gas collection headers and flowlines is critical liquid removal velocity, below which liquid accumulation mode kicks in in the flowline and possibility of plug flow arises.

In general case, the critical gas stream velocity v_{cr} is to various degrees influenced by the following parameter: internal diameter of the pipeline H_0, density of the accumulated liquid ρ_{lq}, viscosity of the accumulated liquid ν_{lq}, gas density ρ_g, sine of slope angle of the upsloping pipeline section to horizon α and free-fall acceleration g (Fig. 3). Thus, the critical velocity is a certain function depending on the parameters noted above:

$$V_{cr} = \varphi(H_0, \rho_{lq}, v_{lq}, \rho_g, sin\alpha, g)$$

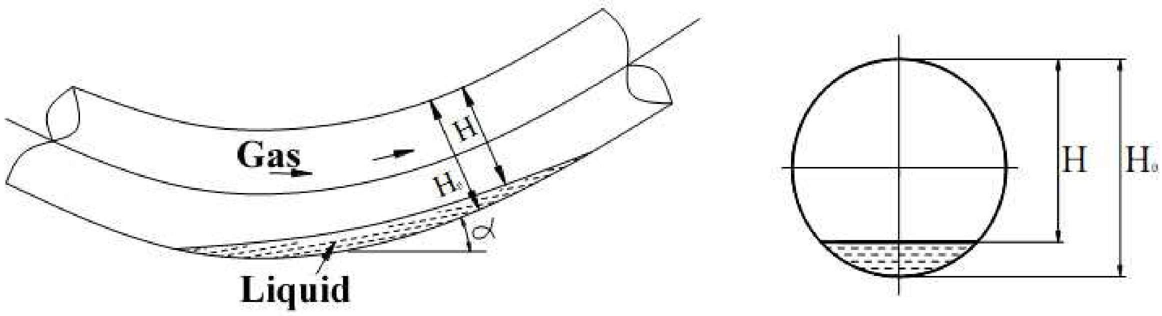

Figure 3. Liquid accumulation at an upslope section of a gas pipeline

There are various calculation methods for minimum gas velocity necessary to ensure liquid removal from a pipeline [6-10]. The critical velocity may be calculated with the formula:

$$V_{cr} = \sqrt{2\frac{\rho'+\rho''}{\rho'\rho''}} \cdot \sqrt[4]{\sigma \cdot g(\rho' - \rho''} \text{m/s}, \quad (1)$$

where ρ' is density of the liquid, kg/m^3;

ρ'' is density of the gas, kg/m^3;

σ is surface tension of the liquid, n/m;

g is free-fall acceleration, m/s^2.

This equation does not take into account the pipeline slope, which is a drawback. At the same time, in [9] there is a condition obtained that determines accumulated liquid removal from a low-lying section of a pipeline:

$$sin \propto < \frac{\frac{\lambda_\Gamma}{4} \cdot \frac{Fr_r}{\pi^2 \cdot \overline{p}^2(S)}}{\frac{\varepsilon}{\overline{p}(S)} - \frac{Fr_r}{\eta \cdot \pi^2 \cdot \overline{p}^3(S)}} \quad (2)$$

where $\overline{P}(S) = \frac{P_a + \gamma_{lq}(Z_a - Z_0 - Ssin\alpha)}{P_I}$.

Fr_r is reduced Froude number;

λ_G is the hydraulic resistance coefficient when there is accumulated liquid in upslope segment;

$\varepsilon = \frac{\gamma_{LQ}}{\gamma_{GI}}$ is a dimensionless parameter equal to ratio of the liquid bulk density to that of the gas;

$\eta = \frac{P_I}{\gamma_{LQ} \cdot R}$ is a dimensionless parameter which is directly proportional to a pressure at the initial section of the pipeline and inversely proportional to the bulk density of the liquid and radius of the pipeline.

Otherwise, the liquid is not removed completely, forming a fixed layer underneath the flowing stream of gas.

That is why, to evaluate minimum allowable productivity of a pipeline that prevents liquid phase accumulation in low-lying segments of the GCS, it is practical to employ a formula that takes into account the slope angle of the upslope pipeline segment, e.g., [10]:

$$V_{rmv} = 0.1(sin\alpha)^{-0.33} v^{-0.36} \sqrt{2gd \frac{\rho_{LQ} - \rho_G}{\rho_G} sin\alpha} \quad (3)$$

where v_{rmv} is the speed of removal of accumulated liquid phase from low-lying segments of the route, m/s;

α is the slope angle of the upslope segment;

$v = \frac{v_G}{v_{LQ}}$ is the ratio of kinematic viscosities of gas (under operating conditions) and v_G the liquid phase v_{LQ};

g = 9.81 m/s;

d is the internal diameter of gas pipeline, m;

ρ_{lq} is the density of the liquid phase having accumulated in the low-lying segment of the gas pipeline, kg/m^3;

ρ_G is the density of the gas stream under operating conditions at the entrance to the upslope segment of the gas pipeline, kg/m^3.

This model accounts for thermobaric conditions in an indirect way: depending on their values and molecular weight of the gas, the value of gas kinematic viscosity is determined for the operating conditions v_G.

To assess the minimum value of velocity v_{rmv}, necessary to remove water, calculations were conducted for several low-lying sections of a GCS from a cluster of Cenomanian wells D_y 500. Values of initial data: v_G = 0.716 cSt; v_{lq} = 1.465 cSt; v = 0.4887; d = 0.5 m; ρ_G =15.09 kg/m^3; ρ_{lq} = 998.3 kg/m^3. Thermobaric conditions: P = 20.5 kgf/cm^2, T = 8.5 °C. The calculations were performed for a range of slope angle α of the upslope segment from 4 to 16°, which corresponds to the real-life geometry of the GCS flowlines. The calculation results are listed in Table 1.

Table 1. The calculation results of speed of removal of the liquid phase.

Slope angle with respect to the horizontal axis α,°	4	6	8	10	12	14	16
Speed of removal of the liquid phase from low-lying segments v_{rmv}, m/s	2.08	2.23	2.34	2.43	2.5	2.57	2.62

The results obtained show, that, for instance, at the GCS segment 1221 (slope angle α=12°) to maintain necessary mixture velocity v_{rmv} = 2.5 m/s a flow Q = 830 thousand m^3/day is necessary, while the actual total of production in this area does not exceed 120 thousand m^3/day.

In [11], a model is proposed where the minimum necessary gas stream velocity providing liquid removal from the pipeline at 90÷95% is determined with accounts for flowline pressure:

$$V_{min} = 3.3 \cdot \left(\frac{P}{P_0}\right)^{0,15} \cdot \left(\frac{\sigma \cdot g}{\rho_{lq} - \rho_g}\right)^{0,25} \cdot \left(\frac{\rho_{lg}}{\rho_g}\right)^{0,5} \cdot (\sin\alpha)^{0,25} \quad (4)$$

where P is a pressure in the system, MPa;

P_0 is atmospheric pressure, MPa;

(ρ_{lq} - ρ_g) is a difference of density of the liquid and that of the gas at operating conditions, kg/m^3;
σ is a surface tension;
g is free-fall acceleration, m/s^2.
α is the slope angle of the pipeline with respect to the horizontal axis.

The velocity necessary for a complete (90÷95%) removal from flowlines at current pressure calculated from the formula (3) is equal to 7 m/s. However, when the pressure falls, e.g., down to 10 kgf/cm^2, this value increases to 9 m/s, which is almost impossible to provide under falling production conditions.

3. Results and Discussion

Currently, about 65% of the GCS operates under liquid accumulation mode, which amounts to 1100 km in absolute value (out of the total length of 1690 km). Further operation will be accompanied by deterioration in removal conditions and by 2030 the length of such segments will reach 87% of the total pipeline length. Taking into account, that forecast temperature at the valve station inlet will be negative by 2030 (see Fig. 1), and reducing well production will not be able to provide critical velocity of the gas stream, the probability of ice and hydrate plugs increases sharply. Most proposals aimed at solving the liquid accumulation issues in GCS assume reducing the pipeline profile to values at which gas stream velocity will be sufficient to ensure water removal. This, however, leads to increased resistance of the flowlines.

On the other hand, the presence of water in the flowline itself is not a critical factor for GCS operation if its volume is at an acceptable level, as it does not create any significant resistance to gas flow. That is why, if complete water removal from the GCS pipelines is impossible, it is practical to develop an innovative technology preventing its freezing. A possible solution is supply of heating by trace heater, so that the liquid is constantly maintained unfrozen while GCS hydraulic resistance changes insignificantly.

It is practical to use rejected heat as a source for GCS heating, as significant resources are spent to dissipate it, in particular, the heat from air cooler units of booster pump station (BPS ACU). The heat tracing is coiled tubing laid inside the existing flowlines. At the cluster side end of the flowline they are connected to existing methanol line, forming a closed loop. Heat exchange medium circulates in this loop, preventing the liquid from freezing and providing its removal during pipeline purge by a compressor.

A proposed flowline heating system operating on recuperation of gas ACU rejected heat is shown in Fig. 4.

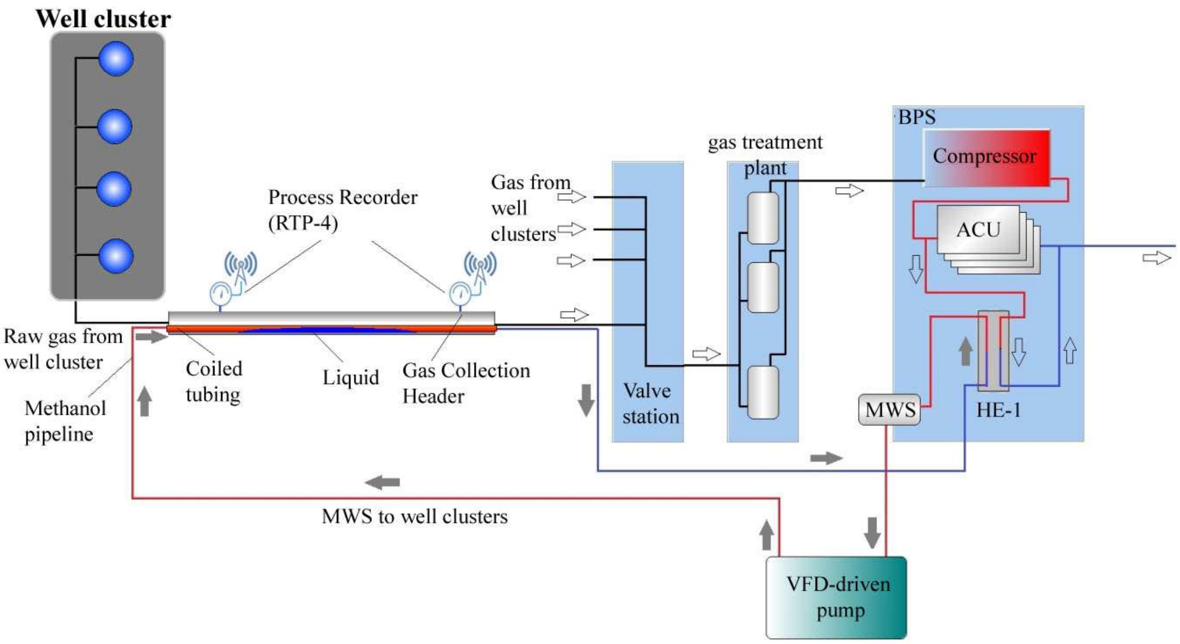

Figure 4. Flowline heating system operating on recuperation of gas ACU rejected heat.

Heat from the gas that underwent compressing at the BPC is transfered to an intermediate heat exchange medium, a methanol-water solution (MWS) with a concentration that prevents its freezing from the lowest ambient temperatures during the cold period of year. MWS is transported inside the GCS through a flexible metal tube by means of VFD-driven pumps. A coiled tubing with OD of 40 – 60 mm laid pipe-in-pipe is used as a pipe. ACS for this technology is based on industrial-grade controllers that control the pump operation maintaining necessary levels of pressure and temperature in all controlled points on the basis of data coming from RTP process recorders, thus providing equilibrium mode of GCS operation.

The main task in determining necessary amount of heat to provide gas transportation with water to the valve station without formation of ice plugs is calculation of heat losses in the GCS gas pipelines. Non-uniform nature of thermal insulation and pipe laying technology create most difficulties for such calculations. Each GCS gas pipeline may be partially laid underground at various depths, on the ground surface or as an elevated pipeline on piperacks. At that, thermal insulation may be partially disturbed or completely missing. In case of surface pipelines, it is quite common that extensive length of the pipeline are completely or partially submerged in water. Significant variation of seasonal temperature and solar irradiation, changes in wind speed and snow cover depth, significant variation in heat transfer ratio along the gas pipeline route do not allow performing the calculations with acceptable accuracy.

Estimation of the MWS amount necessary for gas heating was performed with a mathematical model from data obtained at GPP-5 of the Urengoy OGCF.

Optimal (for absorption gas dehydration) value of gas temperature at the heat exchanger outlet is +15 ^{0}C. To ensure this value for MWS temperature inlet of +1 ^{0}C at the heat exchanger inlet and gas temperature of +90 ^{0}C during peak removals, it is necessary to supply 100 t/h of MWS. At that, the outlet temperature of MWS is 80 ^{0}C. WMS concentration that prevents its freezing when being cooled to the coldest ambient temperature is 60 wt%. (freezing temperature of minus 75.7°C) [12].

To assess heat losses along the methanol pipeline system and determine MWS temperature at the well cluster, a hydrodynamic model of the methanol pipelines has been developed. The calculations were performed for underground pipe laying for three various types of sandy soil: dry, moist and wet, as the heat exchange rate varies over a wide range depending on water content: from 0.5 to 2.2 W/(m·K) [13]. Initial WMS temperature for all cases was taken as 70 ºC, the soil temperature was taken as minus 5 ºC. The calculations have shown, that with MWS flowrate of 60 m^3/h, its temperature after passing the flowline was 26, 13 and 2 ºC, for dry, moist and wet sand respectively.

As methanol pipelines may be laid on the surface or underground, passing through both swampy and dry land, the results obtained, though approximate, allow concluding that the surface of the methanol pipelines is sufficient for dissipation of the MWS heat.

4. Conclusions

The proposed technology has a great practical importance for gas and gas condensate fields at the final stage of operation. Besides attaining its main goal – prevention of ice and hydrate formation – when using GCS as a heat dissipating loop, a possibility opens to dissipate vast amount of heat (up to 15-20 MW from two stages of ACU), which today consumes up to 1.5 MW*h of electric power.

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