Phase Behaviour Analysis of the Water from Natural Gas Along the Pipelines

CRISTIAN EPARU*, SORIN NEACSU, EUGEN MIHAIL IONESCU, MIHAI ALBULESCU, ALINA PRUNDUREL

Petroleum - Gas University of Ploiesti, 39 Bucuresti Blvd., 100520, Ploiesti, Romania

Based on the methodology for determining the liquid-vapor equilibrium conditions for wet gas, the paper presents a model of water phase behavior for the water existing in gas transmitted through pipelines, model based on Simone simulator. By using this model, we tried to correlate the measured data of humidity with the values of gas transmission parameters and with the pipeline profile.

Keywords: gas, humidity, transmission

Phase behaviour of the water from gas is influenced by gas pressure and temperature. During gas transmission, pressure and temperature variations cause the change of water phase behavior along the pipeline. In hydraulic calculations of the transmission pipelines, it is usually considered that gas transmission is an isothermal process [1, 2]. This assumption simplifies calculations, as energy equation may be excluded. Considering actual conditions occurring during the transmission of natural gas, as pipelines follow the relief profile - often crossing the mountains - this paper analyzes the equilibrium phase, in case of non-isothermal gas flow, taking into account energy equation.

In order to establish phase behavior, there were calculated, along the analyzed pipelines, the coordinates of water dew point, depending on gas local parameters (pressure and temperature).

The Simone simulator was used to model the flow of gas-water mixture along the transmission pipelines.

Geometric data of the pipelines (i.e. diameters, lengths, profiles) and the values of gas parameters (i.e. pressure, flow, humidity) are real data for several gas pipelines in Romania [3]. Along a pipeline, the values of gas pressure and temperature change, fact which affects the phase behavior of the water present in gas. Even if the value of absolute humidity remains constant, water state of aggregation is influenced by gas pressure and temperature. Knowing the phase behavior of water along the pipeline allows the identification of the areas where water is in vapor phase, and where it condenses, respectively [4].

The paper presents a model of phase behavior for humidity in pipelines based on Simone simulator. Since phase behavior changes according to the local values of the pressure and temperature, the simulator must take into account the pressure variation of the gas in relation to the profile of the pipeline.

For this simulation, there was used a non-isothermal flow model, in which soil temperature is constant, and the temperature of the gas varies depending on local energy changes.

Water that gives the humidity of the gas can be found in vapor or liquid state [5, 6]. As Asante [7] demonstrated, the presence of liquid water, resulting from vapor phase condensation, determines in gas transmission pipelines the decoupling of the two phases velocities. The gaseous phase moves through the pipeline faster than the liquid phase [8]. On the other hand, liquid water begins to

accumulate, as a result of gravity, in the lower portions of the pipelines, thus reducing the flow area of the gas phase and even forming water plugs, which are periodically pushed to the downstream due to the gas pressure. In order to have a picture of the humidity behavior along pipelines, we attempted to correlate the measured data of humidity with the gas parameter values and with the characteristics of gas pipelines. Figure 1 presents a schematic view of the pipelines in which the humidity measurements were carried out. As can be seen the entering point is town C and the delivery points are the 2 town called St and O. Figure 2 presents a view on a 3D map of this pipelines and a 2D of the altitudes for one of them. From point C to point ST the pipelines are crossing by 2 other connection point called S and P.
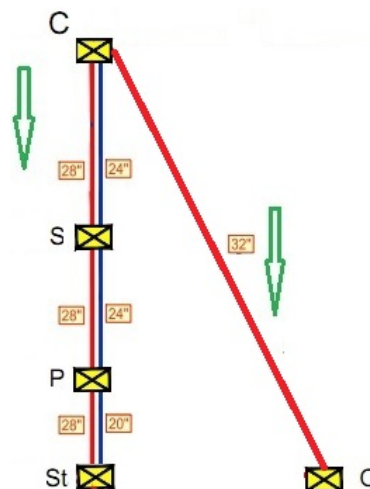

Fig. 1. Pipelines with monitored humidity

Phase behaviour of water in case of isothermal flow

In a first variant of modeling, gas temperature was considered constant over the entire length of the pipeline, and the pressure was determined by simulating the flow, still observing the parameter values (flow, pressure) at the ends of the pipes. During simulations, the pipeline profile (elevation) was also taken into account. All data were introduced into Simone simulator, and the results are shown in figure 3, 4 and 5. From these diagrams it appears that taking into account the altitude causes significant changes of the pressure along the pipeline, which may influence the phase behaviour of the gas humidity as previously demonstrated [9].

The values of gas humidity were measured in the technology nodes, at the ends of the pipelines and were
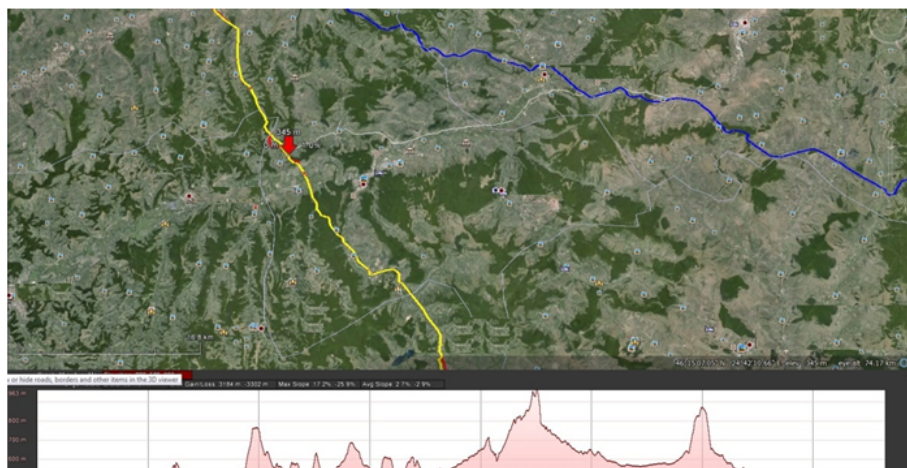
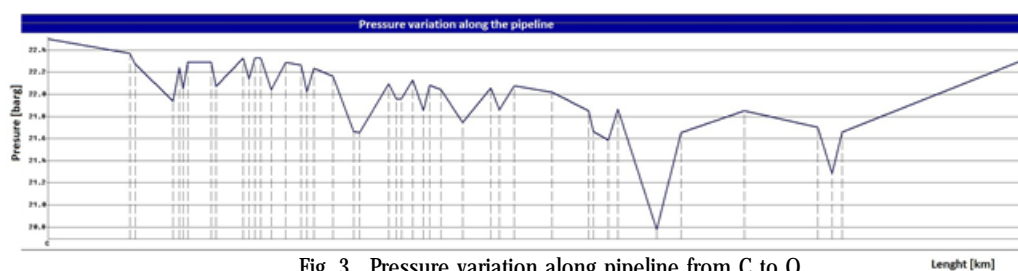Fig. 2. Defining altitudes along the pipelines

Fig. 3. Pressure variation along pipeline from C to O
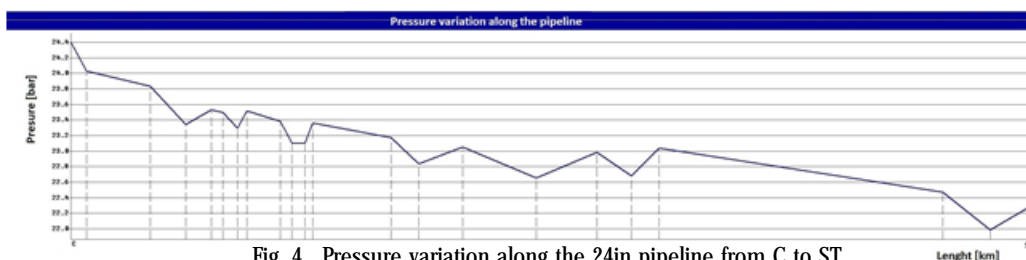

Fig. 4. Pressure variation along the 24in pipeline from C to ST
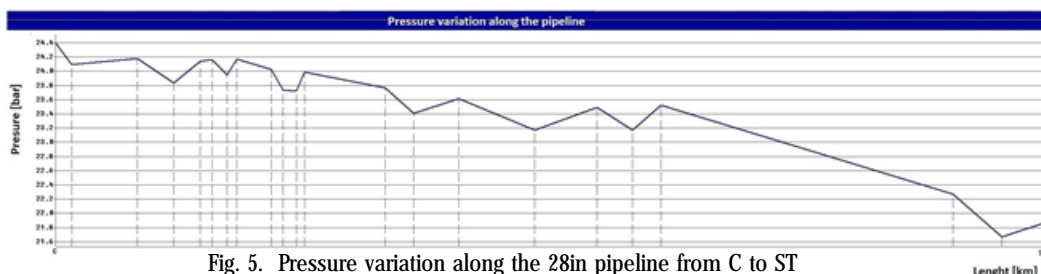

Fig. 5. Pressure variation along the 28in pipeline from C to ST

considered constant along the whole pipe. By using the model presented by Neacsu et al. [9] we intended to establish the areas where water condenses, thus turning into liquid state. The data listed in figure 6 [for C–O pipeline] were used for the calculations whose results are graphically shown in figure 7. Both gas humidity and temperature were considered constant along the pipeline.

In these conditions, one can notice that the dew point pressure is 22 985 bar, a value superior to the gas pressure along the entire length of the pipeline, which means that water representing humidity of the transported gas is in vapor state. By using data measured in node S (fig. 8), there were carried out calculations for C–ST pipeline and the results were shown in figure 9. After having analyzed the results, it appears that, starting from the entrance into

the pipeline up to kilometer 89, water from gas is in liquid phase, then gas pressure becomes lower than the pressure of the dew point, which allows water vaporization. Taking into account the values of humidity, a water flow equal to 1.074 m³/day is transported in the portion where water is liquid.

Phase behaviour of water in case of non-isothermal flow

The hypothesis of the wet gas isothermal flow is restrictive and it does not correspond to the real situation in the transmission systems. If soil temperature is considered constant (or nearly constant), and gas temperature varies, determined by flow hydrodynamic conditions, and by the thermal interaction with the soil – which is a more plausible case – one can notice that the phase balance indicated by the dew point line is not constant along the pipeline anymore, as in the case of isothermal flow.

In order to analyze a more realistic situation, we have created a model in which soil temperature is constant and gas temperature is variable. The variation of gas

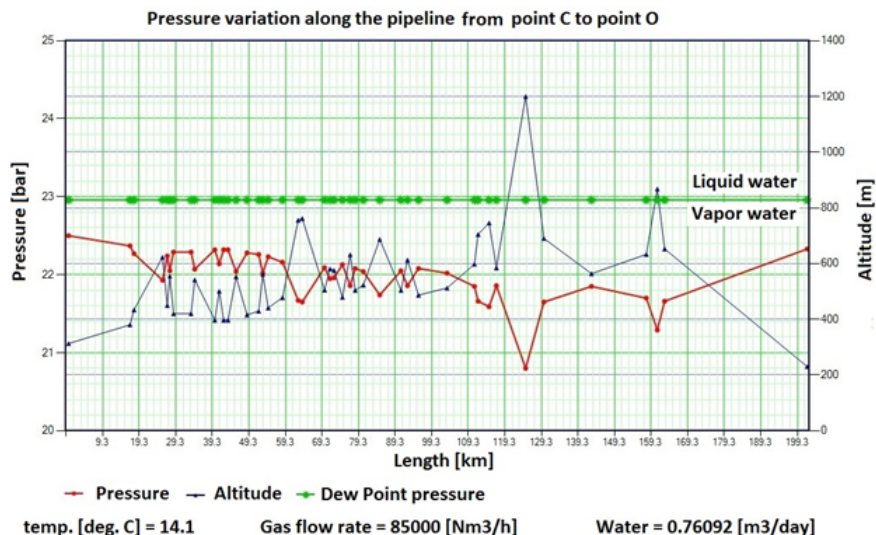| Measure point = | C |
Dew point temperature [°C] =	10.8
Humidity [g/Nmc] =	0.64
Pressure [bar] =	22.5
Temperature [°C] =	14.1

Fig. 6. Calculation data

Fig. 7. Phase behavior of water along C - O pipeline

temp. [deg. C] = 14.1   Gas flow rate = 85000 [Nm3/h]   Water = 0.76092 [m3/day]

temperature in this case is due to the heat exchange with the soil and to the gas enthalpy variation in accordance with the kinetic energy variation. These models with gas variable temperature take into account, in addition to the mass and momentum conservation equations, the equation of energy conservation.

The model was designed with the Simone simulator, and the results were presented in graphical form in figure 10. For this calculation, there were considered a soil temperature of 4°C and a gas temperature at the entrance to the pipeline of 14.1°C. One can notice the variation of the transmitted gas temperature, variation determined by the heat exchange with the soil and by the energy variation due to the pipeline profile (the green line); compared with the case when gas temperature is considered constant over the entire length of the pipelines.

Figure 11 presents the phase behavior of water in this

Measure point =	S
Dew point temperature [°C] =	12.5
Humidity [g/Nmc] =	0.64
Pressure [bar] =	22
Temperature [°C] =	11

Fig. 8. Data measured at point S on 21st November 2012

transmission pipeline. The humidity input data are the ones listed in figure 8. If the values of humidity and temperature are constant, there results that water is in vapor state (fig. 7). In case pressure and temperature are considered variable depending on the pipeline profile, it can be seen that their combined variations modify water phase behavior, especially in the areas where the pipeline is at a higher altitude. According to the results of the calculation, in these areas water condenses and occurs in liquid state.

Given the results presented, it can be concluded that gas transmission parameters (pressure, temperature and pipeline profile) strongly influence the phase behavior of gas humidity.

If the local analysis of the water phase behavior, correlated with gas pressure and temperature, leads to certain conclusions, they may not be valid throughout the entire transmission system. Therefore, the problem of gas humidity is to be related to the geometry of the transmission system (to which altitude has to be added), to the transmission pressures and to the temperature of the soil.

The distribution of gas humidity in the transmission system can be realized with a numerical simulator which also has this module.
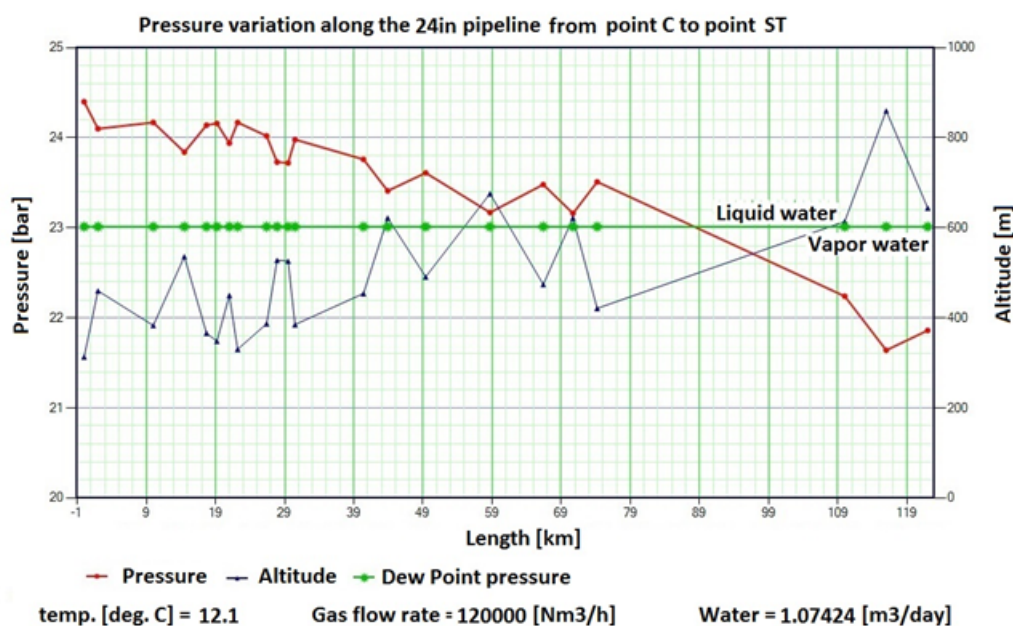

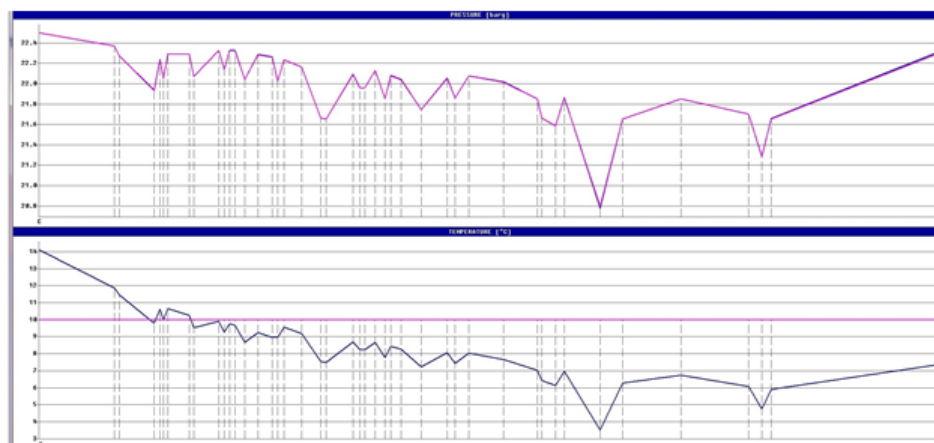Fig. 9. Water in C-ST pipeline is liquid up to kilometer 89.

temp. [deg. C] = 12.1   Gas flow rate = 120000 [Nm3/h]   Water = 1.07424 [m3/day]

Fig. 10. Pressure and temperature variation along the pipeline
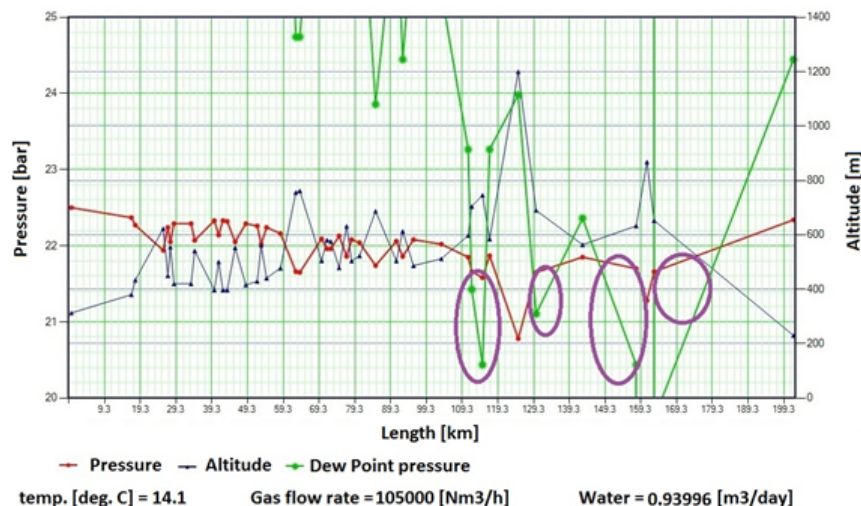
Fig. 11. Phase behavior of water in case of variable gas temperature

— Pressure — Altitude — Dew Point pressure

temp. [deg. C] = 14.1   Gas flow rate =105000 [Nm3/h]   Water = 0.93996 [m3/day]

Conclusions

Gas humidity negatively affects the transmission process when water vapors condense and create the danger of accumulation in the pipelines.

From the analysis of the gas phase behaviour in certain measurement points, as well as of its behaviour along the pipeline, there results that the condensation of the water vapors depends on the humidity value, on pressure and temperature. Therefore, in addition to the humidity values, the pressures and temperatures of the transmitted gas should also be monitored. The models proposed in this paper may be useful to determine the areas where there is the danger of water condensation and the humidity limit values for which this phenomenon occurs.

The paper presents, for the first time, the phase equilibrium dynamic of wet natural gas along the transmission pipelines that crosses a mountain chain, using a non-isothermal flow model. The simulations show that water condensation is influenced by the relief altitude. This results are confirmed by the transmission network operator.

The most effective method of controlling the presence of liquid water in the gas pipelines consists in gas dehydration in order to maintain low humidity values, so that the water from gas remains in vapor phase.

Pressure and temperature influence the phase behavior of water representing gas humidity. Pressure variation is defined by the transmission process and cannot be changed in order to change the phase behavior of water. Thus, a lower pressure reduces the risk for the water vapors to condense, but this also decreases the capacity of the transport system, and, as a result, it cannot be considered a viable solution.

The temperature of the transmitted gas is determined by the atmospheric conditions that affect soil temperature. During the summer, when soil temperatures are higher, there can be transmitted gas with higher humidity, but in winter, when temperatures drop, gas humidity must be limited in order to prevent condensation and the occurrence of liquid water.

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