INFLUENCE OF JOULE THOMPSON EFFECT ON THE TEMPERATURE DISTRIBUTION IN VERTICAL TWO-PHASE FLOW

Abstract:

Flow of hydrocarbons inside pipelines that connect production wells to platforms are quite complex, as the flow is typically turbulent and at least two phases (gaseous and liquid) are present. These phases can be arranged in several flow patterns (dispersed bubbles, annular, intermittent or stratified), depending strongly on the phases superficial velocities and pipeline configuration (diameter and inclination). In deepwater operations, these pipelines are immerse in the ocean at low temperature, and heat loss to the environment leads to a drop in the fluid temperature. The temperature drop often drives an exponential increase in the oil viscosity, thereby affecting the pressure drop. Further, if the oil temperature falls below the "wax appearance temperature" (WAT), wax crystals precipitate out of the solution and deposit may form along the pipeline inner wall (Merino-Garcia el at, 2007, Azevedo and Teixeira, 2003). Deposition of wax components can constrain the flow area and in the worst case even block the pipeline causing loss of production (Aiyegina et al 2011).

Another phenomenon found on this type of flow is the temperature variation induced by the pressure (Joule-Thompson effect). Thus, if the Joule-Thompson effect is significant, pressure variations can induce a further decrease in temperature, enhancing the paraffin deposition. However, if the temperature drop due to pressure variations leads to a more uniform temperature profile, reducing the wall heat flux, deposition rate would be lower, despite the presence of paraffin crystals in the bulk of the fluid.

Subsea production lines are long and typically have diameters that range from 4" to 8". The above-described problem becomes critical inside the vertical sections of the lines, known as"risers", of variable length depending on the shape (Catenary, Lavy Wave etc) and water depth. Since the flow is vertical upward, the pressure drop is significant due to two contributions: friction and hydrostatic pressure. Therefore, the objective of the present work is to investigate numerically, with the commercial software Fluent, the influence of the Joule Thompson effect in two-phase flow, through vertical upward pipelines. Qualitative indications about the impact on wax deposition are also discussed.

Due to the complexity of the flow, several simplifications were performed. Smaller portions of the vertical pipeline, with only 200 m of length were considered for each type of flow pattern, corresponding to different regions along the riser. The flow was modelled as two-dimensional, assuming it to be axi-symmetric. The liquid was assumed as incompressible. Two equations of state for the gas were employed: the ideal law, and to account for the Joule Thompson effect, the Peng-Robinson equation (Peng. and Robinson, 1976). Mass transfer between the phases was neglected (leaving the phase change as a source of energy for a subsequent study). The $\kappa-\varepsilon$ model was selected to model the turbulence. For all cases, the mass flow rate of both phases was imposed at the entrance, along with the turbulence quantities, and temperature. A constant pressure was defined at the exit. The pipeline was heavily insulated with overall heat transfer coefficient equal to 4 W/(m^{2}K). The sea water was maintained at 4^{o}C. Three scenarios were considered: dispersed bubble, annular and wavy annular (wispy) flows.

The dispersed flow was modeled with the two-fluid model, with bubble size varying from 0.01 mm to 5 mm. Although the bubble size did not present an impact in the solution, a smaller friction contribution was obtained with bubbles of larger diameter. The results obtained showed that the liquid and gas temperatures were nearly the same for all cases investigated. Higher gas concentration was found near the wall. A small temperature decrease was obtained in the wall region, due to heat loss to the environment. A slight increase of the temperature was

observed along the pipeline, due to an increase of the liquid temperature. Although the Joule Thompson effect acts to increase the temperature of an incompressible liquid, this effect is very small for typical hydrocarbons. A possible explanation for the result obtained is the absence to the mass transfer between phases, and the insulation degree. Since the amount of gas in the pipe is very small, the flow is governed by the liquid behavior. For the ideal gas case, the gas Joule Thompson effect is null, but for the real gas case, the Joule Thompson effect acts to reduce the gas temperature, therefore, the mixture does not heat up as much as for the ideal gas case.

The annular flow and wavy annular flow were modeled with VOF method. For these two cases, the liquid phase temperature also increased along the pipeline, being higher than the gas temperature, which was flowing in the core region. However, since for the annular case, the liquid flows along the wall, it loses heat to the environment. Further, the amount of liquid is very small, thus a negligible temperature variation was obtained with both equations of state. Due to the Joule Thompson effect, an axial temperature drop was predicted with the real gas case. However, it did not induce significant differences from the thermal aspect of the problem.

For the wavy annular (wispy) case, when employing the ideal gas model, a small temperature increase in the liquid phase was also observed along the pipeline. This behavior was also obtained for the dispersed bubble case, since both cases present a large amount of liquid in the flow, which induced an increase of the mixture temperature. For the real gas case, the Joule Thompson effect acts to reduce the temperature of the gas phase, and results in an overall small mixture temperature reduction along the pipeline.

For all cases, the pressure distribution along the cross section was approximately uniform. Therefore, the pressure work in the radial direction is negligible, and although temperature is smaller in the inner region, the temperature variation is very small.

The results showed for all flow patterns and operational conditions investigated (no phase change, high insulation), the Joule Thompson effect reduced the gas temperature and increased the liquid temperature. Depending on the gas volume fraction and flow regime, the contribution of one or another dominated the overall temperature variation along the riser.

Having in mind the final objective, to assess the impact on wax deposition, only the wispy annular flow showed a significant temperature gradient towards the bulk of the fluid that could lead to a reduction in wax deposition

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Acknowledgements

The authors thank Repsol, CNPq (Brazilian Research Council) and ANP (Brazilian National Petroleum, Natural Gas and Biofuels Agency) for the support awarded to this work.