THE PROBLEM OF HIGH WAX CRUDE OIL TRANSPORTATION THROUGH SUBSEA PIPELINES FROM A MARGINAL OFFSHORE OIL FIELD

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Summary

In the last few years, Petrovietnam has discovered some marginal oil fields such as Nam Rong, Doi Moi, Ca Ngu Vang, Hai Su Den, Hai Su Trang, and Gau Trang, etc. Most of the oil and gas will be produced from the basement reservoir, but the oil and gas reserves from these fields are modest. The test results of wells during drilling showed that the maximum production rate from the wells of these fields is expected to be about 20,000 barrels/day (3,000 tons/day). The efficient development of these offshore oil fields will be problematic for the engineers. Oil production practices around the world show that, if the production of an offshore oilfield is not more than 20,000 barrels/day, then the tie-in of the marginal fields to the nearest larger oil field will be a more effective way to produce the oil and gas.

In some cases, it will be a larger challenge because of the high pour point (~36°C) and high wax content (19 - 25%) of the crude oil produced from these fields. In addition, the wellhead temperature may be lower than the wax appearance temperature (WAT), which is in the range of 45 - 50°C. The offshore transportation of this oil and gas through long distance pipelines together with conditions of relatively low seabed temperatures (~21°C) will pose serious problems due to the deposition of paraffin wax.

The decision to tie-in smaller, marginal fields with high pour point and waxy crude to adjacent oil production platforms through subsea pipelines is very important for future oil production in Vietnam. This paper will describe the complexities and problems associated with oil and gas transportation from Nam Rong - Doi Moi oil field to the Rong oil field of Vietsovpetro.

Key words: *Wax deposition, pour point temperature, viscosity, Nam Rong - Doi Moi oil fields.*

1. Introduction

Doi Moi oil field is located in the Nam Rong area, about 18km from the fixed platform RP-1 and 21.5km from platform RP-2. The operators of Doi Moi and Nam Rong oil fields will be the "Vietnam - Russia - Japan" JV and Vietsovpetro. The results of well testing showed that the maximum production from Doi Moi oil field should reach 2,000m^3/day and the minimum production may be only 300 - 570m^3/day. Hence, the maximum production of crude oil from both Nam Rong and Doi Moi oil fields will be about 3,600m^3/day and the minimum daily production is expected to be about 500m^3.

The practice of oil and gas gathering and transportation with low flow rates through subsea pipelines often poses a serious problem due to the deposit of wax on the walls of pipeline [1]. Transportation of crude oil from Doi Moi and Nam Rong oil fields through the subsea pipeline will have a low flow rate and is therefore expected to experience problems of wax deposition on the pipeline walls. The problem will be worse in offshore conditions with a minimum seabed temperature of ~21°C.

2. Rheological properties of the crude oil

The crude oil produced from Nam Rong - Doi Moi oil fields has a high paraffin wax and asphaltene resin content. The pour points of these crudes range from 29 - 36°C and their viscosity at 50°C range from 9 - 17.4mm^2/s. Table 1 shows some of the main physical and chemical properties of Nam Rong - Doi Moi crude oil.

The pressure - volume - temperature (PVT) studies in the laboratory demonstrated that the influence of solvent gas on the viscosity of Doi Moi oil is a little effective at temperatures higher than 32°C, however at temperatures lower than 32°C, quantities of solvent gas injected into the oil will reduce the viscosity of Doi Moi crude oil.

Table 1. *Selected physical and chemical properties of Nam Rong - Doi Moi crude oil*

Parameter	Oil field	
	Doi Moi	Nam Rong
Specific gravity, at 20°C, kg/m^3	869.7 - 876.4	865 - 870
GOR, m^3/m^3	45	35
Water content, % V	3.2 - 0.1	0
Solid content, % mass.	0.046 - 0.19	0.02 - 0.04
Viscosity at 50°C, mm^2/s	13.54 - 17.42	9.6 -14.1
Pour point, °C	35 - 36	32 - 33
Sulfur content, % mass.	0.102 - 0.1058	0.1169 - 0.084
Paraffin content, % mass.	17.20 - 17.55	19.56 - 21.8
WAT, °C	58.6 - 59.2	57 - 55
Asphaltene resin content, % mass.	13.3 -14.45	10.56 - 12.41
Boiling temperature, °C	84 - 116	76 - 95

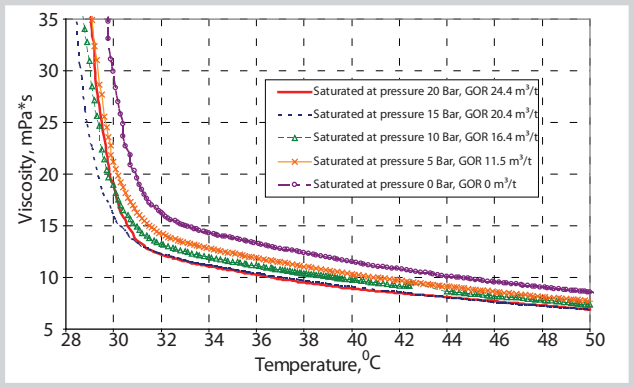
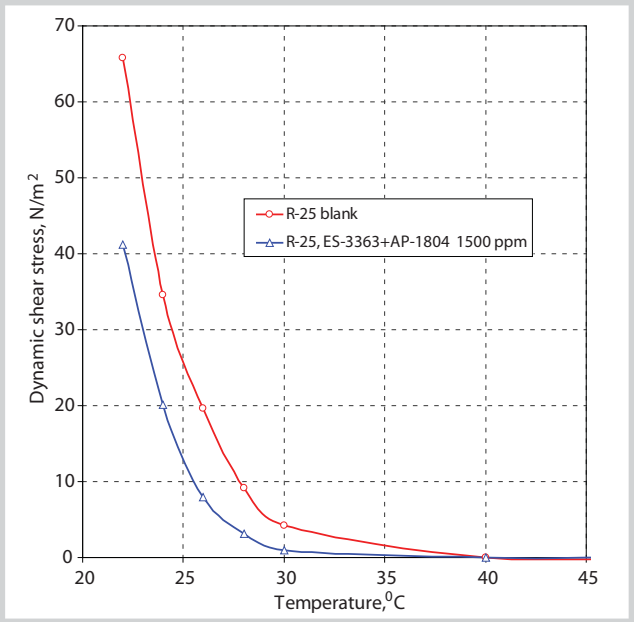


Figure 1. *Viscosity of crude oil from well DM-3X at different gas-oil ratio and temperatures*

Figure 1 shows the influence of solvent at different pressures on the viscosity of a crude oil sample taken from well DM-3X of Doi Moi oil field.

In order to fully understand the crude oil characteristics and rheological properties of Nam Rong - Doi Moi crude oil, with and without pour point depressant, tests were conducted at different temperatures using specialised laboratory equipment - "ROTOVISCO-RV-20". The results are presented in Figures 2 and 3.

As presented in Figures 2 and 3, the laboratory results showed that:



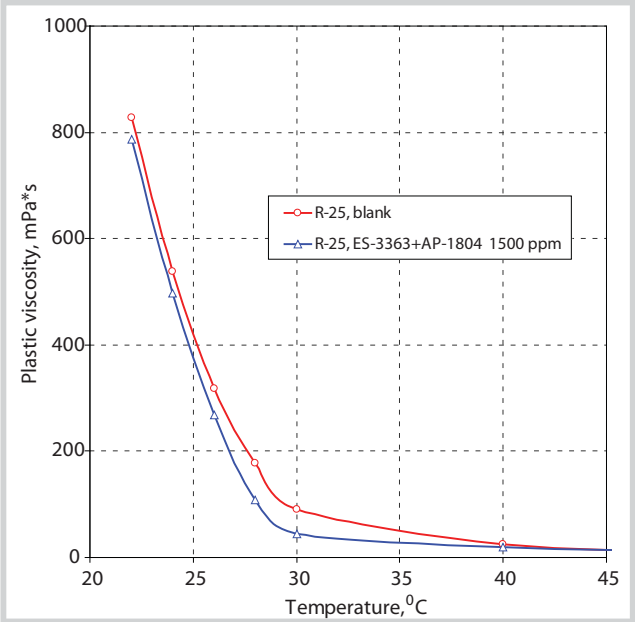
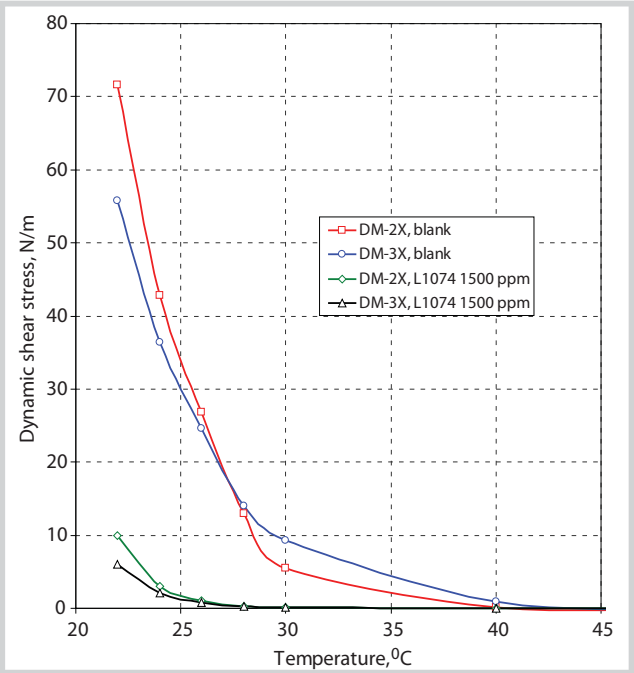


Figure 2. *The influence of pour point depressant on the viscosity and shear stress of Nam Rong crude oil*



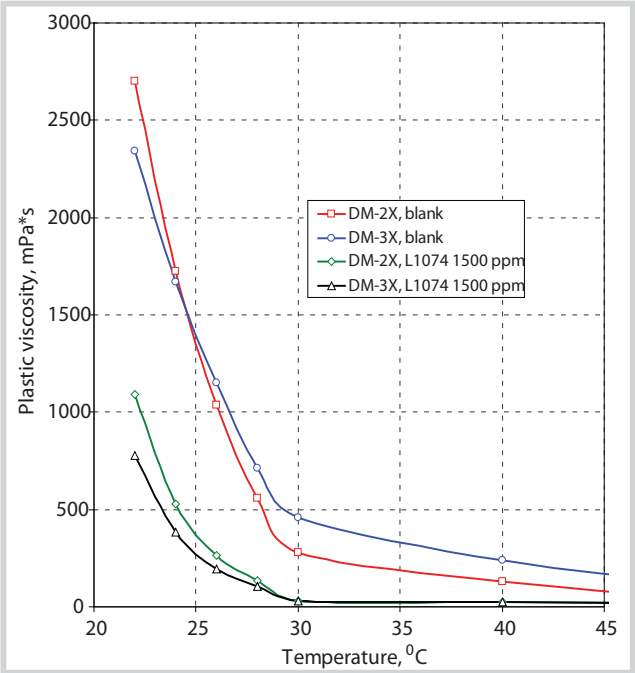


Figure 3. *The influence of pour point depressant on the viscosity and shear stress of crude oil from DM-3X well*

Table 2. *Results of wax deposit studies from Doi Moi crude oil using the "cold finger" method*

"Cold finger" temperature, °C	Oil temperature, °C	The wax deposit tendency g/(m²·h), at shear rate (20s⁻¹) and chemical (PPD) dose of 1,500ppm	
		Well # DM-2X	Well # DM-3X
25	30	15.00	15.12
30	35	4.03	5.41
35	40	2.02	1.64
40	45	0.55	0.80
45	50	0.35	0.65

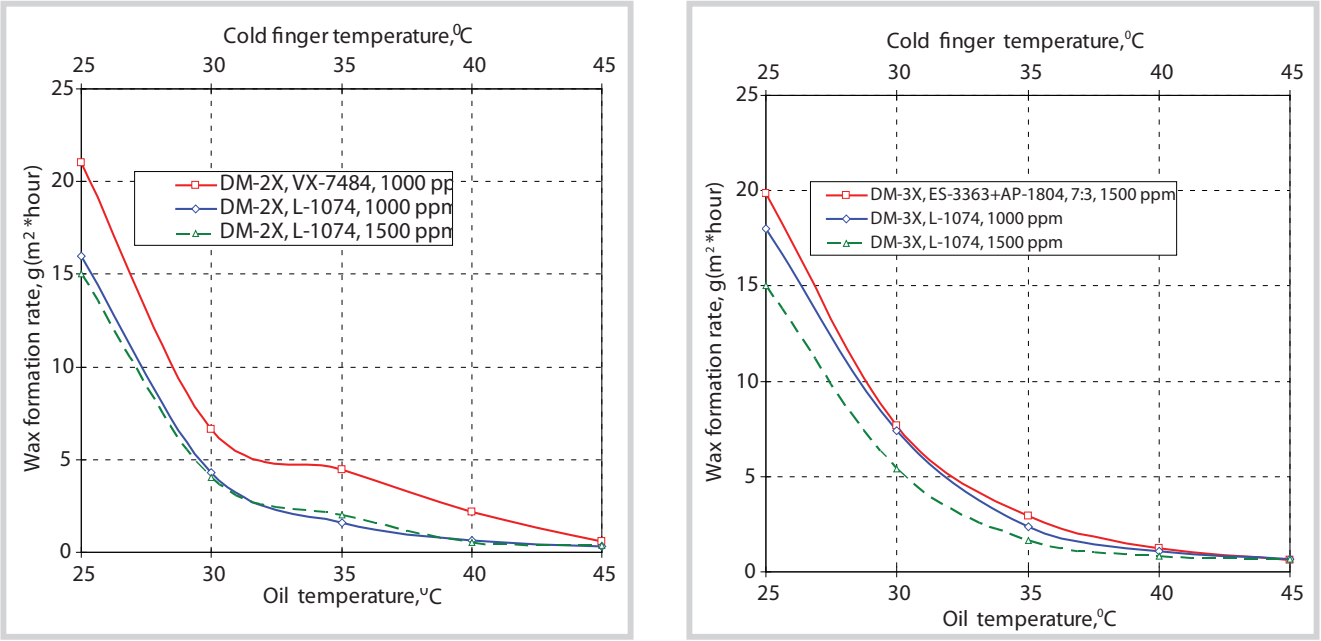


Figure 4. *Wax deposit tendency of Doi Moi crude oil with the addition of pour point depressant*

- The viscosity and dynamic shear stress of crude oil samples from Nam Rong oil field (Figure 2) could be improved a little with pour point depressant;

- Rheological properties of crude oil samples from Doi Moi oil field injected with pour point depressant were strongly improved. The pour point of crude oil could be decreased from 35°C to 24°C with a dosage of 1,500ppm of pour point depressant.

To study the wax deposit tendency of crude oil samples from Doi Moi oil field, the "cold finger" apparatus was used. The results of the studies are presented in Table 2 and Figure 4. The laboratory studies were carried out at different temperatures from 35°C to 50°C. The subsea pipeline, planned to be used in Doi Moi oil field for oil and gas transportation, will be insulated with composite. Therefore, the difference in oil temperatures between the centre and the walls of pipeline will be small. Hence, in the laboratory tests, the temperature difference between the oil and the "cold finger" was kept at approximately 5°C.

The results presented in Table 2 and Figure 4 show that during a decrease of the oil temperature, the wax deposit tendency of the crude oil increased and it was higher when the shear rate was decreased. The pour point depressants used for treatment of Doi Moi crude oil do not help to solve the problem of wax deposition during transportation.

Experience in the Vietsovpetro's Rong oil field of the subsea pipeline RP-3 → PLEM-UBN-3 production [2] demonstrates that when the flow rate is low (not more than 2,000 - 3,000m³/day), serious problems of wax deposition occur on the walls of the subsea pipeline. To solve this problem, increased flow rates through the pipeline are achieved by adding sea water to the transportation pipeline.

It can, therefore, be concluded that the transportation of crude oil from Nam Rong - Doi Moi oil fields with low flow rates through the subsea pipeline to the Vietsovpetro FSO will be associated with problems of wax deposition.

3. The transportation of Nam Rong - Doi Moi crude oil through a pipeline with low flow rate

As described above, at present, Vietsovpetro operates some offshore oil fields in the Southern part of offshore Vietnam. The Nam Rong - Doi Moi oil fields are the nearest to Rong oil field and the tie-in of Nam Rong - Doi Moi oil fields to the Rong oil field will allow the gathering and processing of all production coming from these oil fields on the Vietsovpetro fixed platforms. The only problem to consider is to which fixed platform to transport the crude. A lot of variants had to be considered, but the route from Nam Rong - Doi Moi to RP-1 fixed platform is considered as preferable.

Two satellite platforms (RC) RC-DM and RC-4 are planned to be constructed for oil production in Nam Rong - Doi Moi oil fields. On the RC platforms only wellhead equipment without processing was considered. The production from Nam Rong oil field will be transported to RP-1 for processing. For the transportation of crude oil from Nam Rong - Doi Moi oil fields to RP-1, a thermal insulated subsea pipeline RC-DM-RC-4 → RP-1 from RC-DM to RP-1 will be built with a length of 17km.

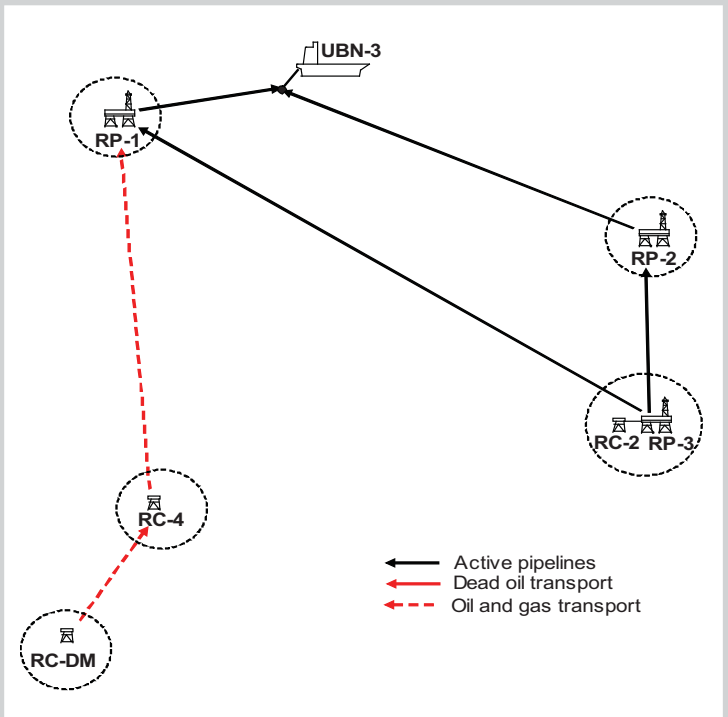


Figure 5. *Schematic of oil and gas transportation from Nam Rong - Doi Moi to RP-1 of Rong oil field*

Table 3. *Maximum production will be through the pipeline RC-DM → RC-4 → RP-1*

Parameter	Transportation value	Production on RC	
		RC-DM	RC-DM + RC-4
Maximum liquid	Q_{liquid}, m^3/day	2,254	3,655
	Water content, % mass.	0.0	0.0
Maximum water content	Q_{liqiud}, m^3/day	914	1619
	Water content, % mass.	66.7	67.8

Figure 5 shows the schematic of the interconnecting platforms in Nam Rong - Doi Moi and Rong oil fields.

To determine the required diameter of the pipelines RC-DM → RC-4 → RP-1, the hydraulic calculation for the maximum flow rate through the pipeline was considered. The maximum production rates that could be expected from Nam Rong - Doi Moi oil fields are presented in Table 3.

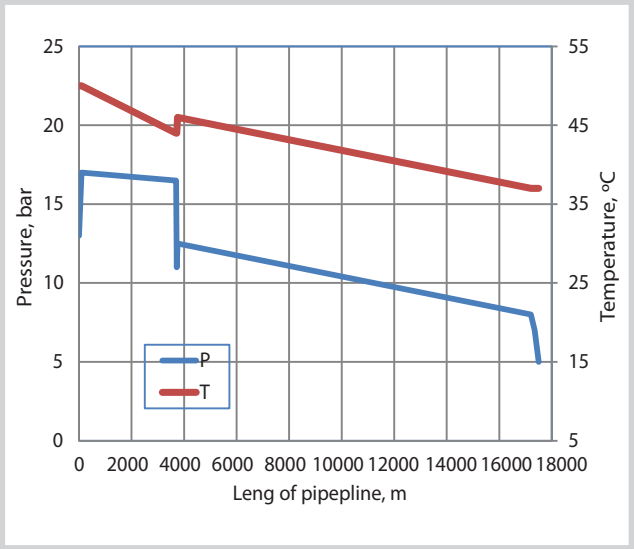
The results of hydraulic calculations for oil and gas transportation from Nam Rong to RP-1 through the subsea pipeline with a diameter of 325 x 16mm, plus composite insulation of 35mm with a head transfer coefficient of 0.1w/(m*K) showed that:

- In the case of maximum liquid flow rate, the drop in pressure for transportation from RC-DM to RP-1 is about 9bars (oil pressure on the RC-DM will be 14bars and on RP-1 5bars). If the temperature on RC-DM is ~50°C, the temperature of oil arriving at RP-1 is expected to be about 36°C.

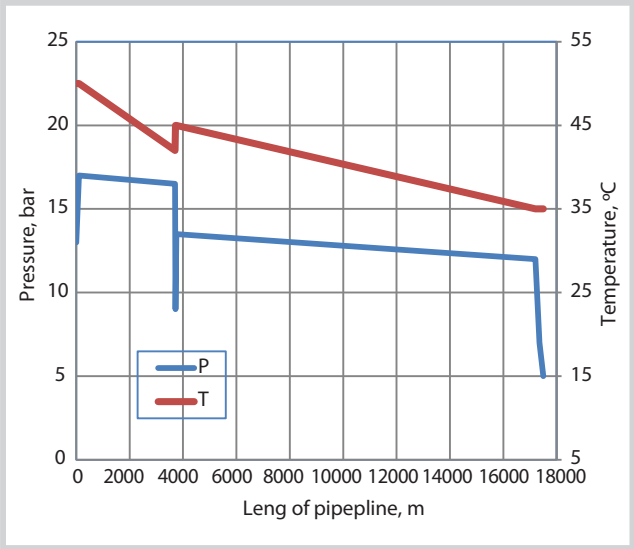
- In the case of maximum water content, the pressure drop for fluid transportation from RC-DM to RP-1 is expected to be about 7bars (oil pressure on RC-DM is 12bars and on RP-1 is 5bars). The temperature on RC-DM is expected to be about 50°C and the oil coming to RP-1 is expected to have a temperature of about 34°C.

Therefore, if the wellhead pressure is about 20bars and the pressure drop for liquid transportation through the pipeline is 9bars, the diameter of the oil transportation pipeline is calculated to be 325 x 16mm. Figure 6 presents the profiles of the pressure and temperature along the length of pipeline RC-DM → RP-1 with a diameter of 325 x 16mm. This line will be used to transport crude oil fluids from Nam Rong and Doi Moi oil fields to RP-1.

During the first year of production from Nam Rong and Doi Moi oil fields, production was be low and expected to be ~930m^3/day. In this scenario, oil production from Doi Moi oil field will be 570m^3/day. Transportation of crude oil from Doi Moi and Nam Rong oil fields through the subsea pipeline will have a low flow rate and be expected



In case of maximum liquid flow in the pipeline



In case of maximum water content in production

Figure 6. *The profiles of pressure and temperature in pipeline RC-DM → RC-4 → RP-1*

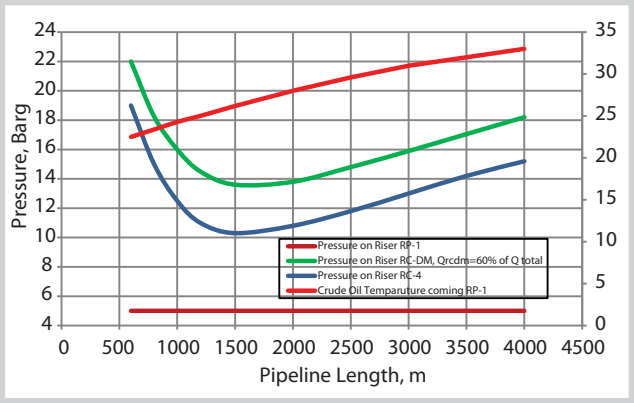


Figure 7. *The effect of pressure and temperature on the flow rate of pipeline liquids coming from RP-1*

to experience problems of wax deposition on the walls of pipeline. The problem will be worse in offshore conditions with a minimum seabed temperature of ~21°C.

To predict the transportation problems of oil and gas from RC-DM to RP-1 via subsea pipeline (diameter of 325 x 16mm and length of 17km), hydraulic calculations for determining the influence between pressure drop and liquid flow rate in the pipeline from RC-DM → RC-4 → RP-1 were carried out.

Figure 7 demonstrates the influence of pressure and temperature on oil coming from RC-DM, RC-4 and oil coming from RP-1 on the liquid flow rate through the pipeline RC-DM → RP-1. The liquid flow rate of Doi Moi crude oil will be about 60% of the total flow rate through the pipeline from RC-4 → RP-1. Hydraulic pressure calculation results showed that if the oil pressure on RP-1 is 5bars and the local pressure drop in the pipeline on RC is about 2bars, then it should be safe to transport crude oil from Doi Moi and Nam Rong fields to RP-1. However, the flow rate through the pipeline from RC-DM → RC-4 → RP-1 should not be lower than 1,500m³/day. In another scenario, the oil temperature in the pipeline during transportation is taken to be lower than the wax appearance temperature (WAT). In this case, the transportation of crude oil from Nam Rong and Doi Moi oil field to RP-1 will pose serious problems of wax deposition on the walls of the pipeline.

To solve the problems highlighted above, the pipeline system will require either a pigging or a hot water pump system on RC-DM to remove wax from the pipe walls.

The hydraulic calculation results shown in Figure 7 highlighted that:

- In the case of a flow rate through the pipeline of 1,500m³/day, the oil pressure in the riser block of RC-DM will be at a minimum and oil coming from RP-1 will be at a temperature of 26 - 27°C;

- In the case of a flow rate higher than 1,500m³/day, the operating pressure on RC-DM will be increased and the oil temperature coming to RP-1 will also be increased to more than 26 - 27°C. In this case, oil and gas transportation through pipeline from RC-DM → RP-1 will be improved;

- In the case of a liquid flow rate less than 1,500m³/day, the oil pressure on RC-DM will be increased and expected to be 18bars when the liquid flow rate is about 800m³/day, the oil temperature coming to RP-1 will be

24°C. In this scenario, the problem of wax deposition in the pipeline will be more serious;

- In the case of a flow rate less than 800m^3/day, the oil pressure in the riser block of RC-DM will be higher than 18 - 20bars and it will not allow the transportation of oil and gas from RC-DM to RP-1 using subsea pipeline with a diameter of 325 x 16mm, because maximum wellhead pressure is only 20bars.

4. Conclusions

Newly discovered marginal oil fields, such as Nam Rong and Doi Moi oil fields, can be connected to the nearest operating platform (e.g. Rong oil field) for oil processing on the fixed platform RP-1 and then for continuous transport to an FSO for processing;

To safely transport crude oil from Nam Rong and Doi Moi oil fields to RP-1 platform in Rong oil field, the liquid flow rate through the pipeline (diameter 325 x 16mm) should not be less than 1,500m^3/day;

The minimum flow rate through the pipeline RC-DM → RC-4 → RP-1 for crude oil transportation from RC-DM to RP-1 could be higher than 800m^3/day. In this case, there will be a serious problem with wax deposits on the wall of the pipeline and the oil pressure in the riser block of RC-DM will increase up to ~20bars. To remove the wax deposits from the pipeline, it will be necessary to add sea water to the pipeline to increase the flow rate in the pipeline, which should not be less than 1m/s [3, 4].

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