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Potential of Mono Ethylene Glycol to Release the Viscous Phase in Subsea Pipeline

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Abstract

As technology develops, operators move into more remote regions, deeper offshore depths, and into regions that yield more challenges. The field of flow assurance, the coupling of multiphase flow and production chemistry, was born out of necessity as it has grown in concern to all operators. Mono Ethylene Glycol (MEG) which is commonly used to prevent hydrate formation, may assist in wax deposition and forming emulsion when combined with waxy crude. Nevertheless, once developed, it can tackle these issues as well. In this study the potential of using MEG is evaluated to release the excess pressure drop in pipeline caused by accumulation of highly viscous phase. Field trials over a gas field with condensate gas ratio around 30 that yields wax in the Mediterranean have been used for this study. MEG can be used as a heat transfer fluid that can be heated to temperature higher than water and keep its energy for longer time that helps in dissolving the deposited wax in the pipeline. The results from these trials demonstrate that cleaning the line of accumulated solids can be achieved by optimizing the volume of MEG injected with the shear force from water hammering effect while restarting the well.

Keywords: *Flow assurance; MEG; Wax deposition; Emulsion; Subsea network; Pressure drop.*

1. Introduction

Wax present in hydrocarbon fluids is a heavy organic constituent primarily comprising high-molecular-weight paraffinic compounds that are crystalline in nature and range from C_{20} to C_{90} [1-3]. There are two types of wax compounds:

1. Normal (straight) and iso (branched) paraffin chains of C_{18} to C_{36}. The normal (straight) paraffin is macrocrystalline wax that forms needle-shape crystals [4] and is the one encountered in production and transportation of crude-oil systems.
2. Naphthenic (cyclo) paraffin chains of C_{30+} [5], which is encountered in tank-bottom sludges.

Thermodynamically, crystalline wax separates from solution at a temperature known as the "wax appearance temperature" (WAT) [6], sometimes termed the cloud-point temperature since it makes the oil seem foggy at this level. The pour-point temperature is another crucial temperature for predicting how wax would behave in oil. The lowest temperature at or above which oil will pour, and the lowest temperature below which oil will solidify is known as the pour-point temperature.

Wax formation is primarily a temperature-driven phenomenon. At high temperatures, wax components are dissolved in the crude oil. As temperature drops below the WAT, wax compounds drop out of solution and wax formation occurs. Deposition of wax is a slow process and extends over long distances in pipelines [7]. Three possible processes are involved in wax deposition: thermodynamic crystallization, molecular diffusion, and shear dispersion [8] as shown in Fig. 1.

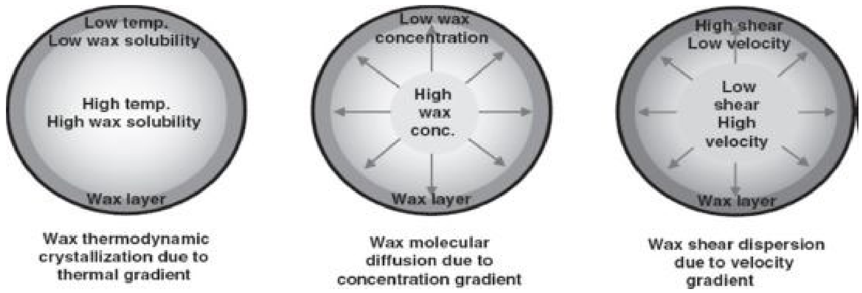

Fig. 1. Wax deposition processes.

- Thermodynamic crystallization: It is the process whereby a thermal gradient brought on by the cold surroundings causes temperature to drop radially from a pipe's center to its wall. Consequently, wax crystallizes/precipitates along the pipe wall when the fluid temperature falls below the WAT, forming a thin gelled layer (deposit) containing wax crystals and enclosing oil. Wax, however, is still dissolved in the bulk oil at a higher temperature in the middle of the pipe.

- **Molecular diffusion**: The wax concentration gradient—a lower concentration of wax in the oil near the pipe wall and a higher concentration of wax in the oil in the middle of the pipe—drives the molecular diffusion of wax particles. To obtain equal concentration, dissolved wax particles are transported from the center of the pipe toward the pipe wall because of a molecular diffusion event. High-molecular weight compounds are still being transported by this process in the direction of the pipe wall, where they might crystallize and "stack" on the expanding wax layer. Since diffusion is a slow process, it may take a while for a sizable wax layer to form.

- **Shear dispersion**: Along the pipeline, there is an axial temperature gradient in addition to the radial thermal gradient. From pipe input to pipe exit, the fluid bulk temperature decreases as a result. Wax in the bulk area will crystallize and is carried (dispersed) to the pipe wall by a shear dispersion process when the bulk fluid temperature falls below the WAT. The mechanism known as shear dispersion distributes wax crystals from a high velocity area with low shear to a lower velocity area with higher shear at the pipe wall. At this point, the flow is laminar, and the wax crystals can merge with the deposit.

2. Wax deposition prevention and mitigation techniques

Oil and gas companies are very interested in preventing wax development in subsea flowlines and it can be accomplished by many ways like thermal management, wax chemical inhibitor injection, mechanical removal, exothermic chemical reaction and cold flow.

2.1. Thermal management

The prevention principle of thermal management is to add heat or preserve the heat of produced fluids to stay above the wax appearance temperature [9]. This can be done by either passive insulation - which increases the resistance to heat flow from the fluids to the surrounding environment to lower the overall heat transfer coefficient (U)- or active heating of the fluids to increase the temperature of flowing fluids.

2.2. Wax chemical inhibitor injection

Wax inhibitors, as contrast to hydrate inhibitors, lessen wax deposition on pipe walls [10] by a different process, resulting in wax crystals being suspended in bulk flow rather than building up. They do not alter the WAT or wax solubility curve or inhibit paraffin crystallization. wax crystal modifiers prevent wax crystals from depositing on the pipe wall by having them crystallize with other wax particles [11]. Surface modifiers, which can be dispersants or surfactants, the dispersant type of surface modifier prevents wax crystals from agglomerating by coating the wax crystals [12]. The surfactant type of surface modifier makes wax crystal surfaces water-wet to prevent wax crystals from adhering to each other.

2.3. Mechanical removal

Pigging involves cleaning pipelines by inserting a device called a pipeline inspection gauge "PIG" into a pipeline. The PIG is launched from a PIG launcher, which is a section of the pipeline with a larger diameter gradually reducing to the normal diameter of the pipeline, then the pig is pushed by the force from pipeline pressure drop across the pig, acting over the pig cross-sectional area to remove accumulated liquid and deposited solids along the pipeline [13].

2.4. Exothermic chemical reaction

This method combines exothermic chemical processes with regulated heat output [14]. There is a lag in fused chemical processes before any real product production. Citric acid included in polymer-coated gelatin capsules promoted a fusion chemical reaction between sodium nitrite and ammonium chloride [15]. They proposed that a strongly fused exothermic chemical process will generate significant heat to melt and redissolve wax at the required place due to the typical delay.

2.5. Cold flow

Cold flow technology is based on allowing wax particles to form but preventing their agglomeration and transporting them in a slurry form over long distance [16]. This is done by cooling down the bulk flow to be in equilibrium with the seawater temperature which is below wax appearance temperature. It is a future technology for preventing hydrate and wax blockage that promises to be cost effective, environmentally friendly and reliable in ensuring flow assurance over long distance transfer. One of the main concerns of this technology is wax deposition in the cool down section during cooling process [17]. There has been continuous effort to improve this technology which points out that in the next few decades, it may successfully be implemented once the main challenges are solved.

3. Materials and methods

Four subsea wells are producing from an offshore gas reservoir with condensate gas ratio around 30 bbl/MMscf that yields wax in the Mediterranean Sea, which is situated at water depth of around 1000 m with unimpaired production capacity of each well during the initial start-up around 100 MMscf/d per each. The subsea structure for the wells includes Christmas tree (XT), High Pressure Protection Integrity System (HIPPS), Pipeline End Manifold (PLEM), infield and main umbilical, 20-inch pipeline and topside / Subsea control equipment. The onshore equipment for gas conditioning includes a slug catcher, Low Temperature Separator (LTS), dew point conditioning and condensate stabilization unit.

The wax management philosophy is injection of a wax inhibitor, while hydrate management philosophy is a continuous injection of MEG directly downstream the chokes. The rich MEG is recovered and separated onshore before being fed to continuous MEG regeneration units. Methanol is injected upstream of the well chokes during start-up and shut-in for the wells.

Three trials have been made to the subsea network to study the potential of using MEG as heat transfer fluid in combination with shear force caused by the slugging flow while restarting the well. It is believed that MEG can provide heat retention to lower the excess pressure differential in the production line caused by viscous wax slurry or waxy emulsion. The trial involves executing a shut in when the well flowrate is maximum. MEG is then injected into the flowline of one of the wells, then start up that well at lowest flow rate for some time to get MEG heated by the well fluids followed by starting up the remaining wells in the network to provide a driving force with high shear rate that drives the condensate and wax out of the steep incline through to the terminal, cleaning the line and returning its capacity.

We use the pipeline conductivity term (flow factor)– Total Gas Flow Rate (MMscf/d) divided by the pressure difference across the pipeline (Bar) as indicator for the success of the trial. If the restriction caused by wax slurry or viscous emulsion is removed the pressure difference across the pipeline will decrease and it yields a higher flow factor.

4. Results and discussion

After successful start-up of the wells and production for some time, an increase in pressure downstream of the chokes was observed which indicates a restriction in the pipeline that is consistently growing risk to production. Based on design, the differential pressure across the pipeline was expected to be around 60 bar, by time, extra 50 bar of differential pressure was encountered in the pipeline and was thought to be caused by wax deposition in the pipeline due to the temperature gradient between the bulk fluid temperature and the pipeline, especially the wax appearance temperature is around 35°C which is considered high and can be lowered by paraffin inhibitor to 20°C. As action raised, it was a necessity to find a way to control growth of differential pressure in the pipeline and keep the pipeline flow efficiency high to prevent further blockage. Admittedly, increasing the injection rate of wax inhibitor may slow down the deposition rate [18], high dose of wax inhibitor was tried but it didn't show better efficiency in slowing down the deposition rate and keep exhibiting excessive delta P in the pipeline resulting in lower arrival pressure to the plant. The option of active heating of the produced fluids by traditional ways was studied, but it is not feasible. The option of cleaning the pipeline with pigging was studied but many worries were raised that the pig would be stuck into the pipeline especially with the pipeline trajectory as shown in Fig .2 and it will be expensive to retrieve it [19].

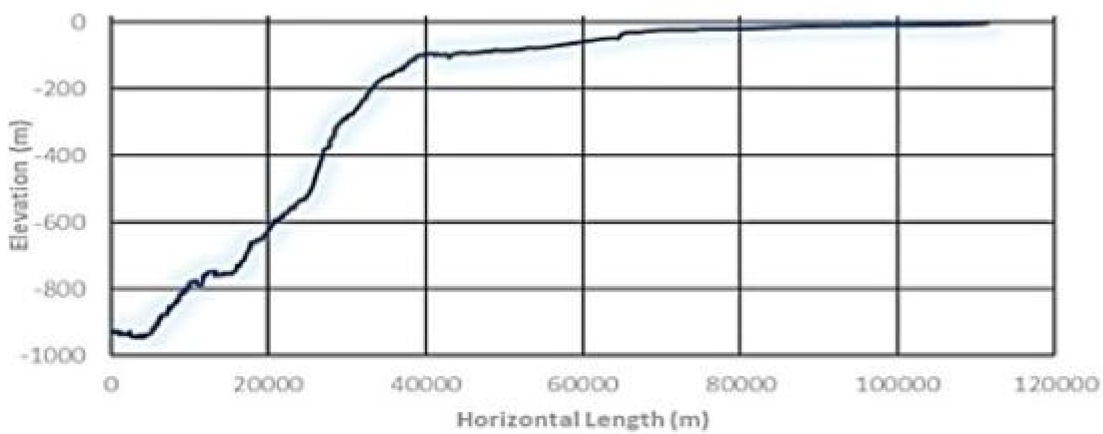

Fig.2. Production pipeline profile.

Based on observations at Coulomb gas reservoir at Gulf of Mexico that has some similarities with our case where they faced elevated pressure drop in the first year of production and That was thought to have occurred as a result of formation and accumulation of a highly viscous phase, thought to be either an emulsion (of condensate, MEG and wax) or a wax slurry, either of which would be stable at the low ambient temperatures encountered in the subsea flowline [20]. An alternative remedial solution was adopted and tried to inject MEG- as a heat transfer fluid- exploiting its ability to provide thermal management to the line commingled with the power of slugging flow from restarting the well to sweep the deposited wax layer/ viscous emulsion over the wall of the pipeline.

4.1. Field trials

Three trials have been made to the subsea network as shown in table 1 to study the effect of using MEG as heat transfer fluid in combination with shear rate caused by the slugging flow while restarting the wells. The trials rely on adjusting the MEG injection volume in conjunction with the wells' ramping up pace to account for the strength of the slugging flow when the wells are restarted. Prior to trials wells were shut in to give more power to the slugging flow after starting up. In first trial, following the normal operation for startup with no excess MEG added- except for hydrate prevention philosophy- and controlled ramp up rate to the maximum flow rate, nearly had no effect on decreasing the pipeline's delta P (only 5 bars were released). In the second trial, increasing the volume of MEG injected to 40 m3 and ramping up the wells rapidly showed good results as 15 bar were released. In the third trial increasing MEG volume to 80 m3 with controlled ramp up rate for the wells showed good result as 11 bar were released.

Table 1. Field trials applied to the subsea network.

Trial	MEG vol (m^3)	Ramp up rate	Delta p (bar) Before	Delta p (bar) After	Delta p released (bar)
1	0	Controlled	108	103	5
2	40	Fast	111	96	15
3	80	Controlled	118	106	12

Figures 3 to 5 summarize the pipeline condition before and after the trials and we can see the effect of MEG injected and the ramping up rate as governing factors on the results of these trials.

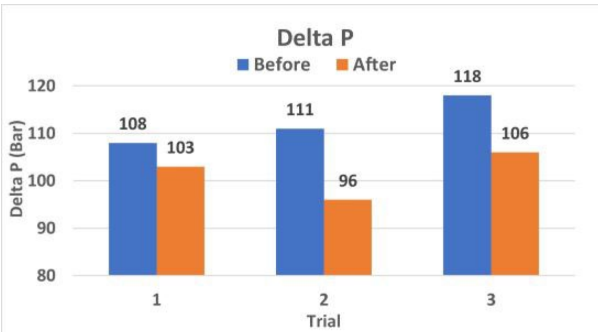

Fig. 3. Pipeline delta power trials

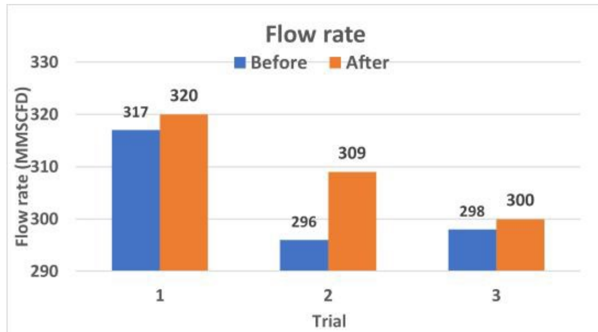

Fig. 4. Pipeline flow rate over trials

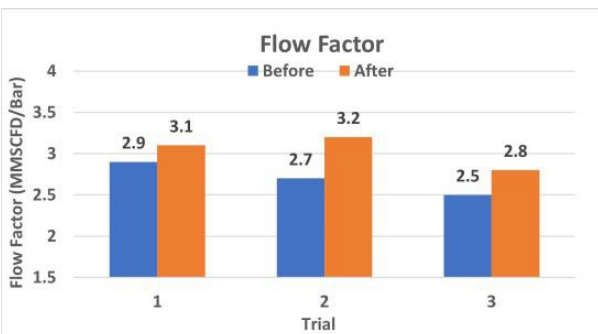

Fig. 5. Pipeline flow factor over trials

Methanol and MEG are the most widely used thermodynamic inhibitors to control formation of gas hydrates. On other hand methanol and MEG can have big impact on waxy crude as it can interact with the polar compounds present in the oil, sterically hindering these molecules and facilitating the aggregation of long paraffins, increasing the WAT, changing crystal structure and facilitating deposition [21]. Furthermore, it can form viscous emulsion with condensate in the presence of wax crystals as emulsifiers [20].

Viscous wax slurry or emulsion adheres to the pipeline surface reducing the pipeline ID causing JT cooling that may eventually lead to hydrate blockage. This implies that MEG, which was proposed to prevent hydrate formation, may indirectly aid in formation of hydrate in presence of wax. As mentioned, MEG may assist in deposition of wax and forming emulsion with the condensate in presence of any solid. Nevertheless, once developed, it can tackle these issues as well.

MEG has the ability to retain energy over time which makes it a superior choice for use as a heat transfer fluid. When applied under shear stress, it can also remove deposited wax from pipelines. The physical properties of MEG provide its power, mixtures of Ethylene Glycol have lower freezing point than water- that's why it is commonly used as an antifreeze-and higher boiling point than water- that's why it is used as heat transfer fluid, for instance, 80% wt MEG has boiling/freezing point 125°/-47°C compared to water 100°/0°C at atmospheric pressure [22]. Ethylene glycol mixtures have lower specific heat capacity(cp) than water [22], which means less energy is needed to raise its temperature by one degree Fahrenheit per one pound. For example, compared to water (cP=1), the cP for 80% wt MEG @ 20°C is 0.683. Besides that, ethylene glycol mixtures have lower thermal conductivity than water, meaning it will retain its energy for longer time. Moreover, ethylene glycol mixtures are slightly more viscous than water, meaning it will provide more retention time in the line resulting in better sweeping efficiency. In addition to its physical properties, dispersed water droplets in waxy crude emulsion system are wrapped in wax crystal structure [23] increasing contribution of dispersed droplets (MEG) weakens the strength of gelled system as shown in Fig 6(a) when water content is low, available area of the water droplets surface which wax crystal can be attached to is reduced leading to formation of Spatial three-dimensional network structure between wax crystals, with increasing water content as shown in Fig 6(b) the majority of wax crystals will be attached to the surface of the water droplets, and the droplets are wrapped in three-dimensional network of wax crystals [24]. Thus, increasing MEG volume lowers contribution of the wax crystals to the structure, which weakens the gel strength. Once shear is applied to it, the thixotropy decreases [25-26]. All above clarifies why, even the wells being ramped up at the same pace, more pressure is released from the pipeline in trial 3 than in trial 1.

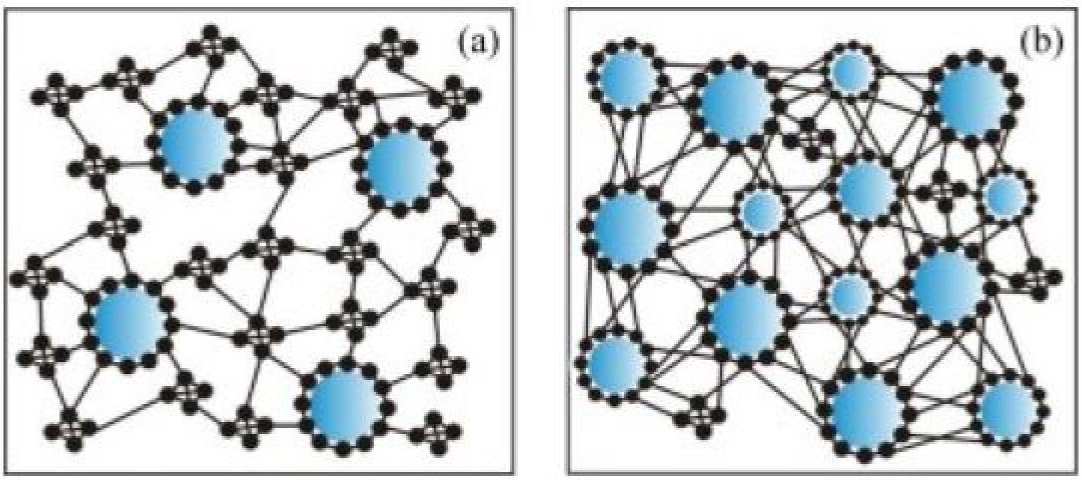

Fig .6. Waxy crude oil emulsion gel at different volumetric water content [24].

Following well shut-in and restart there is thought to be a hydraulic shock (water hammer) in the metal pipe, this pressure disturbance propagates in higher velocity – typically 3 times-than fluid flow velocity [27]. Although we must pay attention to this pressure surge, we may utilize its power to sweep the deposits out of the pipeline. In our case, the pipeline is too lengthy to be affected by the pressure surge effects since it dampens throughout distance [28]. Wax deposition is inversely proportional to the increase in flow rate, as flow rate increases, wax thickness reduces. This decrease was explained as sloughing effect, whereby a higher shear rate was created by higher flow rate that removed some of the deposits from the wall [29]. This explains why, despite the MEG volume being half that of trial 3, the most pressure was released during trial 2, taking advantage of the power from the induced slug flow from fast ramping up.

5. Conclusion

MEG, even it is essential for hydrate prevention in the pipeline, has great impact on waxy crude, it aids in wax deposition and emulsion formation. However, it has good potential in solving these issues too. In addition to high shear rate from slugging flow during wells startup, increasing MEG volume will provide better thermal management to the pipeline, as MEG has ability to absorb heat easily from other fluids and not easily transfer it to others. Furthermore, the waxy emulsion gel strength decreases with increasing the MEG volume which aids in sweeping the viscous deposits in the pipeline and releasing the excess differential pressure in the pipeline.

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