

Numerical simulation of wax deposition in pipelines and wells

Petroleum Engineering

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1 – The problem of wax deposition

2 – Relevance of the study

3 – Background

3.1 – Crude composition

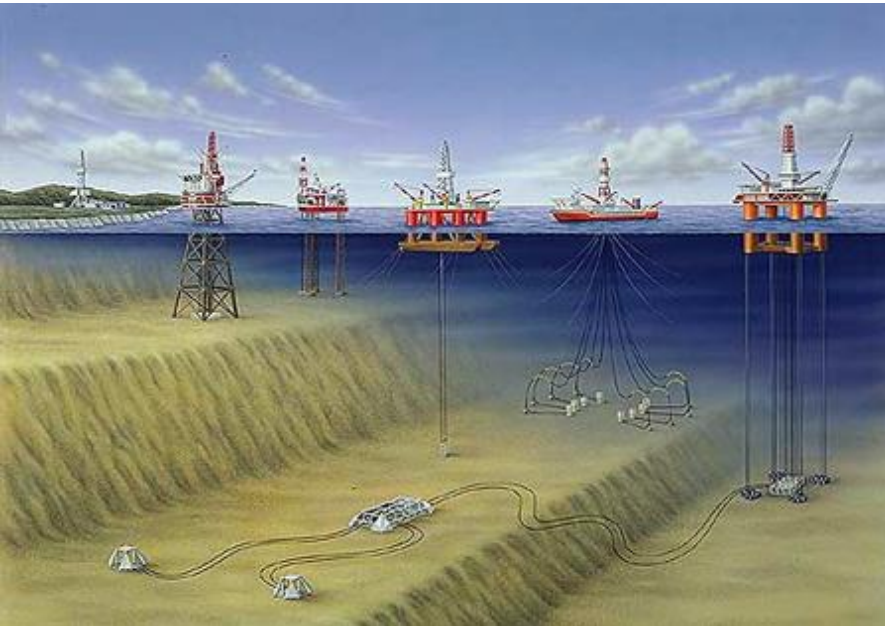
3.2 – Fluid mechanics

3.3 – Wax deposition

4 – Ongoing investigation

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1 - The problem of wax deposition



As oil production is moving further extreme areas, to **colder regions**, with **longer transport distances** and **greater depths**, the industry is facing new flow assurance challenges.

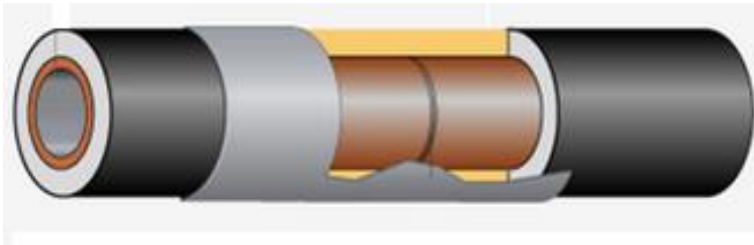
One of the problems arising when tempting to ensure an economically feasible flow of hydrocarbons, is the deposition of high molecular weight paraffin inside the infrastructure wall.

Untreated **wax deposition** leads to a reduced flow area, and in worst case the deposit may even block, with loss of production and capital investment.

1 - The problem of wax deposition

Wax control measures

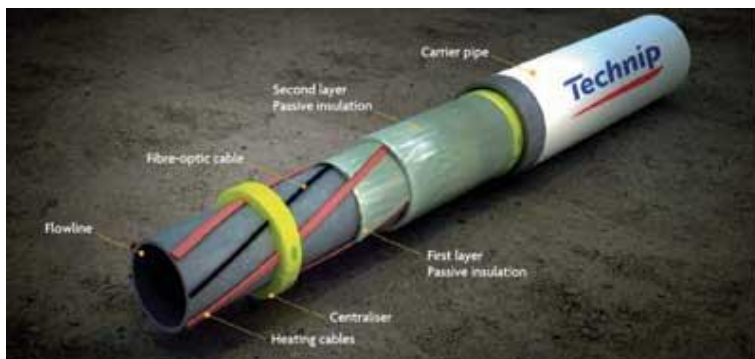
In general four different methods of controlling wax deposition are used:



Pipeline insulation



Chemical injection



Heating



Mechanical scraping (pigging)

2 – Relevance of the study



“The cholesterol of the oil industry”

On global basis, waxy crudes have been estimated to represent about 20% [Stubsjoen, 2012] of the petroleum reserves produced, making prediction of wax deposits a relevant area for the petroleum industry.

Underestimation due to an inaccurate wax deposition model increases the potential risk of stuck pig during a pigging operation. On the other hand, overestimation results in too high pigging frequency. From an economic point of view, an accurate prediction can reduce expenses.

According to the literature there are several wax deposition models. However, the process of deposition still remains poorly understood [Rosvold, 2009].

3 – Background

3.1 – Crude composition

Crude oil is essentially a mixture of many different hydrocarbons:

Hydrocarbons			
Paraffin	Naphthenes	Aromatics	Asphaltene
$\text{H}_3\text{C}-\text{CH}_3$ etano	 ciclopropano	 tolueno	 asfalteno
$\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$ pentano	 metilciclobutano	 benzeno	
 isobutano	 ciclohexano	 o-xileno	

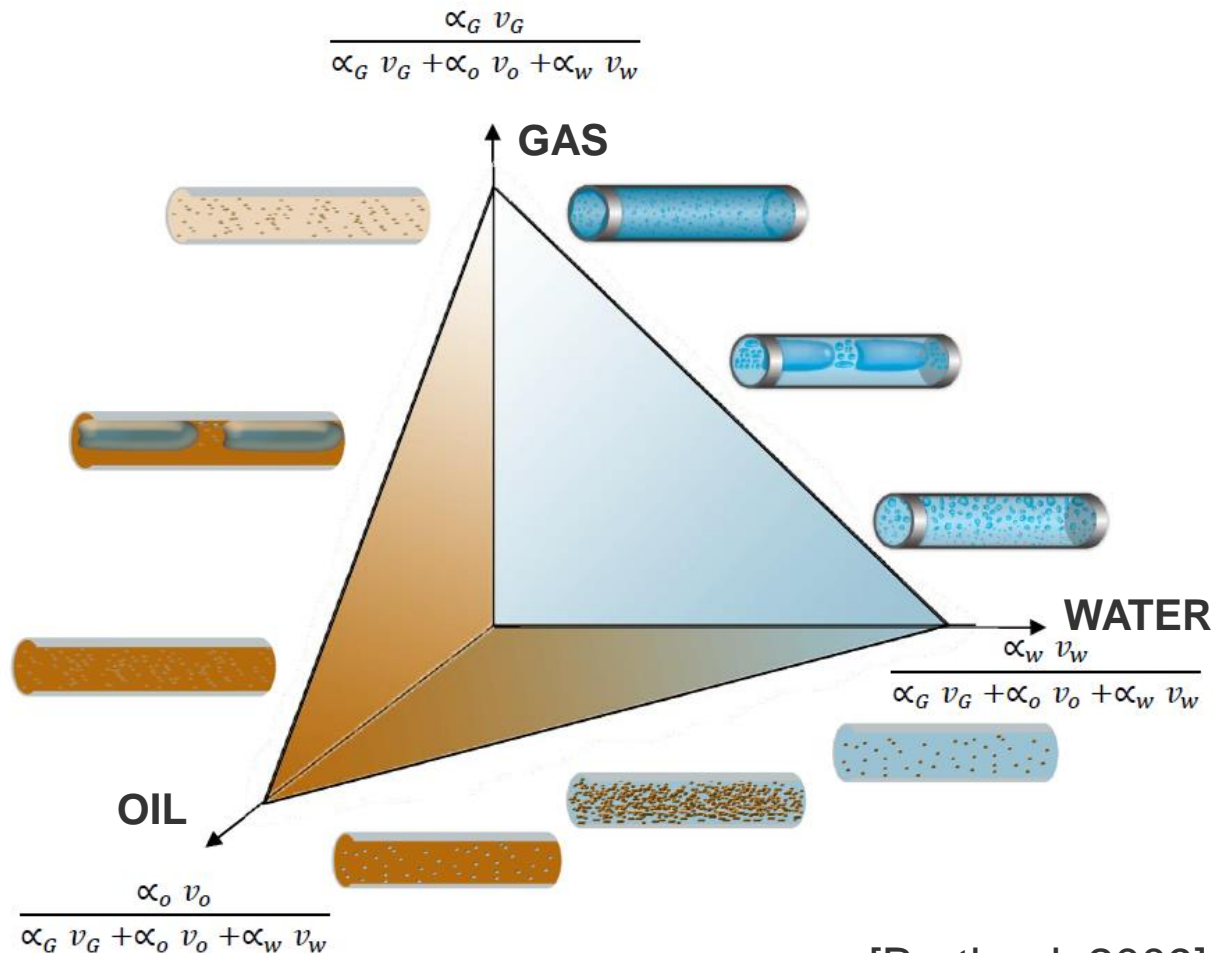
The term wax refers to linear chain alkanes (n-paraffins) that contain more than 16 carbon atoms. The general formula is $\text{C}_n\text{H}_{2n+2}$

3 – Background

3.2 – Fluid mechanics

The term **multiphase flow** is used to refer to any fluid flow consisting of more than one phase or component.

Each of the phases is considered to have a separately defined volume fraction (the sum of which is unity) and velocity field.



[Bratland, 2009]

3 – Background

3.2 – Fluid mechanics

Bubble flow



Slug flow



Churn flow



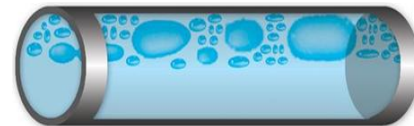
Annular flow



Stratified



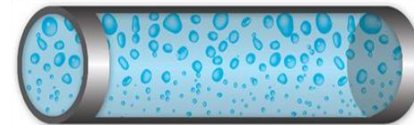
Wavy Stratified



Plug flow



Slug flow



Bubble flow



Annular flow

[Bratland, 2009]

Most of the focus concerning formation and deposition of wax has been put on single-phase transportation of paraffinic oils, but significant problems may also occur in multiphase flow.

3 – Background

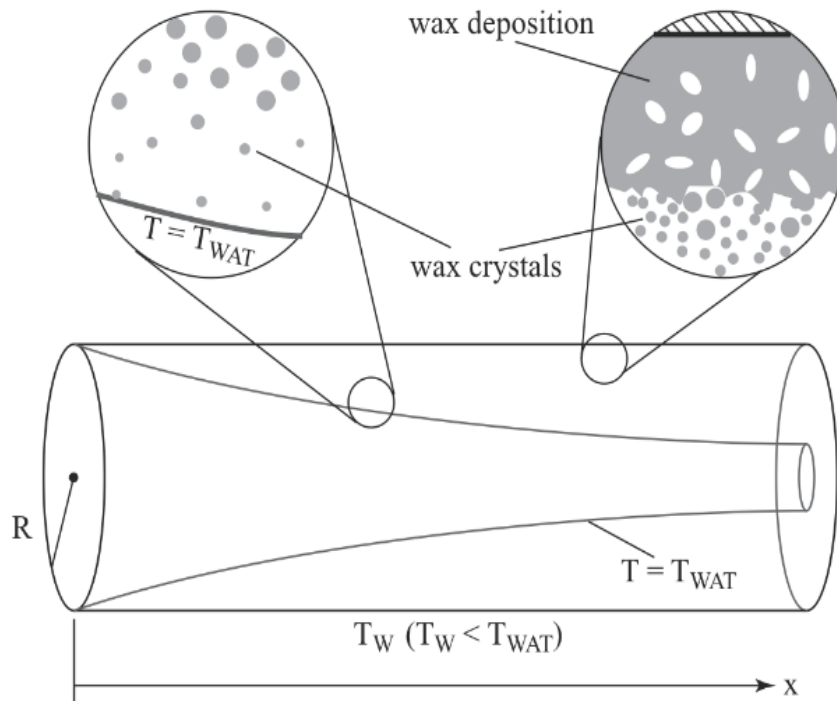
3.2 – Fluid mechanics

Flow models	Applied to:		
	Horizontal pipes	Inclined pipes	Vertical pipes
Aziz, Govier, and Fogarasi	-	-	X
Baxendell and Thomas	-	-	X
Beggs and Brill (1973)	X	X	X
Beggs and Brill (1979)	X	X	X
Duns and Ros	-	-	X
Gregory Aziz Mandhane	X	X	-
Hagedorn and Brown	-	-	X
HTFS, Liquid Slip	X	X	X
HTFS, Homogeneous Flow	X	X	X
OLGAS_2P	X	X	X
OLGAS_3P	X	X	X
Orkiszewski	-	-	X
Poettmann and Carpenter	-	-	X
Tulsa Unified Model (2-Phase)	X	X	X
Tulsa Unified Model (3-Phase)	X	X	X
Tulsa 99	-	-	X

3 – Background

3.3 – Wax deposition

Modeling the wax deposition is a complex process because it involves several disciplines, such as: chemistry, thermodynamics, fluid mechanics...

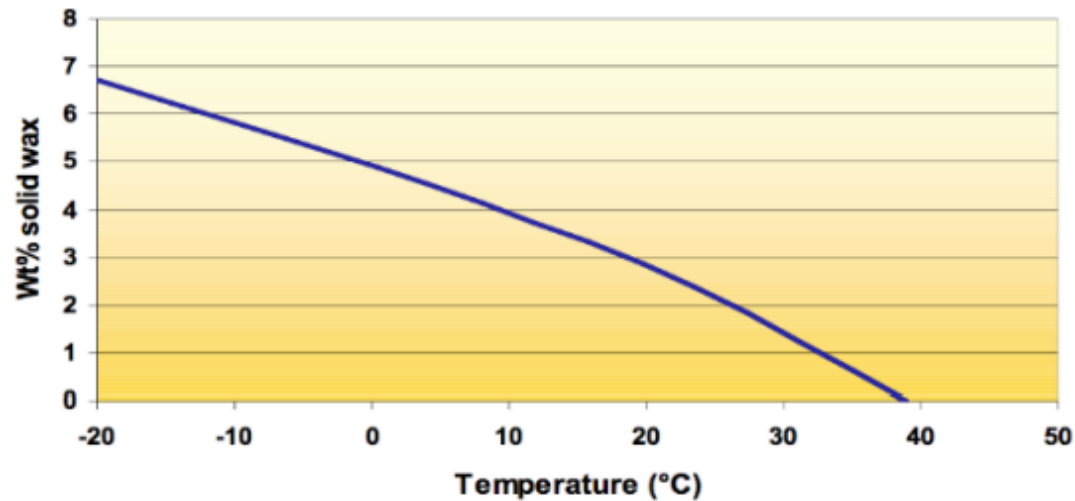


At typical reservoir conditions, temperature ($60 - 150^{\circ}\text{C}$) and pressure conditions ($55 - 103 \text{ MPa}$), the wax molecules are kept dissolved in the oil.

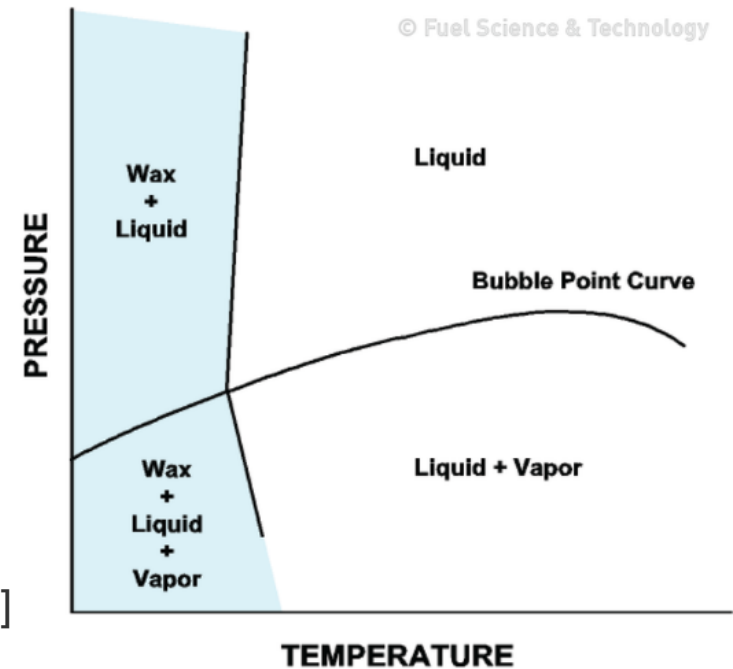
If the temperature of a wax-oil mixture drops below the solubility limit of wax, also known as the Cloud Point or Wax Appearance Temperature (WAT), solid particles are formed.

3 – Background

3.3 – Wax deposition



Norne Crude at 1 bar. Wax precipitation curve [Aske, 2011]



3 – Background

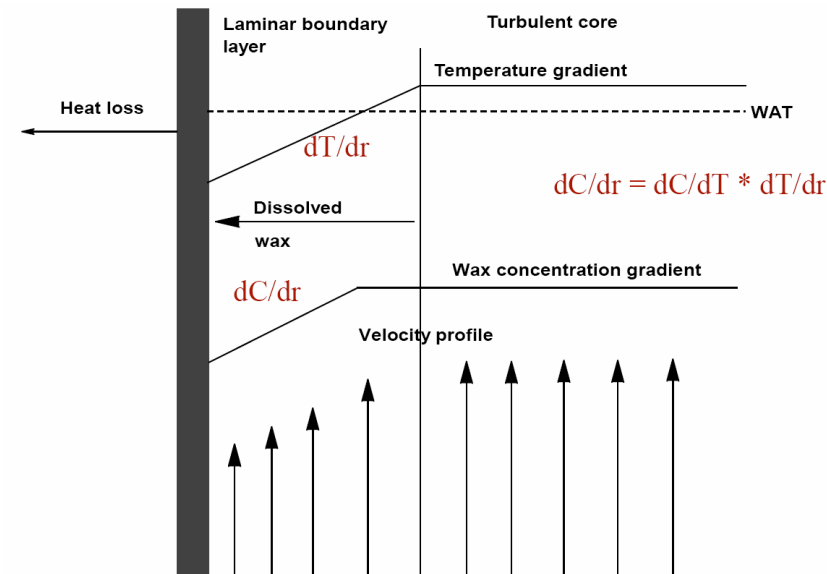
3.3 – Wax deposition

Wax deposition mechanisms

The modeling of wax deposition requires an understanding of the mechanisms responsible for the transport of the wax from the bulk of the fluid to the pipe wall.

Molecular diffusion

When oil is being cooled in a pipe, there will be a radial temperature gradient in the fluid. If in some region the temperature is below WAT, wax crystals will come out of the solution. This area will display a smaller concentration wax, inducing a transport from the bulk to the wall. [Burger (1981)]



3 – Background

3.3 – Wax deposition

Wax deposition mechanisms

Shear dispersion

When wax crystals are suspended in the flowing oil, the wax particles move with the mean speed and direction of the oil. The shearing of the fluid close to the pipe wall also includes a lateral movement of wax particles. This way the precipitated wax is transported from the turbulent core to the pipe wall.

Brownian diffusion

When small, solid waxy crystals are suspended in oil, they will be bombarded continually by thermally agitated oil molecules. Such collisions lead to small random Brownian movements. At a concentration gradient of these particles, Brownian motion will lead to a net transport which is similar to diffusion.

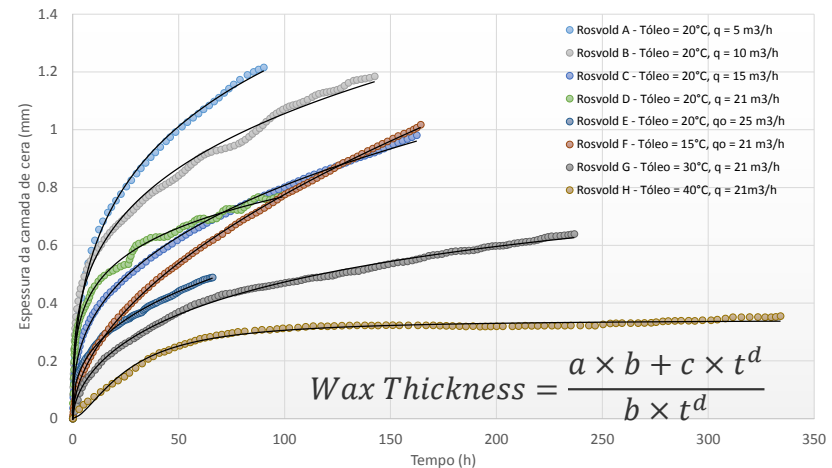
Gravity settling

Precipitated waxy crystals are denser than the oil phase, and therefore gravity settling might be a possible mechanism for deposition. However, results stated that gravity settling had no significantly effect on the total deposition.

4 – Ongoing investigation

Experimental data analysis - Curve fitting for empirical formulae finding

Porsgrum wax rig data	Parameters
Oil pipe, ID (mm)	52.58
Oil pipe, OD (mm)	60.56
Epoxy coating pipe diameter (mm)	51.70
Length (m)	5.31
Water temperature (°C)	10
WAT (°C)	45



Experiments	q (m³/h)	T _{oil} (°C)	Duration (h)
Rosvold A	5	20	90.92
Rosvold B	10	20	142.92
Rosvold C	15	20	162.58
Rosvold D	21	20	98.92
Rosvold E	25	20	65.92
Rosvold F	21	15	164.42
Rosvold G	21	30	236.92
Rosvold H	21	40	334.33

Experiments	a	b	c	d
Rosvold A	-0.069	11.992	3.664	0.405
Rosvold B	-0.056	1.3974x10 ⁸	4.5296x10 ⁷	0.268
Rosvold C	-0.001	1.2948x10 ⁸	2.0157x10 ⁷	0.358
Rosvold D	-0.257	266.954	1.304	0.163
Rosvold E	-0.005	237.161	26.013	0.362
Rosvold F	0.000	4.0214x10 ⁸	2.7639x10 ⁷	0.526
Rosvold G	-0.001	24.254	1.214	0.595
Rosvold H	0.001	170.228	0.344	1.569

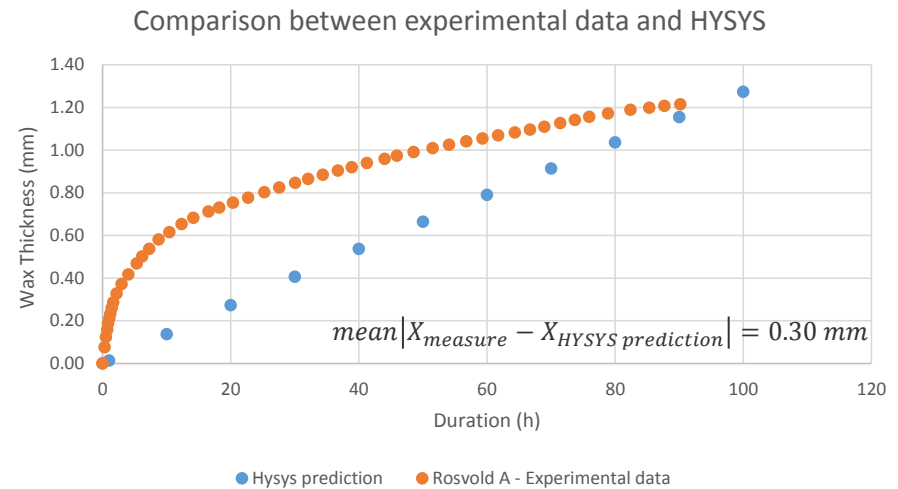
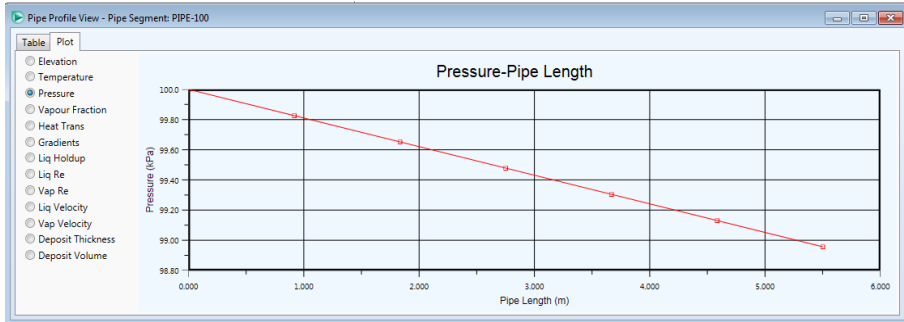
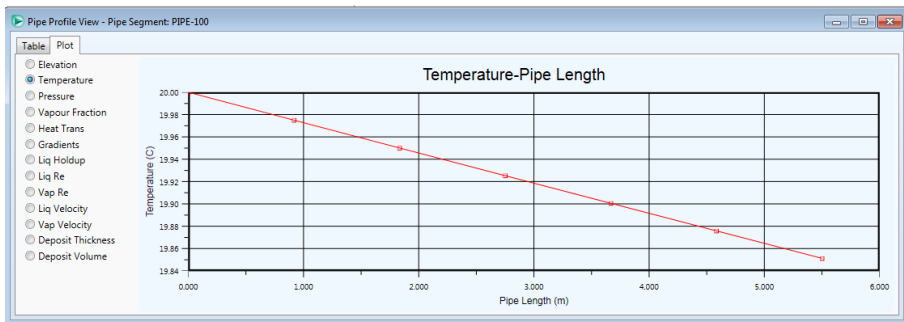
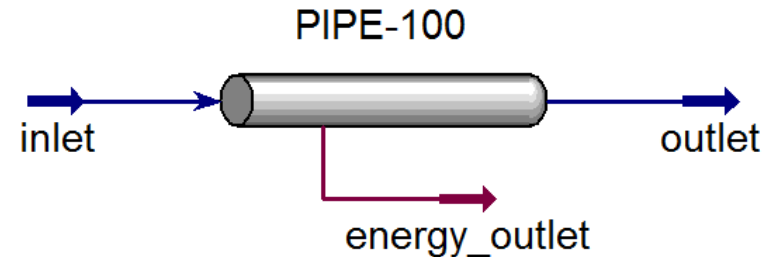
MMF – Best fitting curve

[Rosvold (2008)]

4 – Ongoing investigation

Numerical Simulation 

Aspen HYSYS



The pressure and temperature gradually decreases.

[Rosvold (2008)] and HYSYS model

4 – Ongoing investigation



Mathematical Modelling

Considering the MATLAB code developed by Stubbsjøen (2013) it was possible to predict wax deposits along the pipeline. The developed model takes into account the:

- Temperature variations in the pipeline with position and time;
- Conductive heat flux through the wall;
- Growing layer of wax deposit.

In order to run the simulations, the user will have to provide some values of the design variables: inlet temperature of oil, sea temperature, flow rate, inner pipe diameter, total length, number of steps in lateral direction and number of steps in radial direction.

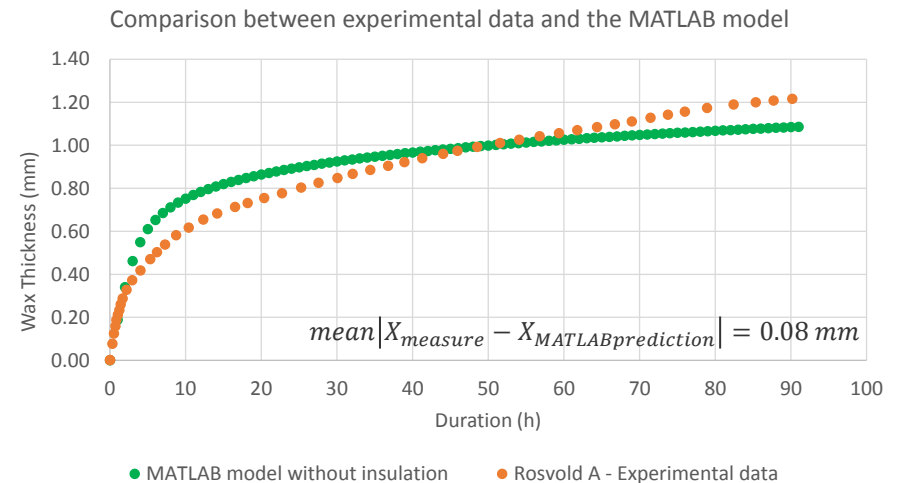
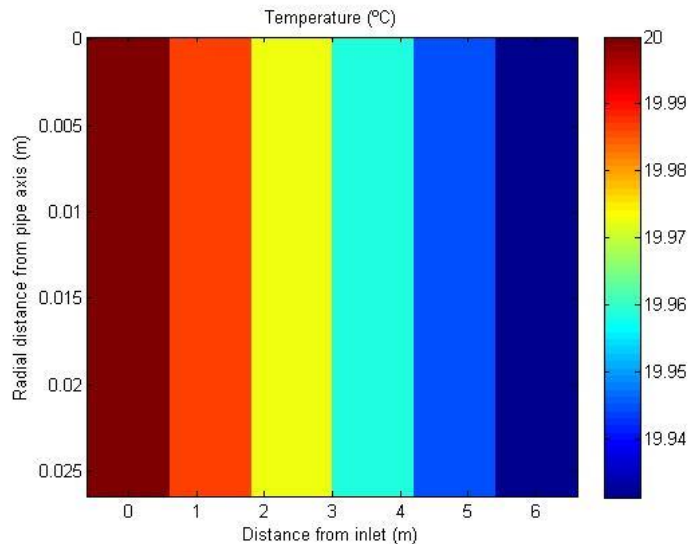
4 – Ongoing investigation



Mathematical Modelling

The fluid properties and heat mass transfer values are provided by Venkatesan (2001) and set as default values in the model.

Applying to the Rosvold experimental data:



[Rosvold (2008)] and MATLAB model

5 - Conclusions

- The experimental data have been compared to the results obtained with a commercial wax deposit predictor (HYSYS– AspenTech) and an mathematical model (Matlab code).
- HYSYS is built upon the same assumption as the Matlab model (Wax deposition mechanism is Molecular diffusion);
- Matlab code assumes constant fluid density and viscosity as simplification. For the future, the impact of these variables will be investigated;
- The comparison showed a discrepancy ($\bar{\varepsilon}_{HYSYS} = 0.30 \text{ mm}$; $\bar{\varepsilon}_{MATLAB} = 0.08 \text{ mm}$) between the expected wax deposit thickness predicted by the two models. A possible explanation is the difference in how the fluid composition is given as input.

References

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