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Prediction of Wax Deposition in Pipelines Using MATLAB Simulator: Case Study of ABC Field Pipeline

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Abstract: **Oil pipeline wax deposition is one of the major problems facing in the crude oil transportation flow line from the offshore to onshore through pipe. The wax deposition occurs because of the crude oil fluids temperature is decrease during the transportation process and cause solidification of wax components. Wax deposition in oil and gas production is one of the major flow assurance challenges the industry faces today. Wax deposition is mostly a temperature driven process which means that subsea pipelines are especially vulnerable. Wax precipitates from oil when it is cooled and the wax may deposit on pipeline walls. Wall deposits can lead to severe problems and need to be removed in an efficient way. It is difficult to perform accurate deposition measurements on real pipelines. The present study intends to use MATLAB simulator to predict wax deposited in a onshore pipeline using MATZAIN model. It provides idea of how wax is being deposited in pipeline and also suitable suggestions are also provided.**

Keywords: **Wax, Oil Pipeline, Flow Assurance, MATLAB, MATZAIN.**

I. INTRODUCTION

The term paraffin wax refers to linear chain alkanes (n-para_ns) that contain more than 16 car bon atoms. The general chemical formula is CnH_{2n+2}. Under ambient conditions the paraffins might either be in a gaseous, liquid or solid phase. Paraffins with less than four carbon atoms(C1-C4) are at a gaseous state, C5-C16 are at liquid state, whereas the paraffin series of C16-C70+ are in a solid state (Leontaritis et al., 2003). Most of the paraffin found in crude oils are in the range from C18 - C65 (Ekweribe et al., 2008).

The carbon number distribution of paraffins in crude oil and condensates varies from one set to another. To determine the composition a laboratory analysis will have to be conducted for each uid in question (Leontaritis et al., 2003). One widely used method to determine the wax content of the oil, is High Temperature Gas Chromatography (HTGC). The molecular weight distribution of the hydrocarbons is then characterized as a function of the carbon number, i.e. the weight percent of all hydrocarbons with a certain carbon number is identified (Singh et al., 2011).

Wax deposition during paraffinic crude oil production and transportation is one of the most serious problems faced in downhole and surface operations. These deposits are mainly constituted by n-paraffins (linear alkanes) and small amounts of branched paraffins and aromatic compounds. Naphthenic (cyclic) and long-chain paraffins also make a notorious contribution to microcrystalline waxes and have remarkable influence on macrocrystalline growing patterns.

Wax Appearance Temperature (WAT) and Wax Dissolution Temperature (WDT):

Wax precipitation is, as presented initially, a phenomena occurring when the temperature of a oil-wax solution drops below the Wax Appearance Temperature (WAT), also known as the cloud point. A solid phase of wax particles, that was earlier in a purely liquid form, appears in the system creating a binary mixture of wax and oil. The WAT is defined at the point where 0.02 mole percent of the liquid has precipitate out of the solution as a solid state. Since the solubility of the solute is temperature dependent, decreasing with decreasing temperature, a lower cloud point results in later occurrence of wax precipitation. Experiments have demonstrated that the WAT is mainly depended upon temperature and the total wax content of the solution.

The WAT determines the onset of wax precipitation, and thus separates a waxy and a wax free zone. Below the WAT there is a region with waxy crystals in a solid phase and oil as the liquid phase. Above the WAT a single liquid phase region exists in which the wax has not precipitated out of the solution yet, and remains dissolved in the oil. The position of the wax appearance boundary is, as a result, inferred from the temperature profile.

Wax is a general term used to describe all kinds of solid matter being precipitated or dissolved during cooling or heating. Wax Appearance Temperature (WAT) is the temperature at which the first wax crystal appears; it is also termed cloud point. The WAT of the Stock Tank Oil (STO) is measured using Cross Polar Microscopy (CPM). The WAT of a live oil sample can be determined by a High Pressure Cross Polar Microscopy (HPCPM) cell. The temperature at which all the wax crystals dissolve back into oil is known as Wax Dissolution Temperature (WDT). WDT is generally higher than WAT.

Wax Precipitation Curve:

The two major parameters affecting solubility of wax in oil is temperature and composition. As presented, pressure has shown to have a less significant effect. (fig 1)

By compositional analysis of the crude in question, a Wax Precipitation Curve (WPC) can be obtained (Villazon and Civan, 2009). The WPC expresses the weight- percent solid wax in solution as a function of temperature, and are utilized to calculate concentration profiles. There are several techniques available to determine the amount of wax precipitated out of solution at different temperatures. These methods include Differential Scanning Calorimetry (DSC), Fourier Transform Infrared Spectroscopy (FTIR), Nuclear Magnetic Resonance (NMR), High Temperature Gas Chromatography (HTGC) and filtration and centrifugation. The shape of the wax precipitation curve affects the equilibrium concentration of wax, and, accordingly, varies the behavior of the mass driving force.

Among the input variables in the wax model, the WPC has shown to be of single greatest importance

among the input parameters (Singh et al., 2000; Huang, 2011). Strong sensitivity towards wax properties is proven, and experimental used data of high quality (composition, WAT and wax content), is necessary to generate correct input to the model. The WPC is often found difficult to measure accurately and thus a challenge in wax modeling.

II. MATZAIN MODEL

A Fick’s law modification by Matzain et al (2001) accounts for the stripping contribution in the model. The rate of wax build up in a wax deposition process is obtained by equation 1

$$\frac{d\delta}{dt} = -\frac{\Pi_1}{1+\Pi_2} D_{ow} \left[\frac{dw_w}{dT} \frac{dT}{dr} \right]$$

equation 1

Where δ is the thickness of wax layer deposited on the wall (m), w_w is the concentration of wax in solution (weight %), r is the radial distance (m) and T is the temperature (°C). Π_1 is the empirical relation for the rate enhancement due to oil being trapped in the deposited wax layer. The relation also accounts for any positive deposition rate which is not accounted by the diffusion constant, D_{ow} . Π_2 is the empirical relation for

$$\Pi_1 = \frac{C_1}{1 - C_{oil}/100}$$

$$\Pi_2 = C_2 N_{SR}^{C_3}$$

equation 2

The diffusion constant is given by the Wilke and Chang (1955) correlation, but this diffusion correlation is not sufficient to represent the proportionality constant that drives the diffusion process. C_1, C_2 *and* C_3 are three empirical constants which are correlated from the single-phase and two-phase flow data. Their values were found to be: $C_1 = 15.0$, $C_2 = 0.055$ and $C_3 = 1.4$. Additionally, C_{oil} is the percentage of oil trapped in wax deposit (%) and is expressed in equation 3:

$$C_{oil} = 100\left(1 - \frac{N_{RE,f}^{0.15}}{8}\right)$$

$$N_{RE,f} = \frac{\rho_o\left(\frac{\upsilon_{sl}}{E}\right)d_w}{\mu_{o,f}}$$

equation 3

Where ρ_o is the oil density (kg/m^3), υ_{sl} is the liquid superficial velocity (m/s), E is the liquid hold up, d_w is the inside diameter as a result of wax build-up (m) and $\mu_{o,f}$ is the oil viscosity(kg/(m.s)). N_{SR} is a dimensionless variable expressed in the form of a flow regime dependent

The temperature gradient is given by

$$\frac{dT}{dr} = \frac{(T_b - T_w)}{\lambda_o} \cdot h_{wall}$$

equation 4

Where λ_o is the oil thermal conductivity (W/(mK)), T_b is the bulk average flow temperature(K), T_w is the inner wall surface temperature (K) and h_{wall} is the inner wall surface heat transfer coefficient (W/(m^2 K))

III. CASE STUDY: ABC FIELD PIPELINE

The current production of ABC field is 500 m^3/d. At GGS 1 the entire ABC crude is heated to 60^{o}C at winter and 50^{o}C in summer and pumped in ABC GGS 1 to GGS 2 crude dispatch line (fig 2). Due to viscous nature of ABC crude high pressure drop is observed during winters in the GGS 1-GGS 2. .

Presently pumping of crude oil at rate of 13 m^3/hr is done from ABC GGS 1 is being pumped after heating it to a temperature of 60^{o}C so as to avoid congealing in the line. The 8”×25 km pipeline is buried at a depth of 1.2 m and having internal diameter 8” with Poly urethane insulation which is 2.5 mm thick. Also crude oil of 34^{o}C API and density of 0.8527 g/cc. Physical properties of crude and pipeline dimensions is given in table 1.

Present study helps to analyze the pressure. MATLAB is the software used for modeling of wax deposition in pipelines over a period of time.

IV. RESULTS

1. For the first day total wax deposited is 0.52 cm towards end of pipeline. WAT is experienced at length of 1-2 km of total length of 25 km of pipeline. (fig 3) Refer annexure 1 for MATLAB codes.
2. For the first week (7 days)total wax deposited is 3.62 cm towards end of pipeline. Also by the end of 20 days the pipeline is completely plugged as maximum thickness of wax is 10.5 cm. . Refer annexure 2 and 3 for MATLAB codes. (fig 4 and 5)
3. For a particular pigging cycle (30 days), total quantity of wax deposited is 15.52 cm. This figure indicates that due to wax deposition the pipeline is completely plugged during winter season even before 1 pigging cycle (28-35 days). So pigging won’t be efficient enough to remove waxes during winter season. Chemical or further treatments have to be considered. (fig 6) (Annexure 4 for MATLAB codes)

Figure and Tables:

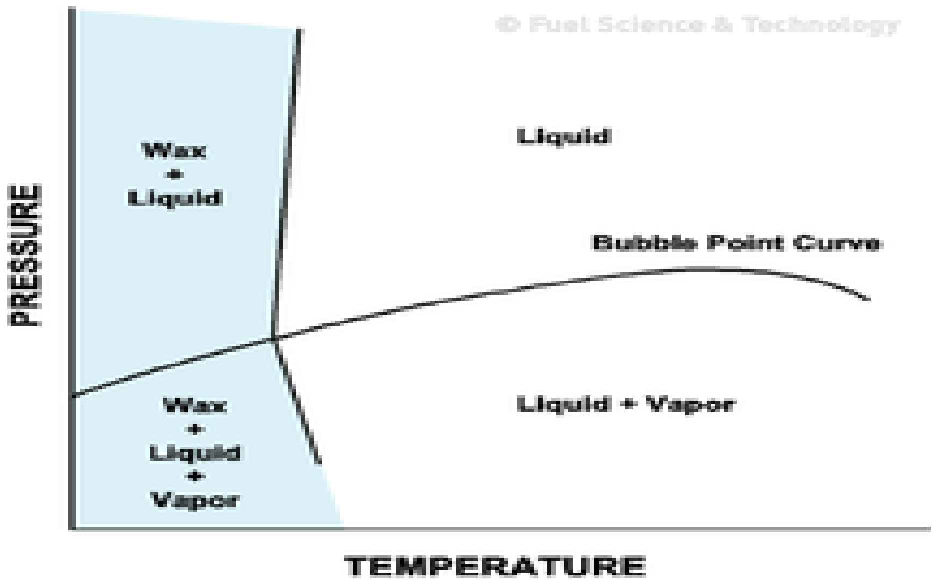

Fig 1.Wax Precipitation Curve (Courtesy: Fuel science and Technology)

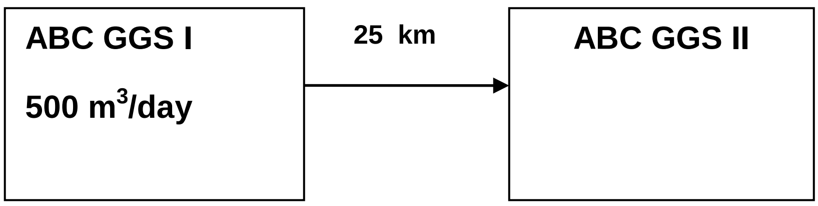

Fig 2.Crude Dispatch Line

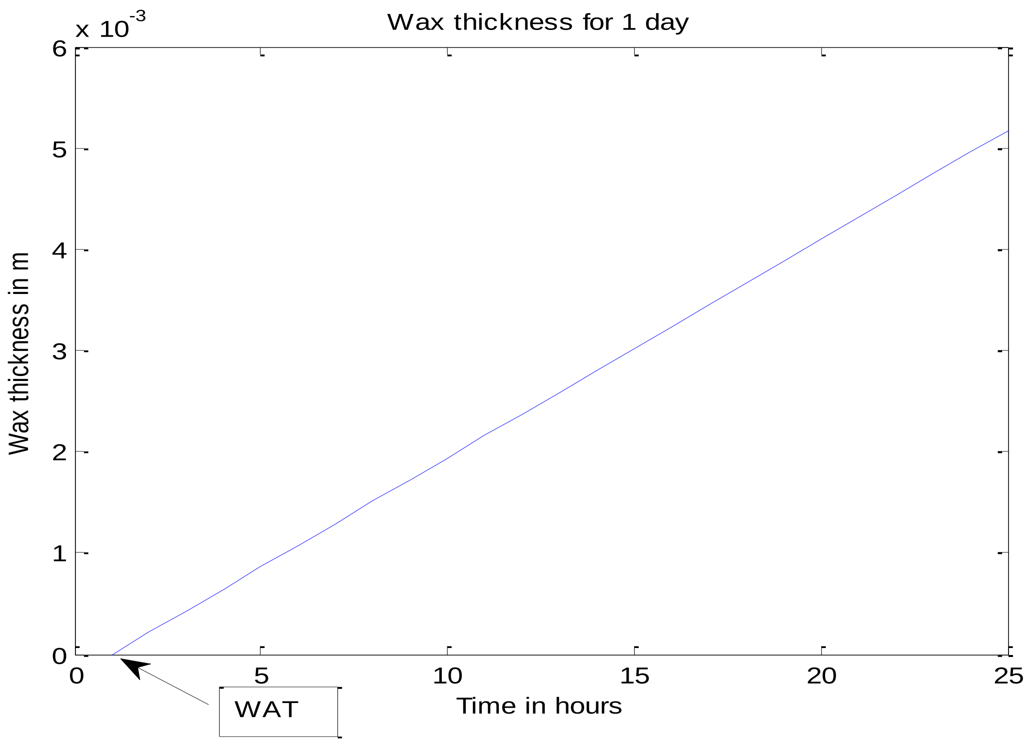

Fig 3.Wax deposition thickness for 1 day

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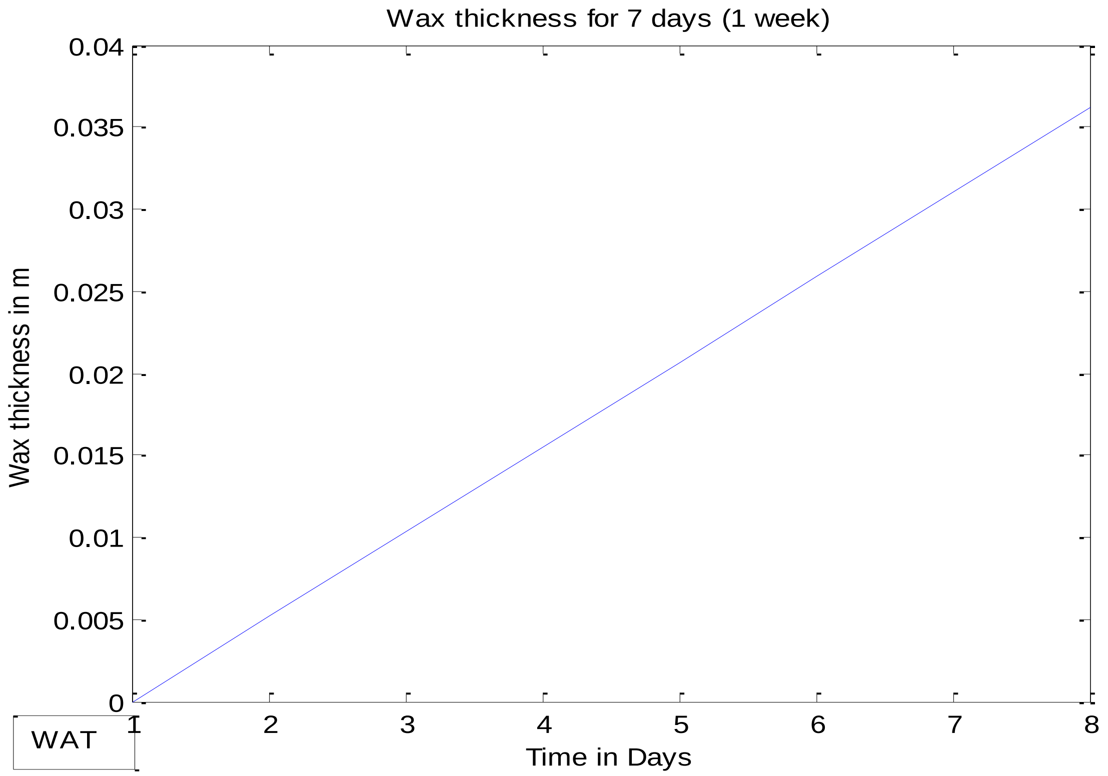

Fig 4.Wax deposition thickness for 1 week (7 days)

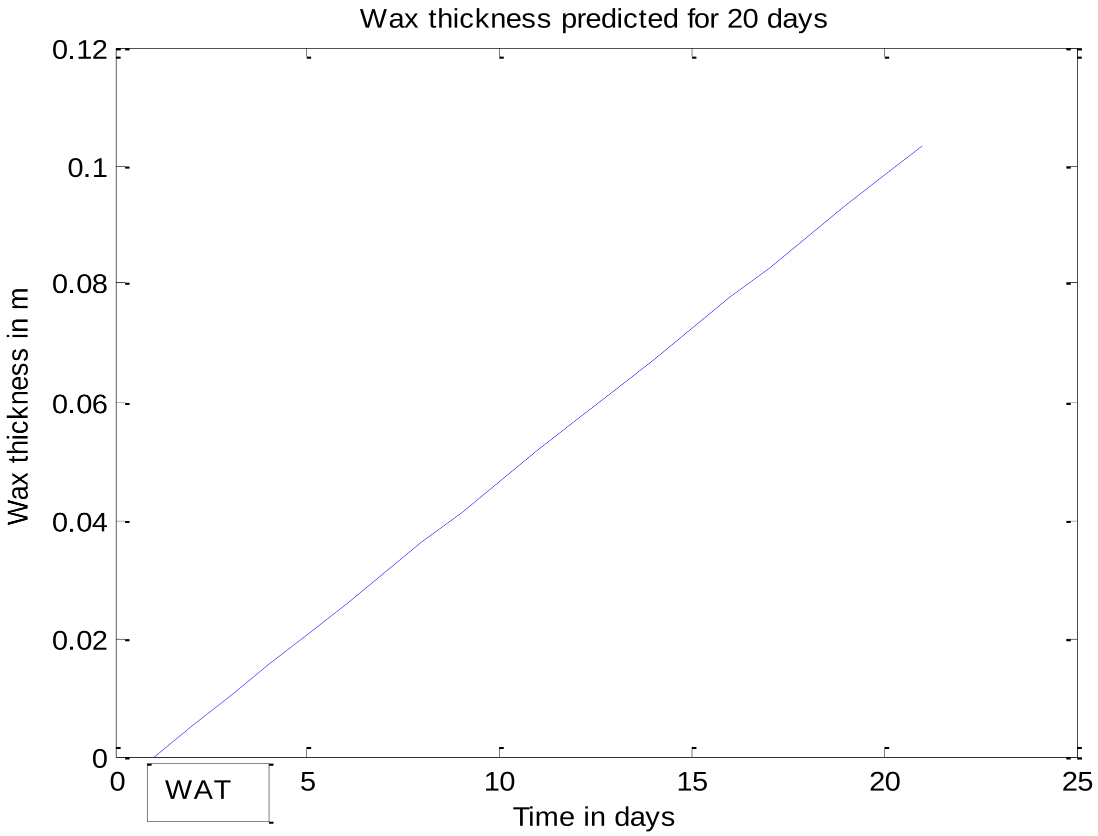

Fig 5.Wax deposition thickness for 20 days

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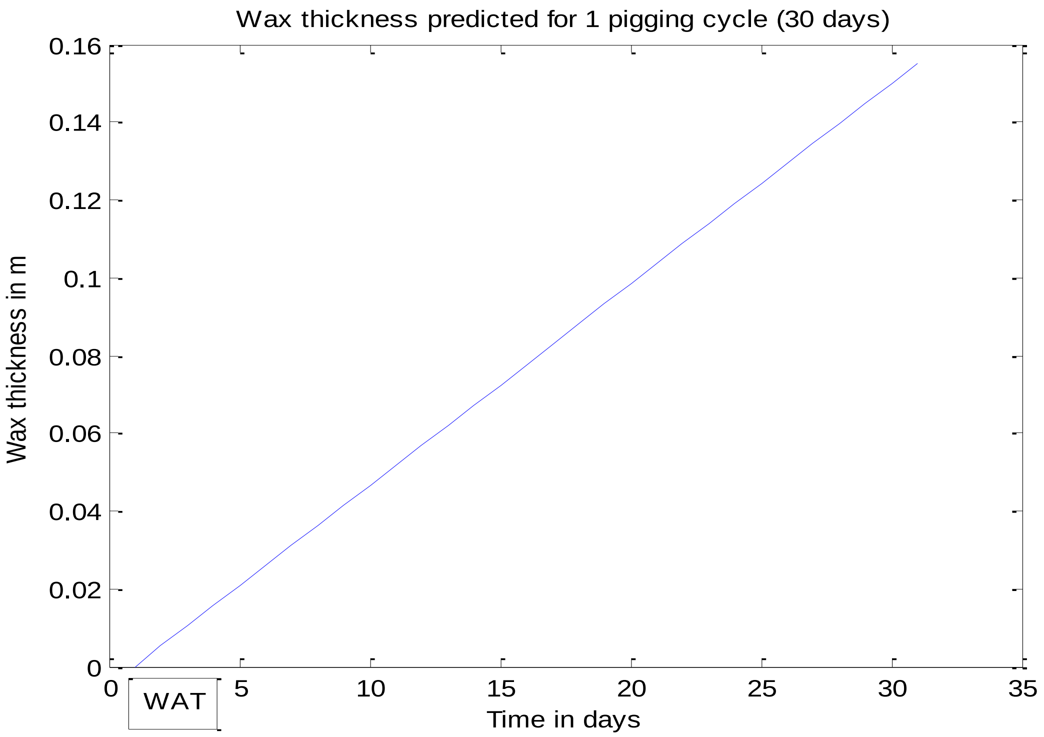

Fig 6.Wax deposition thickness for 30 days (1 Pigging cycle)

TABLE 1.Physical properties of crude and pipe dimensions

Internal Diameter(m)	0.205
External Diameter(m)	0.212
Inlet Temperature(^{o}C)	60(Winter) 55(Summer)
Ambient Temperature(^{o}C)	21(Winter) 35(Summer)
Density(kg/m^3)	852.7
API gravity(^{o}C)	34
WAT and Pour Point (^{o}C)	43/33
Wax content (%)	12
Specific gravity	0.8527
Water Content(%v/v)	10

V. CONCLUSIONS

1. Wax deposition is considered to be one of the most critical problems causing blockages, production losses and even in some extreme cases fully damaging smooth flow in pipeline.
2. ABC GGS 1- GGS 2 pipeline have severe wax deposition problems especially during winter seasons.
3. Since plugging of pipeline occur in 20 days during winter, there is need of further treatments.
4. The basic remedy is to provide chemical treatment in the well site as it reduces the effect of wax problems in pipeline.
5. Also pigging frequency has to be increased, especially during winter season.

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ANNEXURE

Annexure 1

Wax deposition for 1 day

```
rho=852.7                  % density in kg/m^3
v=0.176                    % velocity of flow in m/s
d=0.205                    % diameter in m
mew=0.233                  % viscosity in pascal s
Dw=0.000000000562          % diffusion coefficient in m^2/s
dC=0.191                   %solubility coefficient
Twall=25                   % Temperature in celcius
Tbulk=55                   %Bulk Temperature in celcius
hwall=8                    %heat transfer coefficient in W/(m^2.*celcius)
KL= 0.579                  % Thermal conductivty in W/(m.*celcius)
Nre=rho.*v.*d/(mew)        %Reynolds number
CL=100.*(1-(Nre^0.15/8)) %Matzain constant
c1=0.35                    % constant
Pi1=c1/(1-(CL/100))        %porosity effect on rate of wax deposited
dT=(Tbulk-Twall).*hwall/KL    % Radial temperature gradient
t=0:3600:86400             % Time in seconds
del=Pi1.*Dw.*dC.*dT.*t
plot(del)
```

Annexure 2

Wax deposition for 7 days

```
rho=852.7                  % density in kg/m^3
v=0.176                    % velocity of flow in m/s
d=0.205                    % diameter in m
mew=0.233                  % viscosity in pascal s
```

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```
Dw=0.000000000562          % diffusion coefficient in m^2/s
dC=0.191                   %solubility coefficient
Twall=25                   % Temperature in celcius
Tbulk=55                   %Bulk Temperature in celcius
hwall=8                    %heat transfer coefficient in W/(m^2.*celcius)
KL= 0.579                  % Thermal conductivty in W/(m.*celcius)
Nre=rho.*v.*d/(mew)        %Reynolds number
CL=100.*(1-(Nre^0.15/8))   %Matzain constant
c1=0.35                    % constant
Pi1=c1/(1-(CL/100))        %porosity effect on rate of wax deposited
dT=(Tbulk-Twall).*hwall/KL % Radial temperature gradient
t=0:86400:604800           % Time in seconds
del=Pi1.*Dw.*dC.*dT.*t
plot(del)
```

Annexure 3

Wax deposition for 20 days

```
rho=852.7                  % density in kg/m^3
v=0.176                    % velocity of flow in m/s
d=0.205                    % diameter in m
mew=0.233                  % viscosity in pascal s
Dw=0.000000000562          % diffusion coefficient in m^2/s
dC=0.191                   %solubility coefficient
Twall=25                   % Temperature in celcius
Tbulk=55                   %Bulk Temperature in celcius
hwall=8                    %heat transfer coefficient in W/(m^2.*celcius)
KL= 0.579                  % Thermal conductivty in W/(m.*celcius)
Nre=rho.*v.*d/(mew)        %Reynolds number
CL=100.*(1-(Nre^0.15/8))   %Matzain constant
c1=0.35                    % constant
Pi1=c1/(1-(CL/100))        %porosity effect on rate of wax deposited
dT=(Tbulk-Twall).*hwall/KL % Radial temperature gradient
t=0:86400:1728000          % Time in seconds
del=Pi1.*Dw.*dC.*dT.*t
plot(del)
```

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Annexure 4

Wax deposition for 30 days

```
rho=852.7                      % density in kg/m^3
v=0.176                        % velocity of flow in m/s
d=0.205                        % diameter in m
mew=0.233                      % viscosity in pascal s
Dw=0.000000000562              % diffusion coefficient in m^2/s
dC=0.191                       %solubility coefficient
Twall=25                       % Temperature in celcius
Tbulk=55                       %Bulk Temperature in celcius
hwall=8                        %heat transfer coefficient in W/(m^2.*celcius)
KL= 0.579                      % Thermal conductivty in W/(m.*celcius)
Nre=rho.*v.*d/(mew)            %Reynolds number
CL=100.*(1-(Nre^0.15/8))       %Matzain constant
c1=0.35                        % constant
Pi1=c1/(1-(CL/100))            %porosity effect on rate of wax deposited
dT=(Tbulk-Twall).*hwall/KL     % Radial temperature gradient
t=0:86400:2592000              % Time in seconds
del=Pi1.*Dw.*dC.*dT.*t
plot(del)
```