Steady state Analysis of a Crude Oil Trunk Line: A Case Study

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Abstract– **One of the major problems confronting the petroleum industry is the untimely blockage of oil due to deposition of heavy organics (asphaltene, resin, paraffin wax) present in the oil. In order to overcome these problems Flow assurance is employed. Flow assurance is a relatively new term in oil and gas industry. Flow assurance is successful operations that generate a reliable, manageable, and profitable flow of fluids from the reservoir to the sales point. Taking into consideration the above factors the scope of the paper would be to study the existing system from (Early Production System) EPS-I to EPS-V 8" trunk pipeline & to suggest remedial flow assurance measures. Simulation studies have been carried out on Pipesim Software in order to find out the pressure and temperature drops in the 8"X50 km EPS-I to EPS-V pipeline. Results conclude that heating the crude up to 65°C is imperative before pumping at all 3 installations. The crude oil from EPS-IV,EPS-III,EPS-II is required to be reheated at EPS-I before pumping to EPS-V. It will assist in transportation from flow assurance point of view due to better shear as well as better heat retention in the line.**

Keywords– **Trunk Line, Flow Assurance and Pipesim**

I. INTRODUCTION TO FLOW ASSURANCE

Flow assurance refers to successfully maintaining sustained hydrocarbon production by properly managing the flow (oil, gas, and water) without slugging or restricts/blockages due to undesired phase changes. The term originally covered the thermal hydraulic analysis and evaluation of potential production problems associated with solids formation, such as waxes, asphaltenes, hydrates and scale. Now, it has a much broader definition and includes all issues important to maintaining the flow of oil and gas from reservoir to processing facilities. Flow assurance is essential to the sustained operability of production facilities. Flow assurance failures often result in production shut-down and costly interventions [37].

A) Background

Presently the production from EPS-I field is about 500 m^3/d which is expected to increase up to 600 m^3/d. A 8" x 50 km long trunk line from EPS-IV to EPS-V via EPS-III, EPS-II and EPS-I was laid. Existing dispatch rate from EPS-I is around 350-400 m^3/d with 20% emulsion water. It is planned that in near future all the crude from EPS-I field (~600 m^3/d) will be dispatched via 8" line to EPS-V. Presently pumping of oil at EPS-I is being carried out by 4 nos. of reciprocating pumps of discharge capacity of 12.8 m^3/hr each with pressure rating of 50 kg/cm^2.Similar rating pumps at EPS-II, EPS-III and EPS- IV. Presently the pumping of crude oil from EPS-I is being done after heating the oil up to 65°C on continuous basis in order to avoid any possible congealing in the line. EPS-I Field crude is presently received directly into the storage tank at EPS-V along with EPSV crude (~430m^3/d) from where it is pumped into the existing EPS-V-CTF 8" trunk line. From CTF, the crude oil is sent to refinery. It is also planned to hook up the 8"EPS-I line with the existing 8"EPSV-CTF line so that the receiving of EPS-I crude at EPS-V tank and subsequent pumping of the same could be avoided.

It is apprehended that due to highly viscous nature of EPS-I crude the pressure drop in the EPS-I - EPS-V line may considerably shoot up with the reduction of ambient temperature during winter.

B) 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 [35]. By compositional analysis of the crude in question, a Wax Precipitation Curve (WPC) can be obtained [35]. 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 [14].

Among the input variables in the wax model, the WPC has shown to be of single greatest importance among the input parameters [30], [14]. Strong sensitivity towards wax properties is proven and experimental fluid 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 [14].

C) Wax deposition mechanisms

Most wax deposition models consider molecular diffusion as the dominating mechanism responsible for wax deposition, which is discussed along with the impact of shear dispersion mechanism [23].

Tests performed by Bern et al. (1980) on stabilized crude oil indicated that molecular diffusion was the predominantly responsible mechanism for deposition [10]. On the other hand, Burger et al. (1981) identified four mechanisms for wax deposition. These are molecular diffusion, shear dispersion, Brownian diffusion, and gravity settling. The deposition during start-up was found to be an outcome out of three separate mechanisms which transport dissolved and precipitated waxy crystals laterally. Laboratory tests indicated that gravity settling probably did not affect wax deposition, whereas molecular diffusion, Brownian diffusion and shear dispersion lead to an enhanced wax deposition. Accordingly, the contribution of Brownian diffusion is small compared to the two other mechanisms [13].

The work of Akbarzadeh et al. (2008) presents a novel approach for single-phase wax deposition modeling, and mechanisms which may influence on deposition are described. These mechanisms are particle diffusion, the inertial effect, shear stripping, molecular diffusion, shear dispersion, settling and aging. Particle diffusion and the inertial effect were found to significantly influence the formation of deposit, at realistic transport conditions [23].

In laboratory scale flow loops the dominating mechanism may be molecular diffusion, due to mostly laminar flow experiments. Under normal operating conditions turbulent flow is expected in a field pipeline. Other mechanisms than molecular diffusion, may be dominating at field conditions. Proper laboratory scale equipment is needed in order to simulate the actual flow conditions and give reliable experimental deposition data. This would lead to better identification of the deposition mechanisms [23]. Possible mechanisms to review are therefore molecular diffusion, shear dispersion, Brownian diffusion, shear stripping, aging, settling, particle diffusion and the inertial effect [23].

1) Molecular diffusion

Oil flowing in a pipeline is cooled due to the surrounding cold seawater. Molecular diffusion acts as soon as the temperature of the wall reaches the WAT. At that temperature the oil is saturated with wax in solution and wax precipitates out. Wax precipitation leads to a concentration gradient between dissolved wax in the turbulent core and the wax remaining in the solution at the wall. Due to this, dissolved wax diffuse towards the wall where it is subsequently precipitated [10].

Bern at al. (1980) [10] and Brown et al. (1993) [31] concluded based on experiments that molecular diffusion is the mechanism predominately responsible for deposition. Burger et al. (1981) concluded that molecular diffusion dominates at high temperatures and heat flux conditions [13]. There is a strong agreement that the main wax deposition mechanism is molecular diffusion [11].

Fick's law states that a deposit will only form if oil is cooled, and the equation is used to find the rate of transport of dissolved wax to the pipe wall [10].

$$n=\rho w\times DM\times A\times(dC/dT)\times(dT/dr) \qquad \ldots 1$$

Where n is the mass flux of dissolved wax molecules to the pipe wall (kg/s m^2), ρw is the density of solid wax (kg/m^3). The wax solubility coefficient dC/dT describes the solubility of wax components as a function of the temperature of the bulk oil (per °C). The solubility coefficient increases with decreasing oil temperature, and thus the deposition rate increases. (dT/dr) the radial temperature gradient close to the wall (°C/m). DM is the molecular diffusion coefficient of dissolved wax molecules (m^2/s).

Diffusion coefficient for oil can be described as inversely proportional to the dynamic viscosity of the oil.

2) The diffusion coefficient

This coefficient may be expressed as an experimental constant divided by the viscosity of the oil or by an empirical correlation. Empirically the diffusion coefficient for oil can be described as inversely proportional to the dynamic viscosity of the oil [10].

$$D=(B/\mu o) \qquad \ldots 2$$

Where B is the constant for a particular crude oil (N) and μ_o is the dynamic viscosity of crude oil (N s/m^2). The diffusion coefficient used in the various models is usually expressed by the Wilke-Change (1955) or the Hayduk-Minhas (1982) correlations, which both are developed for normal paraffins. The Hayduk-Minhas (1982) correlation is expressed as:

$$D_M=13.3\times10^{-12}\times T^{1.47}\times[\mu^{((10.2/V)^{\wedge}0.791)}/V^{0.791}] \qquad \ldots 3$$

given that T is the temperature (Kelvin),$\rho_w$is density of wax, μ is the dynamic viscosity (cP), V is the molar volume in cm^3/g and its given as:

$$V=M/\rho_w \qquad \ldots 4$$

Hayduk and Minhas state that the small error associated with the diffusion correlation in normal paraffin solutions is of 3.4 %, which indicates the high degree of consistency of the measurements [29]. Matzain et al. (2001) refers to Lund who concludes that the diffusion coefficient correlations, as Wilke-Chang and Hayduk-Minhas, significantly under predict wax deposition thickness for high flow rate cases in single-phase flow [16]. The diffusion coefficient is believed to decrease with increasing viscosity, and thus deposition increases.

3) Shear dispersion

Shear dispersion concerns already formed particles settling on the cold pipe surface due to roughness of the wall and intermolecular forces [14]. Burger et al. (1981) concluded that shear dispersion is the dominating mechanism at low temperature and low heat fluxes [13]. Based on experimental measurements and field operating experience, Brown et al. (1993) concluded that deposition by shear dispersion was insignificant. This due to no deposition observed under conditions of zero heat flux [31].

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 known as shear dispersion. This way the precipitated wax is transported from the turbulent core to the pipe wall. Wax crystals in the oil will migrate towards the wall where they deposit, because of the lower velocity near the wall compared to the center of the pipe, At the wall the wax may form a deposit on its own or link with wax which is already deposited by molecular diffusion [10].

Parameters likely to affect the shear dispersion mechanism are [10]:

- The wall shear rate
- The amount of wax out of solution
- The shape and size of the wax particles

Shear dispersion becomes important when the precipitated wax content in the turbulent core is high. This occurs when the bulk oil temperature is below the WAT. Increasing shear rate leads to more wax particles dispersing toward the wall, but the corresponding increase in wall shear stress may cause the looser held deposits to be stripped from the wall [10].
The shear dispersion coefficient proposed by Burger et al. (1981) is expressed as

$$D_s = \gamma_o \times d_w^2 \times \phi_w / (10) \quad \ldots 5$$

Where dw is wax particle diameter in meter, ϕ_w is the volume fraction concentration of wax out of solution at the wall and γ_o is the oil shear rate at the wall.If disregarding shear dispersion, wax deposition rate due to molecular diffusion should equal to zero when the radial temperature gradient is zero. Experiments carried out at the University of Tulsa observed no deposition with an absence of temperature gradient. This indicates the unimportance of the shear dispersion mechanism. The same phenomena wax experienced in the Porsgrunn flow loop [11].

4) 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 of the suspended particles. At a concentration gradient of these particles, Brownian motion will lead to a net transport which is similar to diffusion. The Brownian diffusion coefficient for special, non-interacting particles follows as [13].

$$D_b = RT/(6\pi\mu\alpha N) \quad \ldots 6$$

If referring to experiments by Burger et al. (1981), Brownian diffusion can be ignored [13].

5) 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. Some mathematically studies proposed that shear dispersion may redisperse settled solids in the flow, and therefore the effect of gravity settling would be eliminated [13]. Experiments by Burger et al. (1981) showed that gravity settling has no impact on wax deposition.

Several researchers have concluded that shear dispersion, Brownian diffusion and gravity settling are of less importance concerning wax deposition [11].

6) Particle diffusion and inertia effect

Wax particles in the fluid flow complicate the deposition process. The complexity and the lack of experimental proof is the reason why particulate deposition in oil pipelines usually has been neglected in deposition models. This assumption may be acceptable for laminar flow, but in turbulent flow large eddies and vortices containing wax particles will hit the pipe walls and easily penetrate through the boundary layer [23].

Particles which are entrained in turbulent eddies are assumed to travel toward the wall by a combination of turbulent and Brownian diffusion to the more quiet region adjacent to the wall. Turbulent eddies dissipate, but particles continue to move toward the wall and they impact on the surface by depositing due to their inertia. The inertial effect becomes noticeable for larger particles and leads to greater particle deposition rates. A particle has large inertia; it will reach the wall and stick to it [23]. If the particle sticks or not, depends on shear, particle size and deposit bond strength. The sticking probability of a particle has been investigated empirically by researchers [23].

7) Shear stripping

The deposit grows over time, this leads to an increasing flow velocity and thereby wall shear stress. If the shear stress exerted by fluid flow at the deposit interface is high enough, then some of the deposit may be mechanically removed [23]. Results from the University of Tulsa show thicker deposits in laminar flow tests where the shear rate is lower. Hsu et al. (1994) concluded that the shear removal generated during turbulent flow conditions significantly impact on wax deposition rate, and should therefore not be neglected [8].

8) Aging

The aging mechanism leads to hardening of the deposit over time. Deposited wax on the pipe wall traps oil in the wax network structure. The heavier molecules diffuse into the deposited gel through the trapped oil, and due to counterdiffusion the trapped oil diffuse out of the deposit. This leads to an increased fraction of solid wax inside the deposit and also an increase hardness of the deposited gel over time [23].

D) Introduction to Pipesim

PIPESIM is a steady-state, multiphase flow simulator used for the design and analysis of oil and gas production systems. With its rigorous simulation algorithms, PIPESIM helps you optimize your production and injection operations.

PIPESIM models multiphase flow from the reservoir through to the surface facilities to enable comprehensive production system analysis.

PIPESIM is most often used by reservoir, production or facilities engineers as an engineering user type to model well performance, conduct nodal (systems) analysis, design artificial lift systems, model pipeline networks and facilities, and analyze field development plans and optimize production [38].

II. INPUT DATA AND LABORATORY ANALYSIS

Proposed Trunk line details (EPS-IV to EPS-V), are mentioned in the Table 1.

Present Production = 395 m^3/d

Max future production envisaged = 600 m^3/d

A) Laboratory Analysis

Composite crude oil sample was collected from EPS-I field and was analyzed at laboratory to ascertain the compositional as well as rheological properties of the crude. The results of the evaluation studies are as under: The viscosity of the composite crude oil sample was determined at different temperatures 25°C, 30°C, 35°C, 40°C and 45°C and at shear rates 5 s^{-1}, 10 s^{-1}, and 15 s^{-1} using MV DIN Sensor system and M-5 measuring system of Haake viscometer.

In order to study the effect of water on transport properties, viscosity measurements were carried out by dehydrating the composite sample, as well as by forming different emulsions with varying of water.

The results of Physical Characteristics of crude oil from EPS-I field is mentioned in Table 2.

Sudden increase in viscosity is observed as temperature is lowered from 40 to 35°C. The highlighted viscosity data at shear 5/sec with 20% emulsified data have been taken for the simulation studies

Conclusions of laboratory study:

1. Dehydration has not caused any change in the Pour Point and transport property of the sample.

2. With the increase in percentage of emulsified water content from 20 to 50% a declining trend in viscosity is observed.

III. SIMULATION STUDIES AND THE RESULTS

Simulation studies have been carried out on Pipesim Software in order to find out the pressure and temperature drops in the 8"x 50 km EPS-I - EPS-V pipeline.Following simulation cases have been studied to arrive at the optimum transportation conditions in the existing system from flow assurance point of view:

Basis of study for the simulation of EPS-I Field crude from EPS-I to EPS-V through 8"x 50 km trunk line, Simulation Studies and the Results are mentioned in Table 8.

IV. ANALYSIS OF SIMULATION RESULTS

Comparative simulation results Table 9.

Simulations for scenario 1A, 1B, 1C, 2A, 2B and 2C have been carried out with a view to

- Comparing the simulated results with the reported field data of Summer and rainy season
- The effect on pressure drop during winter for the same through out
- The effect of heating the crude to 65°C before pumping.

It is observed from the simulation results that:

- Simulated results for pressure drop are almost matching with the reported field data.
- The pressure drop during winter comes to be about 32kg/cm^2 for 360 m^3/d, and
- Heating the crude up to 65°C is always preferable irrespective of weather/seasons as the pressure drop increases to 42 kg/cm^2 without heating in summer, to 75 kg/cm^2 in the rainy season and to 128kg/cm^2 in the winter.

Simulations for scenario 3A, 3B, 3C, 4A, 4B and 4C have been carried out with a view to:

- Finding pressure drops when the pumping is done for the entire quantity of 500m^3/d from all the 4 installations of EPS-I during summer, rainy and winter.
- Finding pressure drops when the pumping is done from for the entire quantity of 500m^3/d only one installation i.e. EPS-I during summer, rainy and winter.

It is observed from the simulation results that

- Pumping pressure of EPS-I field crude from the three installations into the EPS-I to EPS-V pipeline particularly in winter season shoots up to 63kg/cm^2 at EPS-IV, 60 kg/cm^2 at EPS-III,51 kg/cm^2 at EPS-II and 49 kg/cm^2 at EPS-I despite heating the crude up to 65°C . Taking into consideration the design pumping pressure of 50 kg/cm^2 of the reciprocating pumps, it is not feasible to transport the crude through through 8-inchx50km trunk line.
- It is found that pumping of the entire crude becomes quite comfortable i.e16kg/cm^2 in winter provided the entire liquid of 500 m^3/d is pumped from only one installation i.e. EPS-I with inlet temperature of 65°C .
- The pumping pressure for 500 m^3/d of crude will virtually come down to 8kg/cm2 from the present pumping pressure of 10kg/cm^2 (for 350 m^3/d) as in Scenario-4A due to better shear as well as better heat retention due to 20% emulsion water in the line.

Keeping the above points in consideration, it is suggested that the crude from EPS-IV,EPS-III and EPS-II would be collected at EPS-I and pumping of the entire liquid of 500 m^3/d would be done from there to dispatch to EPS-V.

It is observed from the simulation results that:

- Heating of the crude to preferably 65°C is required imperatively otherwise it may not be feasible to dispatch the crude to EPS-V as the pumping pressure shoots up very high.

Simulations for scenario 5A, 5B, 5C, 6A, 6B and 6C have been carried out with a view to finding out as to what will happen if pumping from the 3 installations i.e. EPS-IV,EPS-III and EPS-II to EPS-I is done without heating as well as with heating.

It is observed from the simulation results that:

- Pumping of 120m^3/d each from EPS-IV,EPS-III and EPS-II to EPS-I will also require heating up to 65^{o}C before pumping particularly in winter season as the pumping pressure shoots up to 56kg/cm^2 ,40 kg/cm^2 and 27kg/cm^2 at EPS-IV,EPS-III and EPS-II respectively as in scenario-5C.
- After heating the liquid up to 65^{o}C at both EPS-IV,EPS-III and EPS-II as in scenario-6C, the pumping pressure eases to 10 kg/cm^2,8 kg/cm^2 and 6kg/cm^2 at EPS-IV,EPS-III and EPS-II

V. RECOMMENDATIONS

- Recommended to heat the crude oil up to 65^{o}C prior to pumping at all the installations irrespective of weathers/seasons.
- Recommended that the crude from EPS-IV,EPS-III and EPS-II would be collected at EPS-I and after heating up to 65^{o}C pump the entire liquid (500m^3/d) to EPS-V. It will assist in the transportation from flow assurance point of view due to better shear as well as better heat retention in the line.
- Recommended for continuous pumping from all the four installations of EPS-I field considering the highly viscous and congealing nature of the crude.

Table1: Proposed Trunk line details (EPS-IV to EPS-V)

Line size	Inches	8
OD	Inches	8.625
Grade	APIL	X-46
Wall Thickness	Inches	0.277
ID	Inches	8.071
Length(EPS-IV toEPS-III to EPS-II toEPS-1 to EPS-V)	Km	9+13+15+13=50
Burial depth	M	1.2
Coating		Coaltar enamel

Table 2: Physical Characteristics of crude oil from EPS-I field

Properties		Values
Density	15^{o}C	0.9506
Sp. Gravity	60/60 ^{o}F	0.9511
API Gravity	60 ^{o}F	21.47
Pour Point	(^{o}C)	37^{o}C
Water Content	(v/v%)	50%
BS &W	(v/v %)	62%
Wax Content	(%wt)	6.70%

Table 3: Viscosity of dehydrated crude oil composite sample from EPS-I field. Water content Traces, Pour Point 37°C

Sl.No.	Temperature °C	Viscosity in Cp		
		Shear Rate 5	Shear Rate 10	Shear Rate 15
1	45	363	163	126
2	40	483	181	148
3	35	861	565	508
4	30	10150	4216	2517
5	25	40300	15770	9837

Table 4: Viscosity of composite sample (containing 20% emulsified water) from EPS-I field

Sl.No.	Temperature°C	Viscosity in Cp		
		Shear Rate 5	Shear Rate 10	Shear Rate 15
1	45	233	210	190
2	40	262	234	207
3	35	1780	1064	830
4	30	12110	4749	2970
5	25	22530	11840	8486

Table 5: Viscosity of composite sample with water (30%) from EPS-I field.

Sl.No.	Temp. °C	Viscosity in Cp		
		Shear Rate 5	Shear Rate 10	Shear Rate 15
1	45	576	558	544
2	40	894	820	757
3	35	4933	2713	1004
4	30	5991	2908	2188
5	25	16980	6858	5365

Table 6: Viscosity of composite sample with water (40%) from EPS-I field

Sl.No.	Temp.°C	Viscosity in Cp		
		Shear Rate 5	Shear Rate 10	Shear Rate 15
1	45	517	437	372
2	40	970	397	172
3	35	2655	1911	1469
4	30	2830	2248	1775
5	25	7929	3819	2671

Table 7: Viscosity of composite sample with water (50%) from EPS-I field

Sl.No.	Temp. °C	Viscosity in Cp		
		Shear Rate 5	Shear Rate 10	Shear Rate 15
1	45	287	229	210
2	40	439	385	289
3	35	1775	1407	1148
4	30	3593	1967	1334
5	25	4273	2197	1531

Table: 8 Simulation Studies and the Results

Item	Unit	Quantity
Line ID	Inch	8
Length(EPS-IV toEPS-III to EPS-II toEPS-1 to EPS-V)	Km	9+13+15+13=50
Viscosity	Cp	233cP @45^{0}C & 1780 cp @35^{0}C (Shear rate = 5 / Sec)
Pumping rate	m^3/d	500 (max.)
Line inlet temperature	°C	40, 60
Line outlet pressure	Kg/cm^2	1 (at DEPS-I)
Water cut (emulsion)	%	20
Free water	%	Nil

Gas rate	SCMD	0
Ambient Temperatures	°C	30 (Summer), 25 (Rainy season), 21 (Winter) for buried line

Scenario 1(A): Present pumping (for 360 m^3/d) from EPS-I during summer with inlet temperature of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	360	13	10	65
EPS-V	-	-	1	37

Scenario 1(B): Present pumping (for 360 m^3/d) from EPS-I during rainy season with inlet temperature of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	360	30	17	65
EPS-V	-	-	1	33

Scenario 1(C): Present pumping (for 360 m^3/d) from EPS-I during winter season with inlet temperature of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	360	30	32	65
EPS-V	-	-	1	30

Scenario 2(A): Present pumping (for 360 m^3/d) from EPS-I during summer with inlet temperature of 45°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	360	13	42	45
EPS-V	-	-	1	32

Scenario 2(B): Present pumping (for 360 m^3/d) from EPS-I during rainy with inlet temperature of 45°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	360	13	75	45
EPS-V	-	-	1	31

Scenario 2(C): Present pumping (for 360 m^3/d) from EPS-I during winter with inlet temperature of 45 ºC

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(ºC)
EPS-I	360	13	128	45
EPS-V	-	-	1	29

Scenario -3A: Pumping from all the FOUR installations of EPS-I field to EPS-V IN SUMMER with inlet temperature of 65ºC

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(ºC)
EPS-IV	120	9+13+15+13	20	65
EPS-III	120		19	65
EPS-II	120		17	65
EPS-I	250		15	65
EPS-I	-	-	1	37

Scenario -3B: Pumping from all the FOUR installations of EPS-I field to EPS-V IN RAINY SEASON with inlet temperature of 65ºC

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(ºC)
EPS-IV	120	9+13+15+13	37	65
EPS-III	120		35	65
EPS-II	120		30	65
EPS-I	250		28	65
EPS-V	-	-	1	33

Scenario -3C: Pumping from all the THREE installations of X field to D EPS-1 IN WINTER with inlet temperature of 65ºC

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(ºC)
EPS-IV	120	9+13+15+13	63	65
EPS-III	120		60	65
EPS-II	120		51	65
EPS-I	250		49	65
EPS-V	-	-	1	31

Scenario -4A: Pumping from ONLY ONE installation of EPS-I field to EPS-V IN SUMMER with inlet temperature of 65ºC

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(ºC)
EPS-I	500	13	8	65
EPS-V	-	-	1	40

Scenario -4B: Pumping from ONLY ONE installation of EPS-I field to EPS-V IN RAINY SEASON with inlet temperature of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	500	13	11	65
EPS-V	-	-	1	37

Scenario-4C: Pumping from ONLY ONE installation of EPS-I field to EPS-V IN WINTER with inlet temperature of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-I	500	30	16	65
EPS-V	-	-	1	34

Scenario-5A: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN SUMMER (WITHOUT HEATING)

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	17	45
EPS-III	120	-	12	45
EPS-II	120	-	10	45
EPS-I	-		1	33

Scenario -5B: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN RAINY SEASON (WITHOUT HEATING)

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	31	45
EPS-III	120	-	23	45
EPS-II	120	-	16	45
EPS-I	-		1	30

Scenario -5C: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN WINTER (WITHOUT HEATING)

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	56	45
EPS-III	120	-	40	45
EPS-II	120	-	27	45
EPS-I	-	-	1	27

Scenario -6A: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN SUMMER (WITH HEATING) i.e. inlet temp. of 65°C

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	4	65
EPS-III	120	-	3	65
EPS-II	120	-	2	65
EPS-I	-	-	1	39

Scenario -6B: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN Rainy season (WITH HEATING)

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	6	65
EPS-III	120	-	5	65
EPS-II	120	-	4	65
EPS-I	-	-	1	35

Scenario -6C: Pumping from EPS-IV,EPS-III,EPS-II to EPS-I IN WINTER (WITH HEATING)

Installation	Flow rate	Length	Pressure	Temperature
	(m^3/d)	(km)	(kg/cm^2)	(°C)
EPS-IV	120	9+13+15+0	10	65
EPS-III	120	-	8	65
EPS-II	120	-	6	65
EPS-I	-	-	1	32

Table 9: Analysis of Simulation Results

A. When pumping from all the 3 installations					
Install.	Flow rate	Inlet Temp	Pressure (Summer)	Pressure (Rainy)	Pressure (Winter)
	(m^3/d)	°C	kg/cm^2	kg/cm^2	kg/cm^2
EPS-IV	120	65	20	37	63
EPS-III	120	65	19	35	60
EPS-II	120	65	18	33	55
EPS-1	250	65	17	30	51
EPS-V	Taken into storage tank (1 kg/cm2)				
B. When pumping from only 1 installation i.e. X EPS-I					
EPS-I	500	65	8	11	16
EPS-V	Taken into storage tank (1 kg/cm^2)				

Appendix (A): List of Tables

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