CONTROL STARTUP SLUGS OF UNDULATING MULTIPHASE PIPELINE DURING END OF LIFE OPERATION USING OLGA SIMULATION

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ABSTRACT

Shut-in and cooldown of multiphase pipeline will cause accumulation of condensed liquid at all the low points of undulating sections of the pipeline. Successful startup of pipeline from this equilibrium condition, requires sufficient pressure at upstream to overcome hydrostatic pressure of accumulated liquid and high frictional pressure losses during movement of startup slug in the pipeline. During end of life operation, Shut-in Well Head Pressure, may not be adequate for pipeline startup due to depletion of reservoir inventory or the required inlet pressure during startup may exceed the pipeline design pressure. The objective of this project is to study the formation of startup slugs in undulating pipeline and its impact on operating parameters through OLGA simulation. It is also to establish optimum control methods and design for handling startup slugs with low inlet pressure. Using OLGA, startup slug mitigations options such as flaring from Slug Catcher or utilising drag reducing agent (DRA) injection in the feed or gas injection at riser base or requirement of combination of these methods were analysed. By comparing the simulation results, appropriate mitigation method is proposed for optimal benefit. The thermal-physical property table for the fluid, which is the input for OLGA simulator is generated with PVTSim software. Depressurising the pipeline by flaring (Method 1) from slug catcher is helpful to control startup slug due to increase in available differential pressure across pipeline, reduced liquid hold-up in pipeline by vaporization at low pressure and increased superficial gas velocity. Gas injection (Method 2) at riser base can also be helpful, as it can reduce startup pressure requirement by reducing the riser liquid head. DRA injection (Method 3) can reduce the pressure requirement at upstream of pipeline by minimizing frictional pressure losses when startup slugs moves through long pipeline. From simulation analysis, it is concluded that all three methods helped to reduce the inlet pressure requirement within allowable limit. Therefore, combination methods options are not necessary. Through techno economic analysis, startup with flaring (Method 1) is concluded as most optimal method for control of startup slug.

ABSTRAK

Penutupan dan penyejukan pelbagai fasa paip akan menyebabkan pengumpulan cecair terkondensasi pada lokasi rendah pada bahagian paip yang beralun. Start-up saluran paip yang berjaya daripada kondisi equilibrium memerlukan tekanan yang mencukupi untuk mengatasi tekanan hidrostatik pada cecair terkondensasi dan kehilangan tekanan geseran yang tinggi semasa pergerakan start-up slug dalam paip. Semasa operasi Akhir hayat, Shut-in Well Head Pressure (SIWHP) mungkin tidak mencukupi untuk start-up disebabkan oleh kekurangan reservoir inventori atau tekanan semasa start-up boleh mengatasi design pressure saluran paip berkenaan. Objektif projek ini untuk mengkaji pembentukkan start-up slug dalam saluran paip beralun yang bersaiz 24 inci besar dan 150 km panjang untuk Rich Associated Gas feed dan impaknya terhadap parameter operasi melalui simulasi OLGA. Ia juga untuk mewujudkan keadah kawalan dan reka bentuk yang optimum untuk mengendalikan start-up slug dengan inlet pressure yang rendah daripada available shut-in well head pressure atau design pressure paip, mana-mana yang lebh rendah. Menggunakan OLGA, kaedah mitigasi start-up slug seperti flaring dari Slug Catcher atau mengunakan drag reducing agent (DRA) injection di feed atau gas injection di pangal riser atau keperluan untuk mengunakan gabungan kaedah kaedah akan dianalisis. Dengan membandingkan keputusan simulasi, mitigasi yang sesuai akan dicadangkan untuk faedah yang optimum. Thermal-physical property table untuk cecair, yang merupakan input untuk simulator OLGA akan dihasilkan dengan perisian PVTSim. Depressurising saluran paip dengan flaring (Kaedah 1) dari Slug Catcher membantu untuk mengawal startup slug kerana peningkatan available differential pressure merentasi saluran paip, penyusutan liquid hold-up dalam saluran paip dengan penguapan pada tekanan rendah dan peningkatan superficial gas velocity. Gas injection (Kaedah 2) pada pangkalan riser juga boleh membantu, kerana ia dapat mengurangkan keperluan startup pressure dengan mengurangkan riser liquid head. DRA injection (Kaedah 3) boleh mengurangkan keprluan tekanan di hulu saluran paip dengan memminimumkan kehilangan tekanan geseran apabila startup slugs bergerak melalui saluran paip yang panjang. Dari analisis simulasi, ia disimpulkan bahawa ketiga-tiga kaedah ini membantu mengurangkan keperluan inlet pressure dalam had yang dibenarkan. Oleh itu, pilihan kaedah gabungan tidak diperlukan. Melalui analisis techno economic, startup dengan flaring (Kaedah 1) disimpulkan sebagai kaedah yang paling optimum untuk mengawal startup slug.

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LIST OF ABBREVIATIONS

DRA	-	Drag Reducing Agent
FWS	-	Full Well Stream
GLR	-	Gas Liquid Ratio
GOR	-	Gas Oil Ratio
H&MB	-	Heat and Material Balance
HSE	-	Health, Safety and Environment
IFE	-	Institute for Energy Research
Leda Flow	-	Hydraulics and Thermodynamics Simulation Software
Multiflash	-	Fluid Properties Simulation Software
OLGA	-	Hydraulics and Thermodynamics Simulation Software
PFD	-	Process Flow Diagram
PI Values	-	Proportional and Integral Tuning Constants
P&ID	-	Piping and Instrumentation Diagram
PR	-	Peng-Robinson Equation of State
Promax	-	Fluid Properties Simulation Software
PVTSim	-	Fluid Properties Simulation Software
PVT		Pressure Volume Temperature Relationship
RAG	-	Rich Associated Gas
SIWHP	-	Shut-in Well Head Pressure
USG	-	Superficial Gas Velocity
USL	-	Superficial Liquid Velocity
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

∂t	-	Differentiation in time
∂z	-	Spatial differentiation
g	-	Acceleration due to gravity
φ	-	Pipe angle relative to gravitational vector
P_i	-	Pressure force
F_w	-	Wall friction
Ψ_{ji}	-	Momentum contributions corresponding to mass transfer between j-th and i-th mass field
m_g	-	Mass associated with gas
m_h	-	Mass associated with oil
m_w	-	Mass associated with water
E_i	-	Field energy
H_i	-	Field enthalpy
S	-	Enthalpy source/sink
Q	-	Heat flux through pipe wall
T_{ij}	-	Energy transfer between fields
q_i	-	Heat flow from the fluid
T_f	-	Average fluid temperature
T_{iw}	-	Inner wall surface temperature
h_i	-	Inner wall heat transfer coefficient
q_{amb}	-	Heat flow from outer wall surface
T_{ow}	-	Wall surface temperature
T_{amb}	-	Ambient temperature
h_{amb}	-	Heat transfer coefficient
F_{sL}	-	Slug frequency
D	-	Pipeline diameter
L	-	Pipeline length
U_{Sl}	-	Superficial liquid velocity

CHAPTER 1

INTRODUCTION

1.1 General Overview

Satellite platforms are generally used to produce from marginal oil and gas fields as well as from the fields located in harsh environment. Due to economic reasons, the multiphase produced fluid consisting of hydrocarbon gas, hydrocarbon liquid and formation water are transported directly from well head platform to on-shore processing facilities or offshore centralised processing platform through long distance multiphase pipelines. This results in large cost savings by not having to duplicate separation, dehydration, compression and utilities for new facilities. It also reduces the risk to people as less people are working at offshore facilities. It also reduces risk to environment by having less hydrocarbon inventory at top sides and having fewer routes for release of hydrocarbon to environment. Flow assurance studies for multiphase pipelines involves analysing thermal, hydraulic and production chemistry related issues in order to ensure safe, reliable and economical transportation of fluids from production facility to processing facility. The use of multiphase pipelines presents major challenges in design and operation of the facility.

Figure 1.1 shows various flow related and fluid related flow assurance challenges associated with multiphase pipeline. The list of issues shown at the top left are flow related issues and bottom right are fluid related issues.

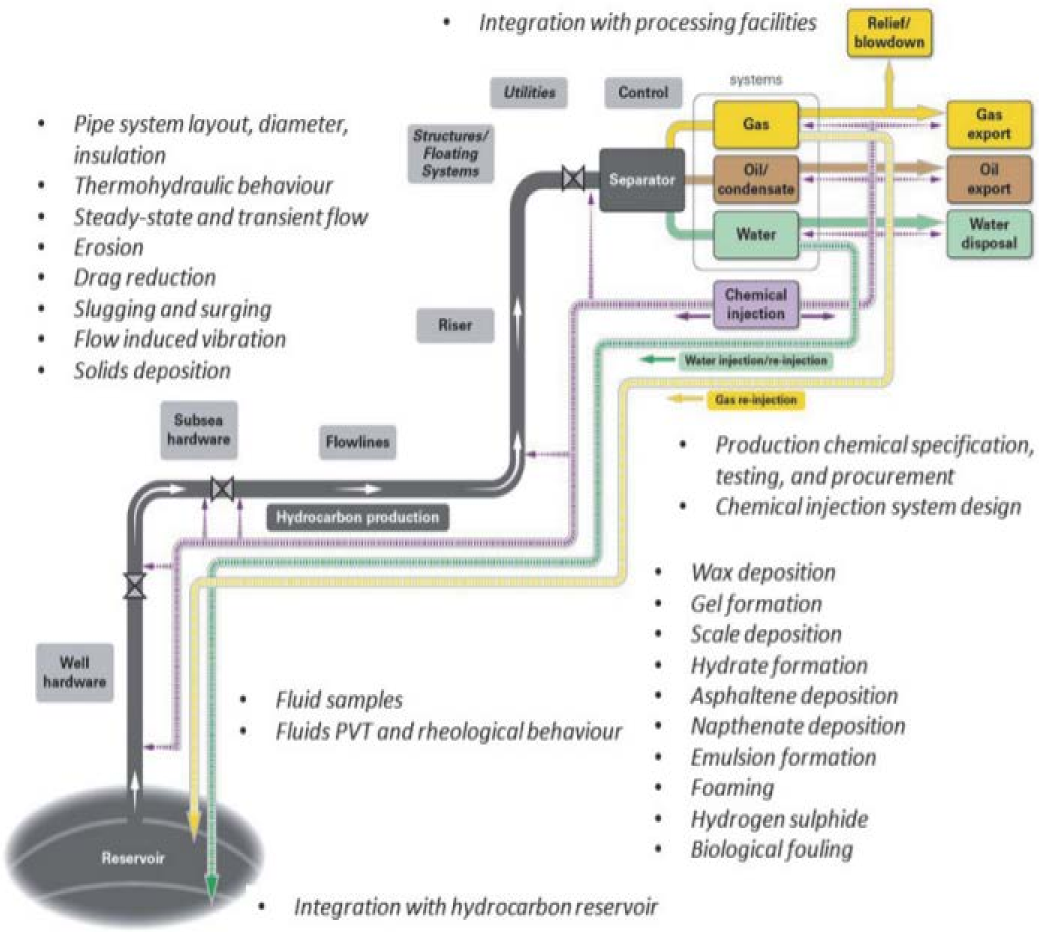

Figure 1.1 Flow Assurance Challenges with Multiphase Pipeline (Hill, 2018)

This project focus on slugging issues in the pipeline. Slug flow is a liquid gas two phase flow in which the gas phase exists as large bubbles separated by liquid slugs. Figure 1.2 shows the slug flow pattern in the case of horizontal pipeline.

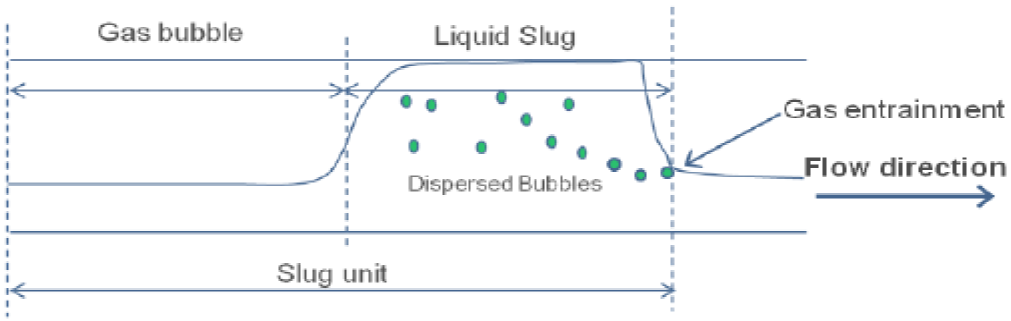

Figure 1.2 Slug Flow in Horizontal Pipeline (Omowunmi et al., 2013)

Slugs are normally classified based on mode of formation. The slug flow formed by flow instabilities such as Kelvin-Helmholts instability (Sharma, Ihara and Manabe, 2002) are called as hydrodynamic slugs. If the slug formation is due to geometry of the pipeline, they are called terrain slugs. Slug formation in riser pipe and in hilly terrain are examples for terrain slug. Formation and movement of riser slug is shown schematically in Figure 1.3 along with velocity and pressure trend at riser bottom. Similar to riser pipe slug, liquid accumulation at low points in the pipeline will cause temporary blockage. This can cause gas pressure behind the blockage to increase and expel the liquid as slug.

The next type of slugs are operational slugs, which are formed due to transient changes in pressure and flowrate during various operating modes of the multiphase pipeline. Some of the types of operational slugs are start-up slug, ramp-up slug, pigging slug and depressurisation operation slug.

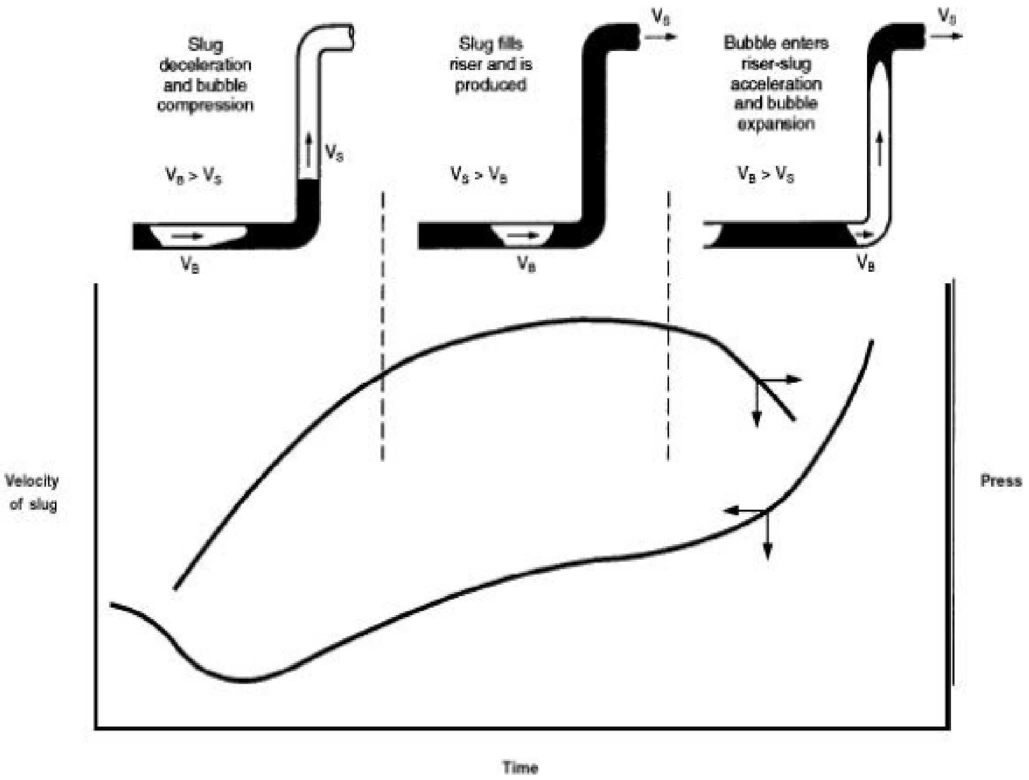

Figure 1.3 Terrain Slugging in Flowline Riser (BP Multiphase Design Manual, 1994)

These liquid slugs moves at much higher velocity than the average liquid velocity. This type of flow can cause severe vibrations in pipeline systems due to impact of high velocity slugs against fittings such as bend, tee etc. This can also cause other flow assurance issues such as increased back pressure, fatigue failure, erosion and unsteady gas and liquid flow into downstream processing equipment of separator. The unsteady gas and liquid flow through pipeline can cause tripping of downstream compression system, which in turn can cause overpressure in the separator. Therefore, managing slug flow is one of the critical aspect of flow assurance in multiphase pipeline. The slug flow behaviour is greatly influenced by thermal, hydraulic and production chemistry related factors and is transient in nature. Following are the examples of those factors affecting the slug flow behaviour in multiphase pipeline:

(a) Thermal factors: Viscosity, density and heat transfer capacity

(b) Hydraulic factors: Pipe diameter, length, elevation and roughness

(c) Chemistry related factors: Hydrocarbon composition, water cut and GOR

Therefore, analysing and controlling slug flow is complex in nature and usually carried out using dynamic simulation software tools such as OLGA and Leda Flow along with fluid characterising software such as Multiflash, Promax and PVTSim software.

The slug analysis and control should also consider changes to operation parameters such as feed composition, pressure, temperature, production profiles, ambient conditions throughout the operating life of the reservoir. This will avoid any requirement for major modification to the facility during operation phase, which is usually expensive when compared to designing the facility compatible for entire operating life of the reservoir. The design of multiphase pipeline system should also consider various operating modes such as startup, normal operation, production turn-down, production ramp up, production ramp down and shutdown. This will improve safety, reliability, operation flexibility, controllability and will optimise production and cost.

This study is to understand operational slug issue in long multiphase pipeline on undulating terrain during pipeline start-up and to contribute in addressing the issue. For slug analysis, this project has considered full well stream (FWS) of Rich Associated Gas fluid transported through subsea pipeline of length 150 kilometres and 16 inches diameter.

1.2 Problem Statement

Liquid holdup in a pipeline during end of life operation is larger than early life operation due to low gas velocity in the pipeline. From steady state operating condition, pipelines are shut down for maintenance reason or for emergency situations. During shutdown of FWS pipelines, the valves at upstream of inlet riser and downstream of outlet riser are isolated under pressurised condition. This will cause the pipeline pressure to get equivalised and reaches settle out pressure. During this time, liquid in the pipeline gets accumulated in the lowest points of pipeline depending on the elevation profile of the pipeline. Produced fluid trapped in the pipeline is further cooled by exchanging heat with surrounding water for subsea pipeline section and with atmospheric air for above sea pipeline and piping sections. This cooldown process causes additional trapped gas to condense and get accumulated at low points due to gravity. If the pipeline is laid over undulating terrain, the condensed liquid gets accumulated at all the low points of the undulating sections of the pipeline. During start-up, pipeline inlet and outlet shutdown valves are opened. Fluid pressure at the inlet of the pipeline will increase to overcome the hydrostatic pressure of accumulated liquid following shutdown and frictional pressure loss due to movement of fluid through the pipeline. Majority of the liquid holdup is evacuated from the pipeline as large liquid slugs into the downstream separator. This is called operational slug of pipeline start-up.

During early phase of life of reservoir, produced fluid will have enough energy to overcome the hydrostatic pressure and frictional pressure loss. During end of life operation, the Shut-in Well Head Pressure (SIWHP) available at upstream of choke valve will be much lesser than early life operation due to depletion of reservoir inventory. In addition to that, liquid phase of production fluid will be enriched with heavier hydrocarbon and will normally have high water cut. This will cause increased liquid fraction in the pipeline, which will cause high hydrostatic liquid head following shutdown. Low gas velocity in the pipeline will also cause increased liquid holdup in the pipeline. Due to these operating characteristics, the available SIWHP during end of life operation may not be sufficient to overcome hydrostatic fluid head and frictional pressure loss during pipeline start-up. Therefore, flow cannot be established through pipeline during start-up. In some cases, the required pressure at inlet of pipeline to mobilize the start-up may exceed the allowable design pressure limit of the pipeline.

Lack of knowledge on operational slugs can severely affect production flow through the pipeline. The existing slug control design and methodologies practiced in industries might be inadequate for startup towards end of life operation of reservoir on undulating pipeline. This is due to large liquid accumulation at many low points, low available pressure at pipeline inlet or the inlet pressure exceeding the design pressure limit of the pipeline. This study will focus on handling startup slug in long multiphase pipeline on an undulating terrain during start-up with required inlet pressure below the design limit of the pipeline and SIWHP during end of life operation.

OLGA is the dynamic simulation tool, which can provide better insight of thermal and hydraulic transient behaviours of multiphase pipeline (Enilari, 2015). In this study, OLGA is used to predict the liquid hold-up following pipeline shutdown and is also used to analyse various methodologies to handle operational slugs during start-up, when production could not be restored due to low available SIWHP or due to high required inlet pressure, which exceeds the design limit. The following mitigation techniques are analysed through simulation studies to overcome the above issue:

(a) Depressurizing the pipeline by flaring

(b) Gas injection at outlet riser base

(c) Drag Reducing Agent injection with feed

(d) Combination of the above methods, if above methods alone is unsuccessful

1.3 Study Objectives

The major objectives of this project are:

(a) To study the formation of startup slugs in undulating pipeline and its impact on operating parameters through OLGA simulation;

(b) To establish optimum control method and design for handling startup slugs with pipeline upstream pressure below the design pressure limit or available shut in wellhead pressure (SIWHP) during end of life operation.

1.4 Scope of Study

The overall scope of study involves analysing the following:

(a) Modelling the carbon steel pipeline system of length 150 km and diameter 24 inches. Large undulation are assumed at 10 sections of the pipeline and small undulations at 3 sections of the pipeline. These undulations are evenly spread across the entire length of the pipeline. The elevation changes at large undulated sections vary between 6 m and 13 m. The inlet and outlet risers elevation change are 112 m and 50 m respectively.

(b) Establishing optimal design and/or operational mitigation method for handling startup slugs by the following 3 methods:

   i. Method 1: Flaring from slug catcher

   ii. Method 2: Gas injection at riser base

   iii. Method 3: DRA injection in the feed

Note: Combination of above methods are to be analysed only if startup by above methods alone is unsuccessful.

(c) Comparing the results from all the above methods and propose the appropriate method for optimal benefit.

1.5 Significance of Study

This study is useful to understand the background of flow assurance issues due to startup slugs in the undulating multiphase pipeline;

This study aimed to provide optimum design option to handle startup slugs during end of life operation of reservoir, when available SIWHP is not enough to drive the accumulated liquid in the pipeline and production flow cannot be established through multiphase pipeline during start-up.

This study is also useful to establish optimum operating philosophy for handling startup slugs, so that transient operating conditions are within safe operating envelope for the entire system. This will also enable reliable and efficient operation of the unit by minimising production interruptions caused by process trips during pipeline startup operation.

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