UNIVERSITI PUTRA MALAYSIA

NUMERICAL SIMULATION OF FLOW CHARACTERIZATIONS OF FLUIDS AROUND BYPASS PIPELINE INSPECTION GAUGE

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By

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NUMERICAL SIMULATION OF FLOW CHARACTERIZATIONS OF FLUIDS AROUND BYPASS PIPELINE INSPECTION GAUGE

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In oil and gas industry the transportations of fluids such as oil, gas and petroleum in production plants are operated by pipeline networks. During regular operation, the pipeline wall faces various obstructions, debris, deposits and corrosions, which cause several damages to the pipelines. Therefore, regular maintenance, cleaning and inspections of the pipelines are necessary for continuous pipeline operations. Pipeline Inspection Gauge (PIG) is a device used for such purposes, which moves forward in the pipeline due to differential pressure of fluid around the PIG. However, the performance of PIG is greatly affected by the PIG speed as very high speed may cause several damages to pipelines wall and the PIG itself. Therefore, it is important to investigate the flow characterizations of the fluid around the PIG and the relation to the PIG speed as the PIG parameters and fluids vary. This study focuses on investigating the relationship between PIG speed and bypass opening percentages of disk bypass PIG with hole in disk for different fluids including water, crude oil and butane using computational fluid dynamics approach. The control volume method along with steady state Turbulent k-ϵ model was applied for simulation purposes by using ANSYS Fluent 19 software. Ten different geometries of disk bypass PIG with hole in disk with eleven different bypass opening percentages (2% to 20%) were considered in this study. Relationship for PIG speed, pressure loss around PIG section and a general correlation for bypass opening percentages were investigated for all considered cases of water, crude oil and butane. By using numerical data, a relationship between PIG speed and other parameters (fluid and PIG geometrical parameters) was developed to determine PIG speed, which provided good agreement with experimental results within maximum 2% standard deviation. The findings of this study showed that by increasing the bypass opening percentages from 2% to 20% the PIG speed has reduced 102% to 189% in water medium, 21% to 52% in crude oil medium, and 85% to 139% in butane medium, respectively. Meanwhile, pressure loss has reduced 85% to 99% in water medium, 77 to 98% in crude oil medium, and 81% to 98% in butane medium for all cases, respectively. This study also developed a general correlation to determine the required bypass opening percentages at a certain PIG speed for water, crude oil and butane, which provided good agreement with

simulation and experimental results. The correlations developed in this study are important towards providing more valuable insights into improving pigging operations for oil and gas industries.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIMULASI BERANGKA BAGI PENCIRIAN ALIRAN BENDALIR DI SEKELILING TOLOK PEMERIKSAAN SALURAN PAIP PINTAS

Oleh

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Pengerusi : Profesor Madya Siti Ujila binti Masuri, PhD
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Bagi industri minyak dan gas, pengangkutan cecair seperti minyak, gas dan petroleum di kilang pengeluaran dikendalikan melalui rangkaian saluran paip. Semasa operasi, saluran paip menghadapi pelbagai halangan, serpihan, mendakan dan hakisan yang menyebabkan kerosakan pada saluran paip. Oleh itu, penyelenggaraan, pembersihan dan pemeriksaan saluran paip secara berkala adalah penting untuk pengoperasian saluran paip secara berterusan. Tolok pemeriksaan saluran paip (PIG) ialah alat yang digunakan untuk mencapai tujuan tersebut, yang bergerak di dalam saluran paip melalui perbezaan tekanan bendalir di sekeliling PIG. Namun, prestasi PIG sangat dipengaruhi oleh kelajuan PIG kerana kelajuan yang tinggi boleh menyebabkan kerosakan pada saluran paip dan juga PIG itu sendiri. Oleh itu, ciri-ciri aliran cecair di sekeliling PIG dan hubungan dengan kelajuan PIG amat penting untuk dikaji apabila parameter PIG dan bendalir berbeza-beza. Kajian ini memberi fokus kepada menyelidiki hubungan antara kelajuan PIG dan peratusan pembukaan pintas bagi PIG pintas cakera dengan lubang dalam cakera untuk cecair yang berbeza termasuk air, minyak mentah dan butana menggunakan pendekatan perkomputeran dinamik bendalir. Kaedah isipadu terkawal beserta model Gelora k- ϵ berkeadaan mantap digunakan untuk tujuan simulasi dengan menggunakan perisian ANSYS Fluent 19. Sepuluh geometri berbeza bagi PIG pintas cakera dengan lubang dalam cakera dan sebelas peratusan bukaan pintas yang berbeza (2% hingga 20%) telah dipertimbangkan dalam kajian ini. Hubungan antara kelajuan PIG, kehilangan tekanan di sekeliling bahagian PIG dan hubungkait umum untuk peratusan pembukaan pintas telah dikaji untuk semua kes yang diambilkira termasuk air, minyak mentah dan butana. Dengan menggunakan data berangka, hubungan antara kelajuan PIG dan parameter lain (bendalir dan parameter geometri PIG) telah dibangunkan untuk menentukan kelajuan PIG, yang memberi persetujuan baik dengan hasil eksperimen dalam sisihan piawai maksimum 2%. Hasil kajian ini menunjukkan bahawa dengan meningkatkan peratusan bukaan pintas dari 2% hingga 20%, kelajuan PIG masing-masing telah menurun 102% hingga 189% dalam medium air, 21% hingga 52% dalam medium minyak mentah, dan 85% hingga 139% dalam medium butana. Sementara itu, kehilangan tekanan telah menurun masing-masing dari 85% hingga 99%

dalam medium air, 77% hingga 98% dalam medium minyak mentah, dan 81% hingga 98% dalam medium butana untuk semua kes. Kajian ini juga telah membangunkan hubungkait umum untuk menentukan peratusan pembukaan pintas yang diperlukan pada kelajuan PIG yang tertentu untuk air, minyak mentah dan butana, yang memberi persetujuan baik dengan hasil simulasi dan eksperimen. Hubungkait-hubungkait yang dibangunkan dalam kajian ini adalah penting ke arah memberikan pandangan yang lebih bernilai dalam menambahbaik operasi ‘pigging’ untuk industri minyak dan gas.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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A	cross-sectional area of pipe
a	correlation factor
D	pipe diameter
d	diameter of PIG
d_0	diameter of disk hole
T	thickness of the disk
f	body force
F	force
H	disk diameter
h	bypass opening percentages
t	time
g	gravitational acceleration
k	turbulent kinetic energy
L	pipe length
l	horizontal bypass length
m	mass of the fluid
P	pressure
t	disk thickness
U	mean velocity
u'	root mean square of the fluctuating velocities
v	velocity
ΔP	differential pressure
Re	Reynolds number
ρ	density

μ	viscosity
ϵ	turbulent kinetic energy dissipation rate
δ	Kronecker delta
I	sum of forces acting on a volume unit
$\vec{F}$	mass force per volume unit and
$\vec{P}$	surface force per volume unit
θ	inclination angle
IMS	integrity management system
IMP	integrity management process
ILI	in-line inspection
MFL	magnetic flux leakage
UT	ultrasonic technology
RSM	Response surface methodology
PIG	pipeline inspection gauge
CFD	Computational fluid dynamics

Subscripts

c	contact
p	driving pressure
t	turbulent eddy
i	x direction
j	y direction
up	upstream
$down$	downstream
in	inlet
max	maximum

CHAPTER 1

INTRODUCTION

1.1 Background

In oil and gas industry, pipeline networks are used to transport various fluids such as oil, gas and petroleum from the wells to production plants. During regular operation, pipeline walls face various obstructions, debris, deposits and corrosion, which affect production rate and pipeline condition. Therefore, regular maintenance, cleaning, and inspections are required for the continuous operation of the pipelines. For these purposes, the pigging technique is applied widely, which is mainly performed by the device called Pipeline Inspection Gauge (PIG). A PIG is generally driven by the differential pressure of fluids around the PIG section inside the pipeline. There are numerous types of PIG for various pipeline applications. The basic PIG such as utility PIG is applied for cleaning purposes while intelligent PIG and smart PIG are utilized for inspection and cleaning. Moreover, the physical state of the pipe is inspected by using a smart PIG. Few examples of PIGs are provided in Figure 1.1 and Figure 1.2.

(a)

(b)

Figure 1.1 : Examples of bypass PIG (a) Liang, (2015) (b) Eureka Efektif Sdn. Bhd

(a) (b)

Figure 1.2 : Example of (a) intelligent PIG (Guo et al., 2014) and (b) cleaning PIG (Liang, 2015)

However, previous studies reported that PIGs would not be effective if it runs at high speed. The high speed of PIGs may create sudden damage or cracks in pipelines. The general standard speeds of utility PIGs are nearly 2-7 m/s for on-stream gas and 1-5 m/s for on-stream liquids (Cordell and Vanzant, 1999). By decreasing fluid speed, these risks can be overcome; however, this minimization of the fluid speed turns the production rates down. This issue can be solved by using PIGs that have fluid flowing path through their main body. This fluid flow path is known as bypass flow, which varies along with differential pressure over the PIG. The PIG with bypass flow is called as bypass PIG (Figure 1.1 is an example of bypass PIG), which is generally used to maintain the production rate by moderating the PIG speed (Chen et *al*., 2020; Hendrix et *al*., 2020; Nguyen et *al*., 2001a). There are various types of bypass PIG, among which disk bypass PIG is most potential for pigging operations (Liang, 2015). Previous studies demonstrated that fluids struck the disk due to the disk's presence, which caused a reduction of differential pressure and PIG speed (Korban, 2014; Liang, (2015); Mirshamsi & Rafeeyan, 2019; Zhang et *al*., 2020).

1.2 Problem Statement

The major problem faced by the pipeline inspection gauges (PIG) is to control and reduce the speed of the PIG during flows through the pipeline, which is usually very high for conventional and bypass PIG. The travelling speed of PIG will seriously affect the operation's results; therefore, strict requirements are necessary on the travelling speed. Very high speed of PIG causes several damages to the pipelines and PIG itself. Therefore, proper control and accurate prediction for PIGs' speed are highly significant during the pigging operations.

PIG speed usually depends on geometrical parameters of PIG, fluids properties and flow characteristics of fluids inside the pipeline. Studies reported that, use of disk in front of bypass PIG is more effective to reduce PIG speed. This is due to the bypass opening section at the disk, which can be adjusted by using different opening percentages that helps to reduce the velocity and pressure loss of fluids at upstream and downstream of PIG section. This decreases in fluid velocity and pressure loss reduces the PIG speed at a moderate rate. Therefore, if bypass opening percentages are not considered correctly during the design of PIG then it may affect PIG speed as well as pigging performance. Other geometrical parameters such as diameter, length, height, shape and thickness also have impact on the PIG speed.

Generally, the pigging operations are conducted in pipelines with different fluid mediums, which may influence the PIG speed due to the change in fluid dynamics properties of fluids. Therefore, it is important to consider design parameters of a PIG based on the fluid mediums to get effective pigging operation.

Despite the importance of geometrical parameters for disk bypass PIG and fluid mediums in pigging operation, the PIG speed and flow characteristics of fluids for different geometrical parameters and fluids were not evolved in literature properly. Moreover, relationship between PIG speed and PIG geometrical parameters for different fluid mediums was not demonstrated in previous studies, which is important to calculate PIG speed during travelling. In addition, general correlation for bypass opening percentages and other parameters (PIG geometrical and fluids) was not examined properly in literature to identify the most effective bypass opening percentages for pigging operations.

1.3 Objectives

The overall aim of this study is to establish relationships among PIG speed, bypass opening percentages and other parameters (fluid and PIG geometrical parameters) for disk bypass PIG with hole in disk. The objectives of the study are as follows.

1. To determine the relationship between PIG speed and other parameters (fluid and PIG geometrical parameters).
2. To determine PIG speed and pressure loss of different PIG geometries and fluids (water, crude oil and butane).
3. To establish a general correlation for PIG bypass opening percentages in terms of other parameters (fluid and PIG geometrical parameters).

1.4 Scope of the Study

Several scopes have been considered in conducting the study which are presented as follows-

- The flow condition of the working fluid in this study was turbulent based on the company's data.
- This study only investigated the fluid mechanics inside the pipe and PIG as influenced by the PIG dimensions. The body of the PIG, including its

deformability, was beyond the scope of the study.

- The roughness of the pipeline wall was not considered in this numerical simulation. According to company data, the pipe for experimental study was smooth and flow of fluid was single phase. Therefore, in numerical study the roughness of the pipeline wall was negligible.
- PIG inside the pipelines was considered as a stop condition due to determine the fluid velocity and pressure around the PIG. During movement, it is difficult to determine the fluid velocity and pressure around the PIG therefore the PIG was treated stop condition inside the pipeline for simulation purpose.
- The influence of heat on the pipeline wall and production fluid was also taken as negligible since, company did not impose any heat flux on the pipe wall during pigging operation.
- The bypass PIG considered in this study was a disk bypass PIG with a hole at the disk section as provided by company.
- Geometry and dimensions were as given by company.
- Ten different PIG geometries and pipe dimensions were considered which was denoted as case 1 to case 10.
- Eleven different bypass opening percentages; 2%, 4%, 5%, 6% 7.5%, 8%, 10%, 12%, 12.5%, 15% and 20% were applied.
- Three different fluids; water, crude oil and butane were considered as fluid medium.
- The flow was assumed axisymmetric. This means that in cylindrical coordinates (r, θ, z), there is no variation in the circumferential direction (θ). Therefore, the geometry in the simulation was 2D. Revolving the 2D geometry 360 degrees about the axis gives the full 3D geometry. As axisymmetric flow by revolving 2D geometry provides the full 3D geometry therefore, this study was assumed axisymmetric flow for simulation.

1.5 Thesis Organization

The thesis is organized in five chapters which are discussed as follows:

Chapter 1: A brief introduction consists of background, problem statement, objectives and scope of the study was explained in this chapter.

Chapter 2: A detail description of published researches on pipeline inspection gauges along with a summary table and research gap were demonstrated in this chapter. Pipeline integrity, categories, purposes, design, operating conditions of PIG were discussed. Moreover, developed correlations for bypass PIG from literature were also summarized.

Chapter 3: The applied methods and materials to conduct the current numerical study were presented in this chapter. Governing equations, geometrical parameters, PIG dynamics equations, grid independency test and verification were explained.

Chapter 4: The findings of the study according to the research objectives were presented in this chapter. PIG speed, pressure loss, velocity and pressure contours and relationships for PIG speed and bypass opening percentages were demonstrated.

Chapter 5: Base on the findings, analysis and discussion, the general conclusions and future recommendations were made.

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