ANTI-SLOSH BAFFLE PERFORMANCE IN HORIZONTAL CYLINDRICAL SEPARATOR TANK

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

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Contents

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Nomenclature

Alphabetical Symbol

C_2	Inertial loss coefficient
D_p	Mean diameter particle size
E_{ij}	Component of rate of deformation
f	Velocity potential for uniform motion
g	Gravitational constant (9.81m/s^2)
k	Turbulent kinetic energy
L	Length of horizontal cylindrical separator
r	Radius measured from the center of cylinder to a particular point
R	Radius of horizontal cylindrical separator
t	Time
u_i	Velocity component in corresponding direction
x_i x_j	Length of component in corresponding direction
z	Length of cylinder measured from x-y plane to a particular point

Greek Symbol

α	Permeability
Ɛ	Void fraction
ϵ	Dissipation
η	Free surface elevation
ρ	Density of respective fluid
∇	Gradient operator
θ	Plane angle measured from y axis in xy plane
Φ	Velocity potential
φ	Velocity potential related to sloshing
μ_t	Eddy viscosity
σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$	Adjustable constant for the k- ε turbulence model equations
	where $\sigma_{k = 1}$, $\sigma_\varepsilon = 1.30$, $C_{1\varepsilon} = 1.44$, $C_{2\varepsilon}=1.92$

Abbreviation

3D	Three Dimensional
Config.	Configuration
PRESTO!	Pressure Staggering Option
SIMPLE	Semi-Implicit Method for Pressure Linked Equations

Abstrak

Dalam proses pengekstrakan minyak, sesekat dipasangkan di dalam tangki pemisah yang berbentuk silinder mendatar untuk menyekat dinamik deburan campuran cecair. Konfigurasi sesekat yang berbeza membawa kesan kepada prestasi proses pemisahan dan penyekatan deburan. Simulasi yang melibatkan konfigurasi sesekat yang berbeza telah dijalankan menggunakan ANSYS Fluent untuk menerokai prestasi sesekat jenis pintu gerbang dan jenis berliang. Hasil daripada simulasi menunjukkan bahawa jenis sesekat berliang lebih baik daripada jenis pintu gerbang dari segi ketinggian deburan and purata kelajuaan campuran cecair yang lebih rendah. Kajian parametrik membuat kesimpulan bahawa konfigurasi 9 yang berjenis sesekat berliang dengan 0.4 kekosongan dan 0.02m purata saiz zarah menghasilkan prestasi yang paling tinggi dalam penyekatan deburan.

Abstract

In oil extraction process, baffle is employed in the horizontal cylindrical separator tank to dampen the sloshing dynamics of the fluids mixture. Different baffle configurations affect the efficiency of the separation process and anti-sloshing performance. Simulation of different baffle configurations was conducted using ANSYS Fluent software to explore the baffles performance of gate and porous types. Results from the simulation show that the porous type baffle performs better than the gate type baffle in terms of lower sloshing height and average velocity of fluid mixture across the inspection surface. Parametric study concluded that configuration 9 of porous baffle with 0.4 void fraction and 0.02 m mean particle size produces the best anti-sloshing performance.

Chapter 1

Introduction

1.1 Brief overview

An offshore oil extraction process requires drilling into the underground under the seabed. Typically, fluids comprise of a mixture of water, oil, and natural gas are pumped to the surface before being processed. To separate the mixture of fluids, horizontal cylindrical tank can be used [2]. As shown in Figure 1.1, it is a fixed structure which is typically located at the offshore platform tower above the sea level.

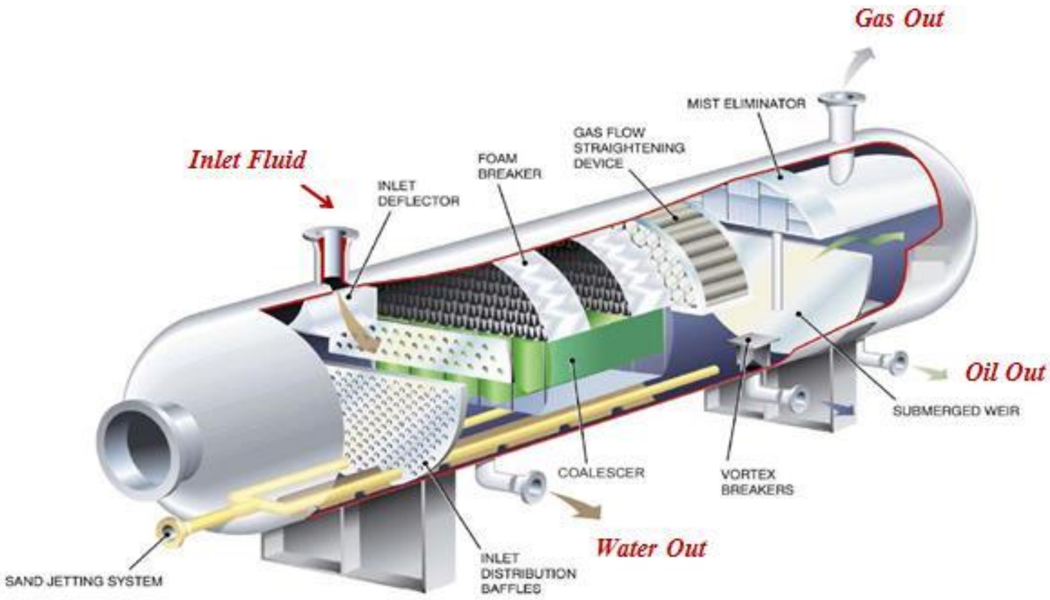

Figure 1.1: Cross section view of a horizontal separator used in offshore [1].

In a separation tank, there is one inlet section which allows the fluid mixture to enter. Water, oil, and gas exit the separation tank separately through different outlet points. The separator operates by the means of gravitational force. The mixture will settle down in time and form three layers of distinguishable components. In the ascending order of densities, the natural gas will be at the top layer with oil lies in the middle layer and water sinks at the bottom layer [2]. However, sloshing dynamics inside the separation tank could affect the performance of the separation process. Usually, a perfect separation is hard to attain. It is common to have entrained natural gas or entrained water in oil phase. To improve the efficiency of the separation tank, the entrained liquids or gases must be reduced.

Often, the presence of sea wave, strong wind blow, and the geothermal effect result in vibration on the separator, thereby generating waves that splash irregularly inside the separator [3]. The sloshing effect will disrupt the settlement of the three layers of fluids during the separation process. Also, uncontrolled sloshing will further induce more vibration on the separator structure. As a consequence, the support on the separator will be affected. To overcome the sloshing problem, a calming baffle plate is installed inside the separator. The baffle could stabilize the flow inside the tank, dampen the wave motion [3] and reduce the emulsion of oil and water.

1.2 Problem Statement

The performance of a separator is influenced by several factors. One of the main factors is the configurations of the baffle plate. To maximize the performance of the separator, the baffle plate needs to be designed accordingly to dampen and minimize the effect of sloshing. Without the baffle plates, the occurrence of sloshing is frequent and this creates vibration that could lead to structure failure. To overcome this problem, the understanding on the sloshing dynamics, with or without baffle plate, in the separator is essential.

1.3 Objectives

1. To explore the performance of different anti-slosh baffle configurations in dampening the inlet well-stream.
2. To examine the flow dynamics across the baffle plate in a separator and compare the performances of baffles with different configurations.
3. To investigate the influences of relevant geometric parameters on the performance of the baffles.

1.4 Scope of Project

There are many types of anti-slosh baffles available in the market. Different types of baffles have different slosh damping performance. Several anti-slosh baffles with different design patterns are selected to conduct simulation of liquid flow through it in a horizontal separator using ANSYS Fluent. Figure 1.2 shows the gate like structure anti-slosh baffle [4]. Figure 1.3 shows the circular perforated baffle plate which is full circular in geometry [4].

Figure 1.2: Gate-like structure baffle plate.

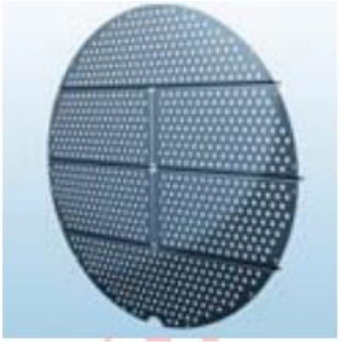

Figure 1.3: Circular perforated baffle plate.

Figure 1.4 shows the circular perforated baffle plate produced by AFP tech [5]. It is interesting to note that the circular perforated baffle is only half circular in geometry. The upper half is not covered by the baffle plate. This prevents plug flow problem in the gas layer.

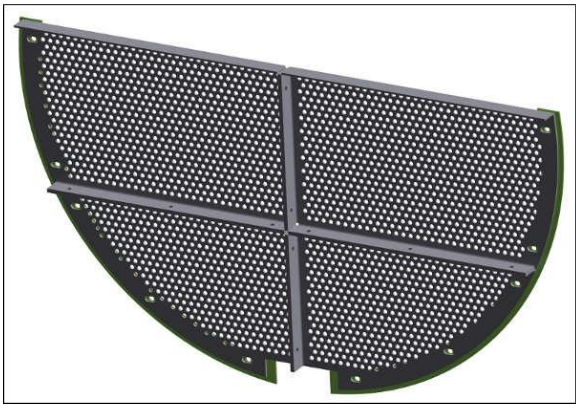

Figure 1.4: Circular perforated baffle plate (Half Circular Geometry).

Figure 1.5 shows the hexagonal hole perforated baffle plate produced by Jk Wire Netting Industries [6]. This type of baffle plate is densely meshed with homogenous hexagonal pattern throughout the entire plate surface. The hexagonal hole provides a sturdy corrosion resistant that could prevent rust and other forms of corrosion.

Figure 1.5: Hexagonal hole perforated baffle plate.

Figure 1.6 shows a square end slot holes perforated baffle plate that is made of carbon steel [6]. Meanwhile, Figure 1.7 demonstrates the staggered centers pattern perforated baffle plate [6]. This type of anti-slosh baffle has high strength-to-weight ratio.

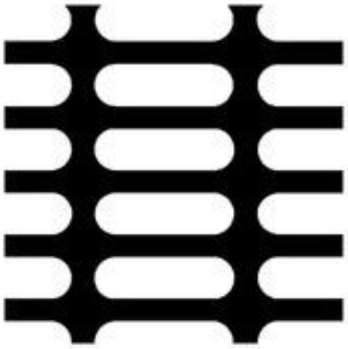

Figure 1.6: Square end slots hole perforated baffle.

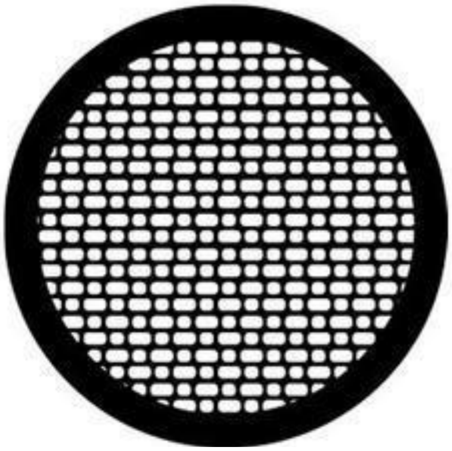

Figure 1.7: Staggered centers perforated baffle.

Other than different designs of baffle plate, the number of baffle plate also directly affects the separation efficiency of the fluid mixture in the separator. Typically, there is more than one perforated baffle installed in the separator at offshore platform. This is mainly due to the presence of sea harmonic motion that may induce sloshing of fluid inside the separation tank. In series arrangement, the distance between two consecutive baffles should be approximately 20% of the separation tank diameter [4].

1.5 Limitation

It should be noted that the simulation of the sloshing phenomenon of the separator tank requires a very long duration to compute the full result, i.e., typically 2 to 3 days for a simple gate baffle for a 20 seconds simulation. Due to the limited computational resources and time constraint, several baffle designs are thus selected for this study. Also, many of the computers available in the computer aided design (CAD) lab still use the older version of ANSYS (14.0 and below). Some of the configurations fail to run due to the different meshing algorithm used in the older version. Latest version of ANSYS (16.0 and above) would be preferred to run the simulation without error during the computation process.

1.6 Thesis Outline

This thesis is organized into 5 chapters:

Chapter 1 begins with a general background relating to the horizontal cylindrical separator in an offshore oil extraction process as well as the significance of installing baffle in the separator.

Chapter 2 briefly reviews the literature and provides useful insights reported pertaining to the baffle performance of different types of configurations in term of types, distance from the inlet and number of baffles employed.

Chapter 3 describes the technique used in this study to simulate the sloshing phenomenon caused by the inlet flux of fluid mixture by using ANSYS Fluent software.

Chapter 4 numerically and graphically explores the effects of different baffle configurations on the anti-sloshing performance.

Chapter 5 highlights the contributions of the thesis and provides recommendations for future investigations.

Chapter 2

Literature Review

Abbas Maleki et al. [3] carried out a study on the effects of different baffle configurations which are ring type baffle and vertical blade type baffle on the damping of slosh in a cylindrical liquid storage tank. Amongst the baffle configurations considered, experimental results show that the ring type baffle has the highest damping ratio. This is apparent when the baffle is installed at a height to radius ratio between 0.5 and 1. On the other hand, for a vertical blade baffle, there is an increase in the damping ratio with increase in the relative liquid height for the location of baffle at below 0.766 of the fluid height. From this research, it can be inferred that the position of baffle being installed will directly affect the damping effect produced.

Lu-hong Zhang et al. [7] conducted a research on the optimal design of a novel oil-water separator for raw oil from Alkali/Surfactant/Polymer (ASP) flooding technology. The research discussed that the optimized operation conditions to achieve the best separation efficiency are 30 minutes of retention duration, 800 mm packing length, inlet design of down box with holes and coalescent packing FDY-2 that is made of ceramic.

A study on the modeling of the multiphase flow of fuel tank sloshing was conducted by Vijay Mail et al. [8]. ANSYS Fluent was used to simulate the sloshing of kerosene of three different circumstances in a rectangular tank. The first situation was without any baffle installed inside the tank. In the second condition, three baffles with zero thickness were installed as shown in Figure 2.1. Meanwhile, for the third case, the tank was installed with three porous baffles and the domain was defined to porous media domain as shown in Figure 2.2. From the simulation studies, it was determined that the presence of baffle reduces the sloshing amplitude compared to the tank without baffles. It also demonstrated that the porous baffle provides more damping effect compared to ones without baffles and with zero thickness baffle.

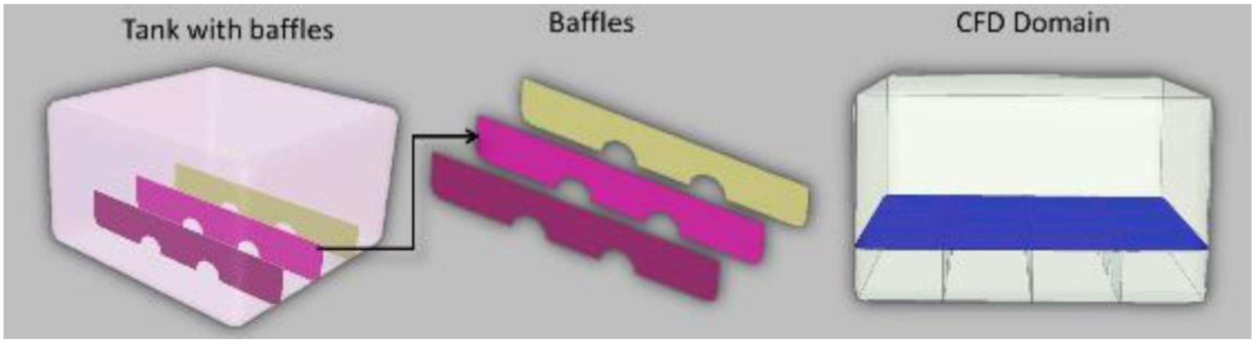

Figure 2.1: Baffles with zero thickness.

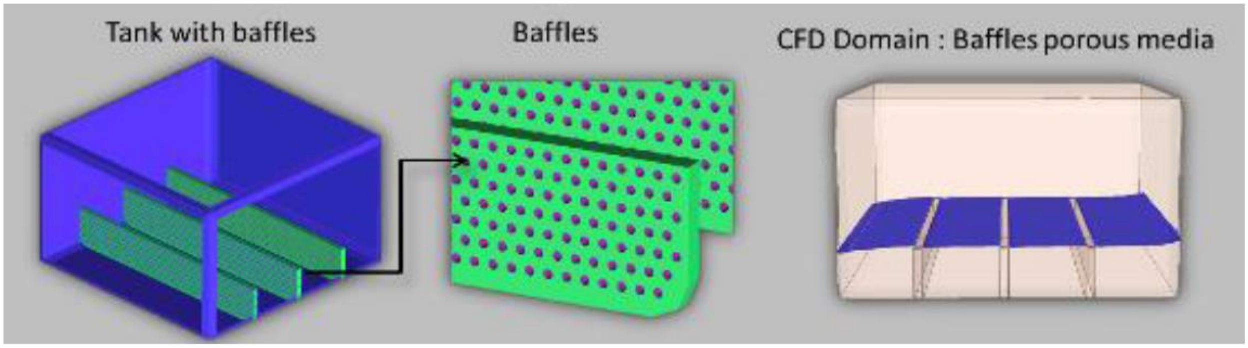

Figure 2.2: Porous baffles with porous media domain.

Derek Wilkinson et al.[9] also carried out a study on the baffle plate configurations to enhance separation in horizontal primary separators. From the CFD model results, it can be inferred that 10% of baffle free area provides greater uniformity of the fluid flow compared to 5%, 15% and 20% of free areas. Also, it was found that the hole size in the baffle has a relatively slight effect on regulating the flow distribution for a fixed free area fraction. Furthermore, multiple baffles are only advantageous when the distance between the baffles is less than 0.1 m apart of each other.

A study was also conducted by I. H. Cho et al.[10] on the sloshing reduction in a swaying rectangular tank using horizontal porous baffle of different porosity ranged from 0.0567 up to 0.3265. The experimental result concluded that lower porosity at 0.0567 has a better anti-sloshing performance to suppress the sloshing dynamics. Yet, the drawback is that lower porosity will in turn increase the impact force of the sloshing fluid against the baffle surface. Hence, optimal baffle porosity needs to be identified by inputting various porosity values for the porous baffle configurations.

Amir Kolaei et al.[11] also carried out an analysis on the anti-sloshing effectiveness of partial baffles in a partly filled cylindrical tank. The baffles were mounted respectively at the bottom part, top part and center part of the cylindrical tank in different configurations to compare and contrast the effect of mounting location on anti-sloshing. Results showed that baffle that is close to the free surface and fully immersed in the fluid domain has a lower fundamental slosh frequency than that of the others. Moreover, baffle that pierces through the free surface between the air and water demonstrated a higher damping effect than that without piercing through the free surface. Based on the findings, it is recommended to install the baffle that is fully immersed in the fluid domain with its tip end of the baffle piercing through the free surface in order to obtain a lower fundamental slosh frequency as well as a higher damping performance.

Chapter 3

Methodology

3.1 Theoretical Formulation for Sloshing Effect in Separator

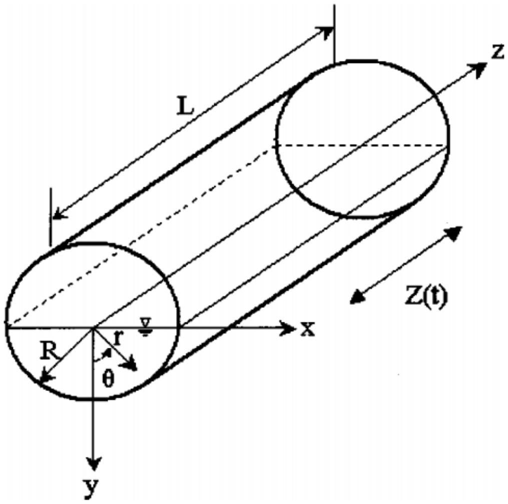

Figure 3.1: Horizontal cylindrical separator.

From Figure 3.1 [12], taking a horizontal cylindrical separator of radius R and length L, it is assumed that the wall of the separation tank is rigid and non-deformable to resist high levels of internal pressure. Also, the amplitude of the external excitation and the resulting free surface elevation are assumed to be sufficiently small to allow linearization.

The fluid in the separator is considered inviscid which can be described by a velocity potential function Φ that satisfies the Laplace equation within the fluid volume;

$$\nabla^2\Phi = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\Phi}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2\Phi}{\partial\theta^2} + \frac{\partial^2\Phi}{\partial z^2} = 0, \qquad (1)$$

$$r < R, -\frac{\pi}{2} < \theta < \frac{\pi}{2}, 0 < z < L$$

The velocity potential is subjected to the linearized dynamic and kinematic free-surface conditions

$$\frac{\partial \Phi}{\partial t} - g\eta = 0\,, \qquad \text{at } \theta = \pm\frac{\pi}{2}, \qquad r < R\,, \qquad 0 < z < L \tag{2}$$

and

$$\pm\frac{1}{r}\frac{\partial \Phi}{\partial \theta} + \frac{\partial \eta}{\partial t} = 0, \qquad at\ \theta = \pm\frac{\pi}{2}, \qquad r < R, \qquad 0 < z < L \tag{3}$$

respectively, where g is the gravitational constant and η= η (r,z,t) is the free-surface elevation. Combination of boundary conditions (2) and (3) leads to the mixed boundary condition

$$\frac{\partial^2 \Phi}{\partial t^2} \pm \frac{1}{r}\frac{\partial \Phi}{\partial \theta} = 0, \qquad at\ \theta = \pm\frac{\pi}{2}, \qquad r < R, \qquad 0 < z < L \tag{4}$$

Moreover, Φ should satisfy the kinematic conditions at the walls of the rigid container

$$\frac{\partial \Phi}{\partial r} = 0, \qquad at\ r = R, \quad -\frac{\pi}{2} < \theta < \frac{\pi}{2}, \qquad 0 < z < L \tag{5}$$

and

$$\frac{\partial \Phi}{\partial z} = \dot{Z}(t), \qquad at\ z = 0, \ \ L, \quad -\frac{\pi}{2} < \theta < \frac{\pi}{2}, \qquad 0 < r < R \tag{6}$$

Subsequently, Φ is decomposed in two parts

$$\Phi(\mathrm{r}, \theta, \mathrm{z}, \mathrm{t}) = f(\mathrm{z}, \mathrm{t}) + \varphi(r, \theta, z, t) \tag{7}$$

where f(z,t) and φ (r,u,z,t) are the ‘‘uniform motion’’ velocity potential and the potential related to sloshing, respectively. The velocity potential f corresponds to a ‘‘rigid body’’ motion of the fluid, which follows exactly the motion of the external excitation source, and satisfies the Laplace equation and the nonhomogeneous part of the kinematic conditions (6) at z=0 and z=L. Thus, the solution of the ‘‘uniform motion’’ is antisymmetric with respect to z=L/2 and it is trivially obtained as

$$f(z,t) = \dot{Z}(t)\left(z - \frac{L}{2}\right) \tag{8}$$