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Modelling of fire risks in an offshore facility

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ABSTRACT

As offshore facilities are growing in size, number and complexity so only the fire and explosion risk. This study is focused on modelling of fire risk for range of accident scenarios. Natural gas one of the common hydrocarbon produced in offshore facilities could cause variety of fires such as pool fire, jetfire, fire ball and flash fire. Two commonly occurring scenarios jetfire and fireball are considered here. These fires scenarios were evaluated with two different fire modelling approaches, solid flame model and Computational Fluids Dynamics (CFD) model. In CFD models, Pyrosim and Fire Dynamic Simulator (FDS) tool are used. In both approaches radiative heat flux from the fire is determined to assess the risk. Furthermore, the radiative heat flux is also used to define the impact to human for different degree of burns. Results from both approaches are compared to determine accuracy in fire risk modelling. Additionally, the CFD based fire models are validated incident report available through the U.S Chemical Safety Board (CSB). The results showed that the CFD method provided reasonably accurate results and thus recommended for offshore fire risk modelling.

1. Introduction

An offshore facility is a massive man-made structure operating at the sea. Depending on the constraints these facilities could be fixed to the seabed or in a floating condition. The function of majority of any offshore facility is to extract, process and store the hydrocarbon from the seabed. These hydrocarbons are classified as a highly flammable substance. Thus, offshore facilities are largely under a high risk of fire and explosion. Fatalities due to the fire are very high. Hence in designing this type of facilities the possibility of fire is one of the major concerns. Particularly the processing of the natural gas is risky, because natural gas possesses to have a higher risk than the liquid hydrocarbons due to its physical and chemical properties. The present study is intended to investigate the consequences of natural gas fire in an offshore facility. This research includes two types of fire that could occur due to natural gas ignition, namely jetfire and fireball. These fires were modelled using two different methods and analysed for their impact to the offshore facility.

Offshore accidents such as the Piper Alpha and Deepwater Horizon have shown that the consequences of a fire on human and nature can be catastrophic [10]. Recently, Vianna and Huser [11] also stated that the total risk caused by fires on offshore facilities is high. Many methodologies are derived to estimate the fire risk, design of fire protection and fire risk mitigation [7]. Based on the report by International Association of Oil & Gas Producers [8], it is known that the fire risk can be evaluated using two approaches; simple mathematical formulae and CFD method. In this study a most common method, solid flame model is used to determine the fire risk [1], The models were subsequently compared with the CFD method. The CFD method requires numerical solution of the Navier–Stokes equations to derive the risk; hence this method requires a high computation effort and proficient software knowledge. Upon completing the modelling of the fires using both approaches, a risk assessment was conducted to determine the fire risk, such as the thermal radiation. This is followed by impact modelling for these fires, where in this study human impact was chosen to be evaluated and analysed.

2. Methodology

The methodology applied in this study is shown in Fig. 1, This study followed following steps:

1. Fire modelling – *part* 1

- Determining the type of fires to analyse,

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Nomenclature

A	Surface area of the flame, m^2
CFD	Computational Fluid Dynamic, dimensionless
CSB	Chemical Safety Board, dimensionless
D	Thermal Dosage, $W^{4/3}$ s $m^{-8/3}$
D_{max}	Diameter of the fireball, m
D_s	Source Equivalent Diameter, m
d	the distance from the receiver point to the flame centre, m
erf	Error function, dimensionless
FDS	Fire Dynamic Simulator, dimensionless
F_{view}	View Factor, dimensionless
F_k	Clothes correction factor, dimensionless
H	Height of the fireball, m
k	Grey gas absorption coefficient, m^{-1}
K	Kelvin, dimensionless
L_B	Length of the flame
LNG	Liquefied Natural Gas
M	Mass, kg
m'	Burning rate of fuel, kg/m^2 s
P	Probability, dimensionless
Pr	Probit number, dimensionless
q	Radiation heat flux, kW/m^2
Q	Net heat released, kW
R_L	Length of the frustum, m
SEP_{max}	Maximum surface emitting power, kW/m^2
t_{max}	Time, s
U_j	Velocity of jet, m/s
V	Volume, m^3
W_1	Frustum base width, m
W_2	Frustum tip width, m
Θ	Angle of tilt, deg
Θ_1 and Θ_2	The angles between the normals of the flame surface and the lines that connects to the receptor, deg
°C	Degree Celsius
σ	Stefan–Boltzmann constant (5.6703×10^{-8}), W/m^2 K^4
τ_a	Atmospheric transmissivity, dimensionless
T_a	Ambient temperature, K
T_f	Temperature at the flame surface, K

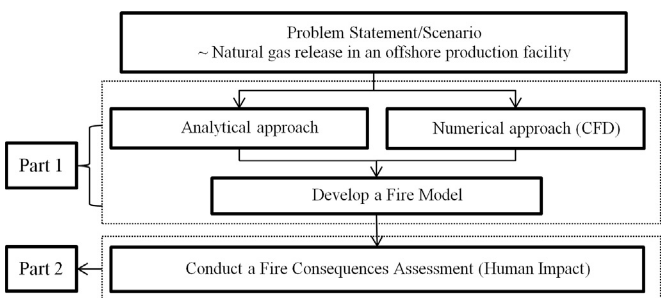

Fig. 1. Research methodology.

i. Jetfire – occurs when an ignition of fuel (vapour) is released at a high momentum in a certain direction.
ii. Fireball – occurs when there is an immediate ignition of a sudden release of high pressurised liquid or gas where the flame takes the form of a sphere.

- Modelling the fire,

i. Solid flame modelling – Analytical.
ii. Field Modelling – CFD.

2. Impact Modelling – *Part* 2.

- The impact due to the fire is modelled using the probit analysis, which is a type of regression used to analyse binomial response variables.
- These impacts, due to the fire are divided into three criteria which are the human impact, failure impact and impairment impact.
- This research will focus on the human impact criteria (thermal impact), where the thermal radiation probits are determined.

2.1. Combustion

Combustion is a chemical process involving rapid oxidation at high temperatures. This leads to the development of hot gases due to combustion and it emits radiation visibly and invisibly. This chemical process is generally accompanied with the fuel oxidation and light is emitted in the presence of oxygen. An oxidising agent and a reducing agent are required for any oxidising reaction, where it can be fuel and oxygen in most cases. When the heat is introduced, the fuel molecules and oxygen molecules start to vibrate vigorously when energy is gained from the heat. This will eventually cause a chain reaction to occur when the energy gained is transferred from one to another fuel and oxygen molecules. This chain reaction causes the fuel to lose the electron while the oxygen will gain the electron, thus the heat and light is emitted due to the exothermic reaction. This reaction is commonly approached using the fire tetrahedral [2].

2.2. Fuel

Natural gas is a compound of gases which mainly contains methane, which itself is an unrefined natural gas. The natural gas also contains other gases such as butane, ethane, and propane. Thus, propane can be counted as a part of the unrefined natural gas which later will be separated from the untreated natural gas. The raw natural gas is extracted and refined in gaseous phase. However it can be stored in both forms either as a gas or a liquid. By changing temperature and pressure, refined natural gas can be liquefied, commonly known as liquefied natural gas (LNG). Thus, this research was intended to analyse for natural gas fire risk in an offshore facility. As mentioned earlier, the two types of fire analysed in this study will use the natural gas as a fuel for the fire.

2.3. Fire risk modelling

Consequences due to fire are vast in an offshore production facility. Therefore, the simplest way of defining the effect of fire is by defining the heat flux, q' produced by the fire at its flame surface. This can be evaluated by using the Stefan–Boltzmann equation:

$$q' = \varepsilon\sigma\left(T_f^4 - T_a^4\right) \tag{1}$$

The usage of this equation does not provide the actual heat flux as since the temperature of the flame fluctuates, in other means this equation overestimated the heat flux. Many approaches have been developed to evaluate accurate heat flux. For this research,