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CFD BASED FIRE CONSEQUENCE ASSESSMENT

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ABSTRACT

The fire exposure of pressurised vessels used in offshore oil and gas production structures can lead to personnel life/safety incidents, environmental release, and facility damage. This paper discusses a Computational Fluid Dynamics (CFD) based consequence assessment of the time to failure for flare knock out drums under pool and jet fire impingement. The ANSYS FLUENT software was used to solve conjugate heat transfer problems such as those posed by fire impingement on flare knock out drums during emergency depressurisation. This allows a determination of whether the vessels can survive the design accident heat load from pool or jet fire and assists in designing fire protection systems.

NOMENCLATURE

M_{LG} mass transfer from liquid to gas
T temperature
T_G gas temperature
T_L liquid temperature
Q heat flux
Q_{IL} heat flux from wall to the gas phase
Q_G heat flux from wall to the liquid phase
Q_O heat load from fire
V_L the volume of liquid
V_G the volume of gas
$\boldsymbol{u}$ velocity
v gas inlet velocity
p pressure
ρ density
μ dynamic viscosity
q_{Loc} local heat load applied to the KO drum
q_{Glob} global heat load applied to the KO drum

ATS Allowable Tensile Strength
BLEVE Boiling Liquid Expanding Vapour Explosion
KO Knock Out drum
UTS Ultimate Tensile Strength
Subscripts
G gas phase
L liquid phase

INTRODUCTION

The process areas of offshore oil and gas platforms are characterised by complex geometry, highly congested areas and difficult escape routes. Although there are safety systems installed on the platforms, the process area is never completely safe (Pula et al., 2006). Among the loss producing events, fire is one of the most frequent reported (Pula et al., 2005). A relatively small fire can escalate to larger and uncontrollable fire that can cause serious injury to personnel, major damage to equipment and can endanger the whole platform. The main objective in this context is to prevent escalation to nearby process equipment resulting in loss of containment and release of significant quantities of combustibles.

The fire begins with the release of liquid or gaseous hydrocarbons into the environment following by an ignition. Two types fire are usually considered for offshore platforms, namely a jet fire and a pool fire (Health and Safety Executive, 2007). The jet fire typically results from the combustion of a material (gas or liquid hydrocarbons) as it is being released from a pressurised process unit and formed jet that is subsequently ignited. The pool fire develops when liquid flammable inventory released on deck forms a pool. The pool fire is continuous following ignition until either all the hydrocarbons are consumed or the ventilation conditions cause the fire to be extinguished (American Bureau of Shipment, 2013). The jet and pool fires represent a significant element of the risk associated with major accidents on offshore installations. The high heat fluxes from either the jet fire or the pool fire to engulfed as well as non-engulfed objects can lead to vessels and pipework failure. Figure 1 shows a schematic representation of pressurised vessel exposed to external fires.

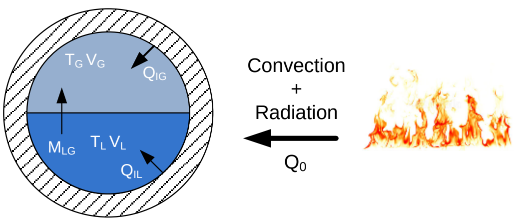


Figure 1: Schematic illustration of fire heat-up of a pressurised gas vessel.

As shown in the figure above, the vessel is heated by radiation and convection received from fire, Q_0. Heat conducted through the vessel wall is transferred to the gas and liquid zone and results in liquid evaporation and causes vapour temperature and pressure increase. The convective heat transfer coefficient between vapour and wall is low, so the vessel wall temperature rises, lowering the amount of stress the wall material is able to maintain at elevated temperature. On the same time, the pressure growth is increasing the stress intensity on the vessel. In case of severe vessel heat up a boiling liquid expanding vapour explosions (BLEVEs) may occur resulting in the loss of containment (Landucci et al., 2009).

The methodology presented in this paper, seek to quantify the time to failure of the vapour-liquid separator (KO drum) when exposed to the fire loads.

MODEL DESCRIPTION

Set up of CFD simulations

During emergency shutdown of the offshore platform the hydrocarbons inventory is diverted to the knock out drum where after separation the gas phase is sent to the flare and liquid is directed to the storage tanks.
In the present study, cylindrical vessels containing only a gas phase are considered. The gas enters the KO drum through inlet pipe and it is removed from the tank by outlet pipe, as seen in Figure 2.

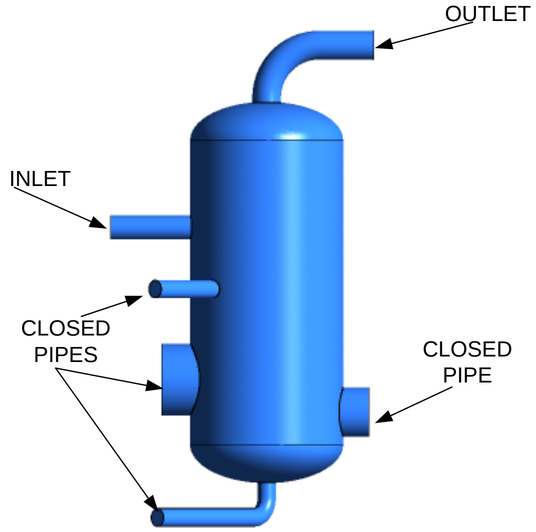


Figure 2: Knock-out drum geometry.

Pressure boundary condition is used for the outlet and velocity inlet boundary for the inlet. As it was mentioned before, during the emergency shutdown, the inventory send to the KO drum is decreasing with time, therefore, a time varying inlet velocity was used at the inlet, see Figure 5.
The external flow (flame and combustion) which applies the heat to the KO drum surface is not modelled directly. Instead, the heat load is applied as boundary conditions for KO drum walls. The specified heat loads aligned with the design accidental load specification document. Case 1 was defined as a jet fire and Case 2 defined as a pool fire. The heat fluxes applied to the inventory were:

- Local peak heat load = 350kW/m^2
- Global average heat load = 100 kW/m^2

for a jet fire case, and

- Local peak heat load = 150 kW/m^2
- Global average heat load = 100 kW/m^2

for a pool fire case.
The location of the local heat load was chosen from the characteristic of the pool and jet fires. The pool fire develops when liquid inventory released on deck forms a pool. Therefore the local heat load is applied to the bottom of the drum in the case of pool fire, while the local heat load from the jet fire is applied to the side of the drum.
A commercial CFD tool, ANSYS FLUENT (ANSYS, 2014), is used to set up the fluid dynamics model. The main equations considered here are: continuity equation, energy equation, momentum equation. The gas phase participation to the radiative heat transfer is not considered. A realizable k-ε model with standard wall functions is used to account for the turbulence.
Table 1 summarizes the features of the CFD model and the geometry of the KO drum. Figure 3 and Figure 4 show the computational grid used for the calculations. Each simulation is run for 60 minutes.

Item	Description or selected value
Vessel geometry	Cylindrical vessel
KO Drum No. 1	External diameter = 1.412 m Wall thickness = 1.4 m
KO Drum No. 2	External diameter = 2.826 m Wall thickness = 2.8 m
Material properties - Mixture of hydrocarbons	
Molecular weight	21.17 kg/kmol
Viscosity	1.08e-5 kg/(ms)
Density	Ideal gas density
Boundary conditions	
Walls	Heat flux
Inlet	Velocity inlet v = 28.68m/s for time < 15s and v = 28.68*exp(-0.0231*(t-15.0) for time > 15s Inlet temperature = 294K
Outlet	Pressure outlet = atmospheric pressure
Convergence criteria	10^{-6} for all equations
Number of elements	463,351

Table 1: Summary of the features of the CFD model

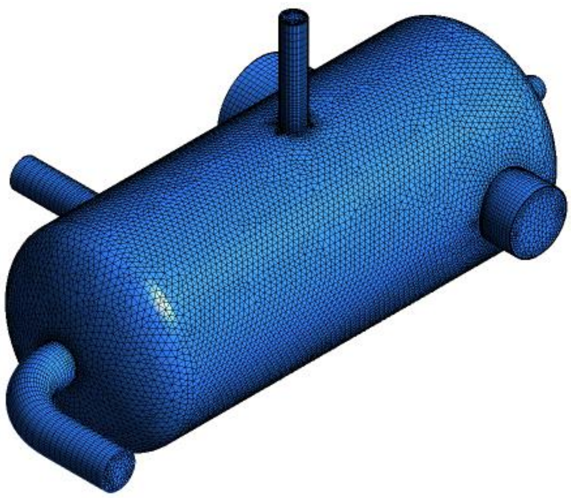


Figure 3: Mesh adopted in the present study.

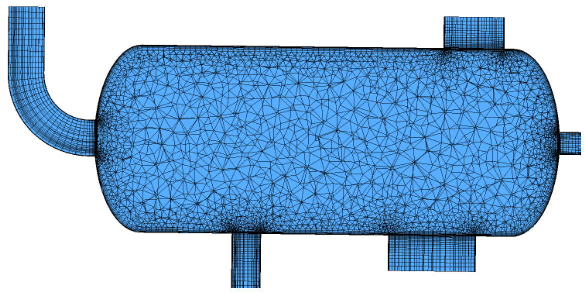


Figure 4: Mesh adopted in the present study.

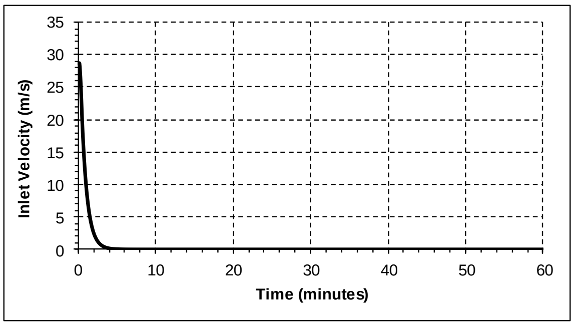


Figure 5: Time varying inlet velocity.

RESULTS

The present section discusses the CFD results obtained for pressurised knock-out drum under heat load from fires. Figure 6 reports the maximum wall temperature of the vessel for all cases as a function of time. The figure shows the increase in wall temperature is more severe for jet fires. In fact, the highest wall temperature is predicted for LP drum under the jet fire impingement.

The advantage of CFD modelling of KO drums engulfed by fires is related to the possibility of obtaining local predictions of temperature and relatively easy identification of critical areas of the vessel that might require passive fire protection. An example of calculated wall temperature distribution is shown in Figure 7.

In the present study, the gas phase is continuously transferred from the drum to the flare. However, if the retention time of the gas is long enough the gas temperature and pressure growth may increase the stress intensity in the vessel wall above the allowable stress, resulting in loss of containment. Figure 8 reports gas temperature obtained for LP drum engulfed in a pool fire. It can be seen that at the beginning of the heat exposure only the gas close to the bottom of the tank is heated to higher temperatures, however the gas temperature rises with time as a results of constant heat load.

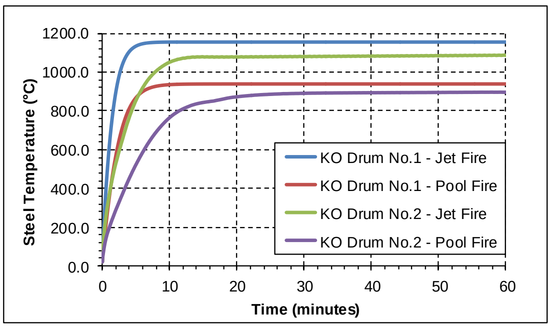
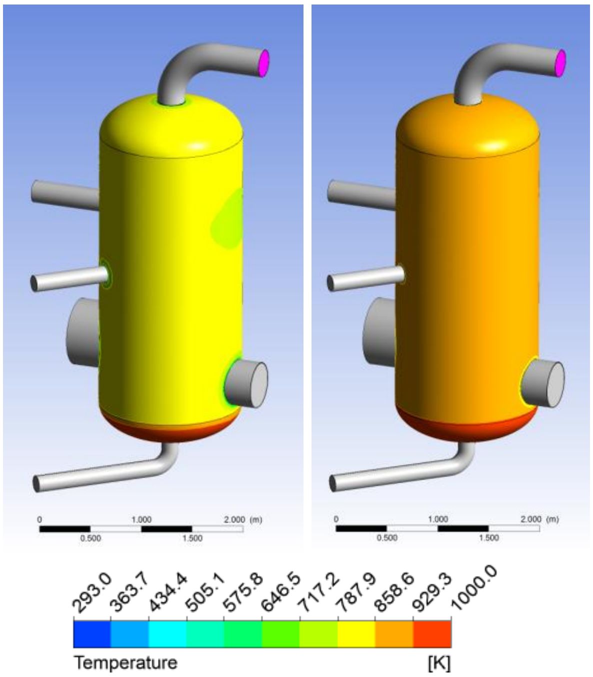
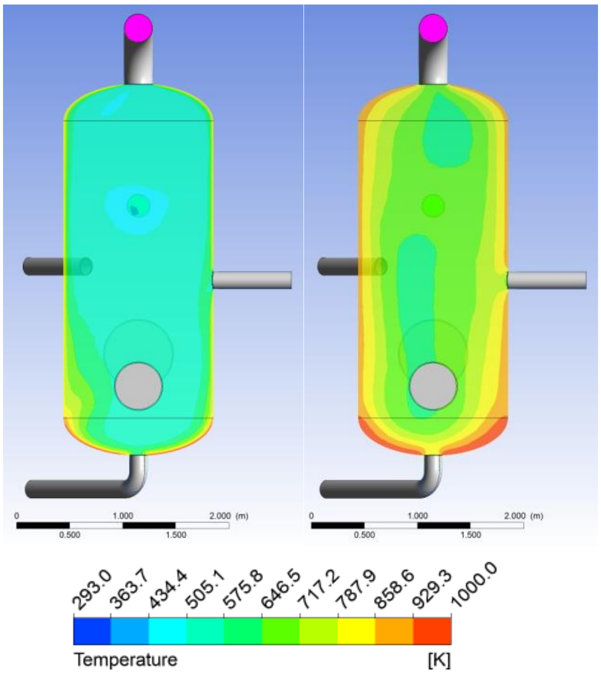


Figure 6: Maximum vessel wall temperature.



After time = 5 minutes After time = 25 minuts

Figure 7: Example of wall temperature for KO Drum No.1 under pool fire.



After time = 5 minutes After time = 25 minuts

Figure 8: Example of gas temperature profiles obtained for KO Drum No.1 under pool fire.

Figure 9 and Figure 10 show charts reporting pressure as a function of time. The figures show that during the emergency shutdown the pressure is decreasing as a result of the gas being sent to the flare.

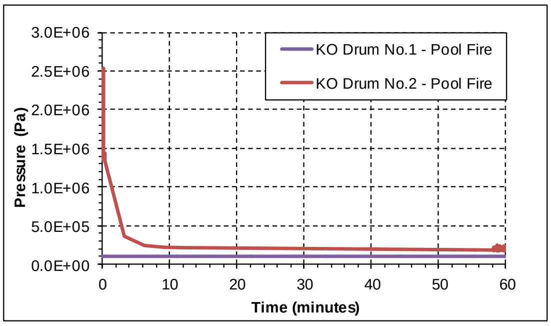


Figure 9: Pressure variation with time for KO drum under pool fire.

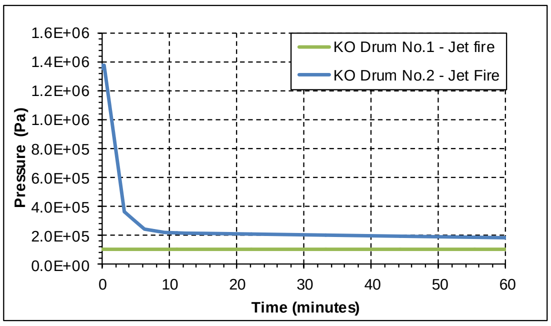


Figure 10: Pressure variation with time for KO drum under jet fire.

To complement the analysis of the KO drum behaviour during the fire exposure, the operating stress and allowable stress have been calculated and shown in Figure 11 and Figure 12 for KO Drum No.1 and Figure 13 and Figure 14 for KO Drum No. 2. To account for the uncertainties in the Ultimate Tensile Strength (UTS) of the material, it is recommended in the industry guidelines (Hekkelstrand and Skulstad, 2004) that it is reduced by a safety factor, *ks* equal to 0.85. It can be seen that the allowable stress limit is dropping very fast during the vessel heat up, approaching the vessel operation stress levels. The calculated operating wall stress does not exceed the allowable stress limit during the simulation time for any of the analysed cases, indicating correct operation of the emergency shutdown system.

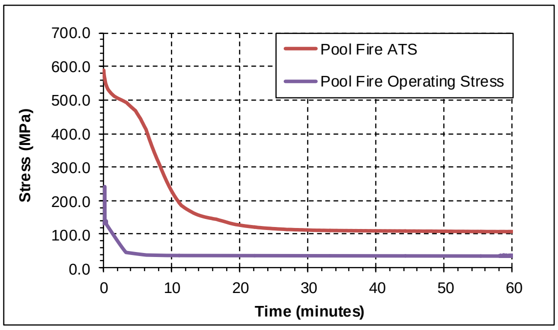


Figure 11: Wall stress variation with time for KO Drum No. 1 under pool fire.

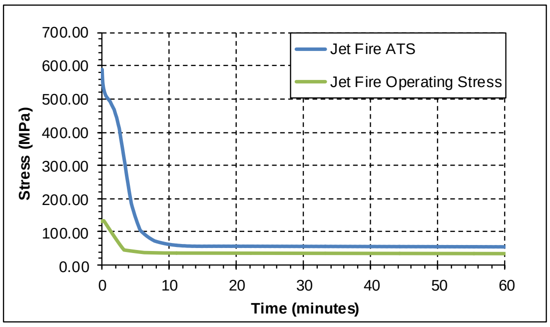


Figure 12: Wall stress variation with time for KO Drum No. 1 under jet fire.

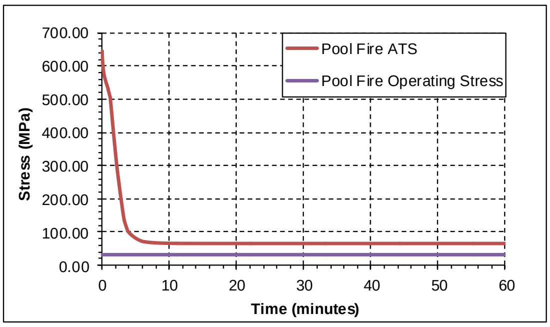


Figure 13: Wall stress variation with time for KO Drum No. 2 under pool fire.

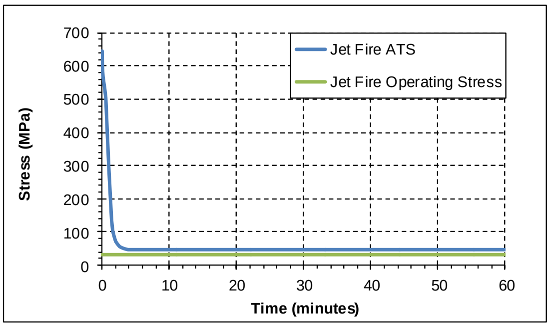


Figure 14: Wall stress variation with time for KO Drum No. 2 under jet fire.

CONCLUSION

In the present study the CFD modelling of pressurised vessel engulfed by fires is presented. The model was developed for pressurised gas, therefore considering only one phase in the domain. The case studies analysed demonstrate the possibilities of the modelling tool in providing detailed information about the behaviour of the KO drum during the fire exposure. A future development will be modelling of the vessel containing gas and liquid phase and take into account evaporation of the liquid phase.

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