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EXTERNAL FLOATING ROOF TANK BOIL OVER: CAUSES, PREVENTION AND MANAGEMENT – A COMPREHENSIVE REVIEW

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ABSTRACT

Boilovers are extremely risky events that have the potential to result in catastrophic human and material losses. The size of a boilover is dictated by the flash point, boiling point, latent heat of vaporization and water cut of a specific crude oil. Tank fires that burn for an extended amount of time are typically associated with boilovers. When a tank catches fire, a heat zone is formed which rapidly converts the water in the tank bottom to steam. This results in an abrupt volumetric expansion of approximately 1700 times more than the original liquid inventory volume, finally erupting as a fireball. Majority of boilover incidents in the oil and gas industry began with a tank fire, which quickly escalated to fireballs and explosions, compounding the initial disaster numerous times. The present studysummarizes the significant researchwork thathave beencarried out in last 3 decades to characterize the boilover phenomenon up to this point. Experiments and theoretical studies carried out by the previous researchers are presented in the currentpaper to understand the boilover characteristics that can be applied to design newer experiments as well as to examine the outcomes with previous experimentsand alsodeliberates an overview of validation models.

KEYWORDS:

Tank fire, Boilover, Volumetric expansion, Fire ball, Validation models,

1. INTRODUCTION

Liquid hydrocarbon storage tanks are key to oil and gas industry supply chain.Over the years, several hazards or incidents have occurred in Tank farms which exposes the vulnerabilities associated with hydrocarbon tank farms viz., Buncefield, UK, 2005[1], Bayamón, PuertoRico, USA, 2009[2]Sitapura, Rajasthan, India, 2009[3], Balongal Refinery, Indonesia incident in March 2021[4],and the recent Cuba's main oil terminal Fire and Boilover in Matanzas[5]. Tank fires are the most typical kinds of catastrophe involving hydrocarbon tanks farmswhich can escalate to further consequences like tank slop over, froth over and boilover events [6].Out of these three escalations, Slop over is referred as in intermittent foaming discharge of liquid hydrocarbon spilling over the tank's side and this is regarded as having least impact of the three due to short duration of fire burning in this process. When the slop over release is continuous it is called Froth over. But, the most significant of the three escalations is the phenomenon known as 'Boilover'. Thisis a sudden discharge of hot hydrocarbons caused by the abrupt vaporization of the tank's water layer [7], [8].

A boilover can develop when a floating roof of tank disintegrates and sinks revealing the content inside tank which ignites[9]. The heat wave generated due to continuous burning descends to tank bottom heating the water beneath and converting it to steam at a rapid expansion ratio. This sudden expansion acts like a cannon and results in an explosion generating a huge fireball and raining burning oil all around the surrounding area of tank, typically between 5-10 times the tanks diameter [10]. The mechanism for boilover and time to boilover are still under study. Several real-time experiments have been conducted to evaluate the boilover phenomenon and establish the basis for boilover events. Some of these notable experiments are listed in Table 3.

2. BOILOVER MECHANISM

A boilover mechanism occurs due to prolonged tank fires when a layer of high boiling point fuel overlays a cold low boiling point water. As the heat generated from burning fuel reaches water, it vaporizes rapidly. As a result, the liquids are thrown out very rapidly leading to a violent explosion and very large fireballs can result[11]. This cycle continues further leading to temperature increase further down the water layer. Over time, this will stir the entire content and will subsequently form a zone at the mixing layer with uniform temperature. The uniform hot zone at the mixing layer is initially a thin layer and it grows in size as the fire continues burning. During this process, the hot zone expands progressively near the tank bottom.The Water at the tank bottom gradually heats up until the boiling point is reached and a large volume may instantaneously get converted into hot steam. Huge quantity of steam can throw the burning fuel high in the air like an explosion. The flying burning oil can spread in the tank surrounding area[12]. Depending on the quantity of fuel and the water content present during the event, the impact area could well be up to ten times the initiating tank diameters.The boilover process is depicted in Figure 1.

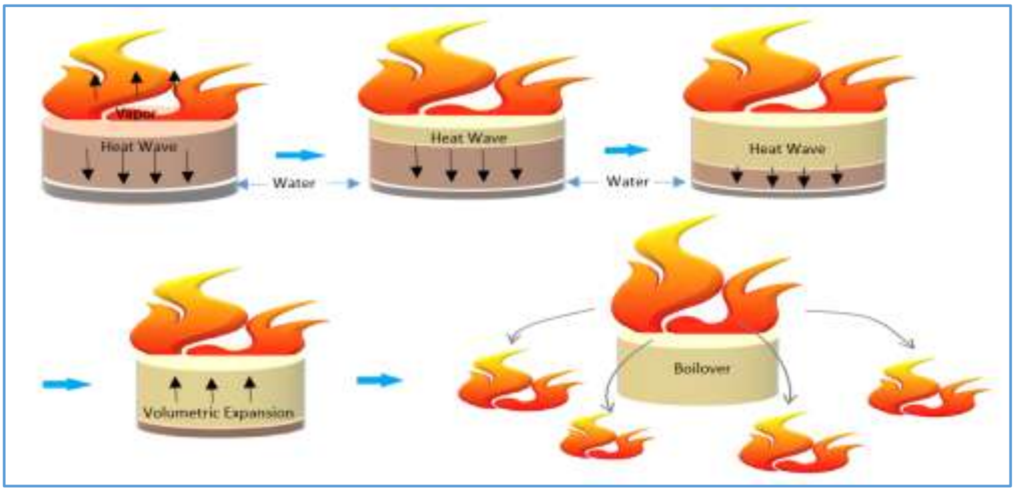


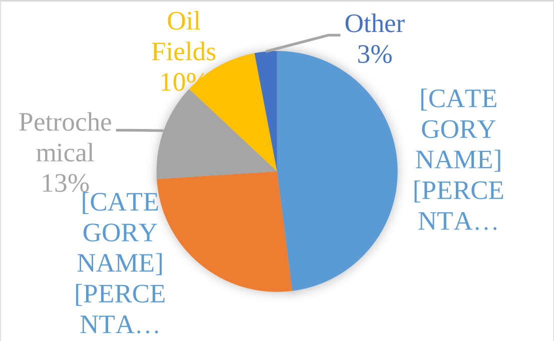
Figure 1: Boilover Mechanism

Although boilovers are more prominent for crude oil storage tanks, but fuels like heavy oils, residual oils, petroleum blends, etc. can also result in boilovers [12]. The observations that were drawn about the boilover mechanism from the experiments conducted by a consortium of 16 oil companies called the Lastfire Project are (i) Any flammable liquid with blend of fuels having different boiling points (e.g. Crude oils, heavy oils, residual oils) and water content at tank bottom can cause boil overs; (ii) Open roof tanks and floating roof tanks are more likely to cause boilovers as compared to fixed roof tanks. At initial stage, the fire starts as a small fire on tank roof like rim-seal fire which escalates to a point when the tank roof disintegrates and sinks allowing fuel content in tank to get exposed (iii) Heat from burning fuel reaches to tank bottom and the water/low boiling point material starts getting heated.

When the water/low boiling point component is heated to its boiling point, there is a sudden volumetric expansion[13]. However, the time to heat the component with lower boiling point can take several hours as the heat travels inside the tank by means of conduction between layers. Due to the abrupt expansion, the burning liquid above is ejected from the tank in an explosion-like fashion. This cycle continues and a single tank can have several such boilovers in the process[14]. The impact area of boilover can be 6 to 10 times the tank diameter depending on the fuel mixture and quantity of low boiling point component present at the tank bottom.

2.1.Storage Tank failure – Common causes and prevention

Storage tanks are critical to any process facility but there are many reasons by which a storage tank can fail. The common causes for tank failure includes design errors, operating beyond safe design parameters, inadequate maintenance, external impact, human errors etc. In 2006, Change and Lin [15]analyzed 242 accidents involving tanksto factor the attributes which leads to a tank failure as shown in Figure 2 (i).The studies on the common causes for tank failures and contribution in overall shows that, 47.9% of these were related to refineries, 26.4% were from pumping stations and oil terminals, 12.8% were related to petrochemical plants, 2.5% were related to the oil fields and rest 10.3% were related toother types of facilitiesincluding power plants, fertilizer plants, gas facilities, etc. They also looked at the failures in terms of the type of tank that was involved in the accidents, presented in Figure 2 (ii). It was found that 55% of all such failures were from floating roof tanks, this was followed by failures in the cone roof tanks with 21% and pressurized tanks with 13% of the total failures. Remaining failures were attributed to internal floating cone roof tanks and refrigerated tanks. Graphical distribution of tank failures assessment is presented below:



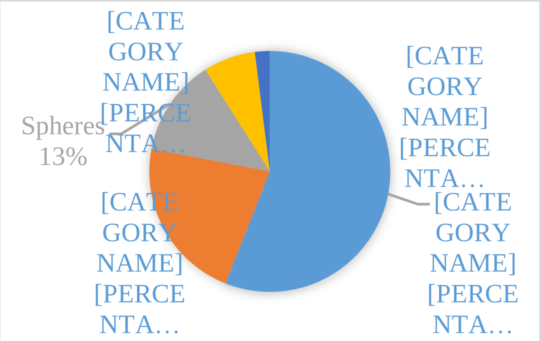


Figure 2: (i) Classification of tank accidents related to the kind of installation [9]; (ii)Classification of tank accidents relative to the tank types [9].

During the study, the causes of tank breakdowns were investigatedand it was found that the most prominent cause was Lightning (33.06%) and this was followed by Maintenance errors and hot work (13.2%). Other factors included Operational error (11.98%), Equipment Failure (7.85%), Sabotage (7.44%), Leaks, static electricity, open flames, natural disasters and runaway reactions together contributed remaining 20% of causes.Figure 3 shows the bar chart representing the cause-contributions related to Tank Failures.

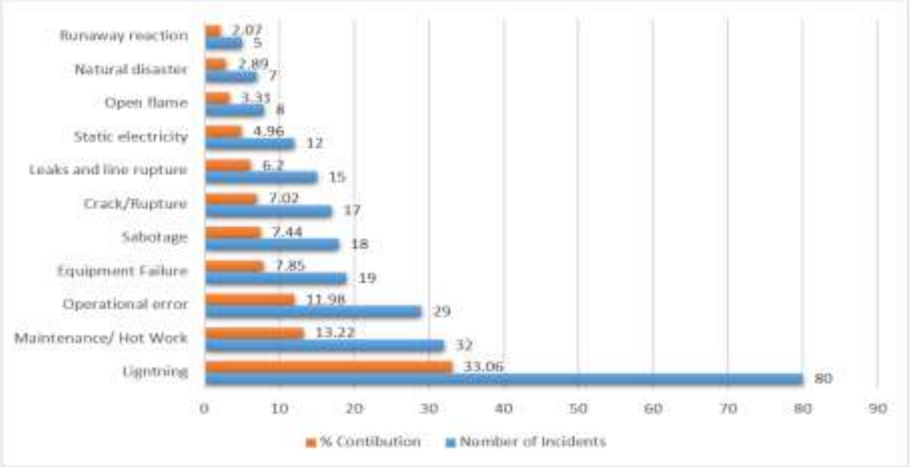


Figure 3: Tank Failure causes and contribution

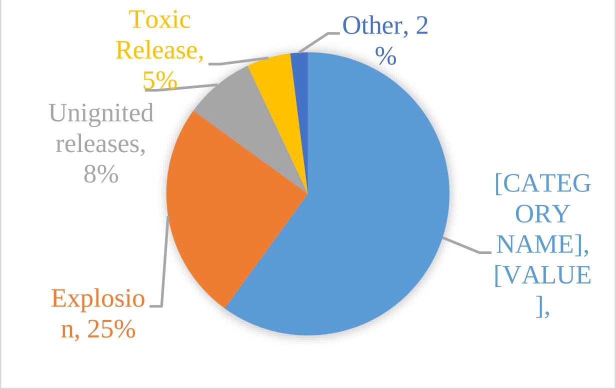


Figure 4: Storage Tanks – Types of accidents

Figure 4 illustrates various types of incidents involving Storage Tanks. The leading type of incident associated with hydrocarbon tanks are Tank Fires (60%) which is evident as we see more cases of tank fires compared to any other type of events. This is followed by Tank explosion and boilovers (13.22%). Almost 8% incidents are unignited releases from leakage and seepages. Toxic releases account for 5% of tank incidents remaining 2% are other incidents such as tank rupture, capsize, deformation etc. The causes of storage tank accident s are analyzed in Table 1. After the assessment of threat, its causes and prevention, it is reasonable to conclude that the majority of storage tank incidents could have been prevented[16].if international standards during engineering, construction, procurement of storage tanks and regular tank inspection and maintenance were implemented.

Table 1: Storage Tank accident causes and prevention

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
Threat: Lightning strike on Tanks		
1. Tank design in non-compliance to IEC, NFPA, OSHA and API guidelines; 2. Inadequate lightening and Surge Protection; 3. No/ Poor earthing of tanks	i) Compliance to Engineering Standards during Tank Design; ii) Lightning protection system installed for storage tanks	ED
4.Tank Rim Seal broken; 5. Liquid HC accumulation on tank roof	i) Tank Inspection as per International Standards; ii) Inspections, tank top surveys	PM
Threat: Accidents due to improper Maintenance		
1.Maintenance procedure not followed. 2. Tanks inspection in non-compliance to API-653 guidelines.	i) Compliance to Engineering Standards	ED
	i) Ultrasonic testing (UT) Inspections and Visual Inspections; ii) Use of certified and approved material; iii) Risk Based Inspections	MP
3. Not using EX-rated equipment as per zone classification	Use of EX-rated equipment based on HAC	ED
	Permit to Work (PTW) system	SOP

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
	Maintenance under supervision	MP
4. Carrying maintenance work/ hot work without proper blanketing	Permit to Work (PTW) system	SOP
	Gas Test prior to tank entry for maintenance	MP
5. Improper grounding during welding; 6. Sparks generated during maintenance; 7. Electrical hazards, short circuits, arcs etc.	i) PTW system; ii) De-energize electrical circuits before work; iii) Pre-Job Inspections; iv) Wear appropriate welding PPE	ESP
Threat: Operator errors		
1.Inadvertent opening / closing of Drain Valves; 2. Standard Operating Procedure (SOP) not followed	i) SOP as per International Guidelines; ii) Method Statements; iii) PTW System	ED SOP
	i)Trained / competent Operators; ii) Work Supervision	SCR
3. Filling hose snaps during loading /unloading	i) SOP; ii) PTW System	SOP
	Visual Inspection and maintenance	MP
4. Inadvertent opening and closing of vents or breather valves during tank loading/ unloading operation	i) SOP as per International Guidelines; ii) Method Statements; iii) PTW System	ED SOP
	i) Trained and competent Operators; ii) Work under Supervision	SCR
5. Oil seepages due to operator errors; 6. Alarms ignored by operators; 7. Untrained, incompetent Operators	i) Trained and competent Operators; ii) Work under Supervision	SCR
Threat: Equipment Failure/ Instrument faults		

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
1.Relief Valve malfunctions / Breather Valve malfunctions; 2. Relief Valve chocked	i) Redundant Instruments; ii) SIL rated system; iii) Fail Safe Design	ED
	ii) Onsite/ Offsite Functional Testing; ii) QA /QC; iii) availability of spares	MP
3. Heater Failure leading to over/under heating	Operating under design condition	SOP
	Regular Maintenance	PM
4. Frozen Valves in cold regions	Visual Inspection and Maintenance	PM
5. Level Indicator malfunction; 6. Failure of thermostat leading to false readings; 7. Oxygen Analyser Failure	i) Quality Control during Procurements; ii) Availability of spares	MP
8. Floating Tank Roof deformation	Compliance to Engineering Std. in tank Design	ED
	i) Tank Inspection as per International Std.; ii) Visual Inspections and tank top surveys	PM
9. Discharge Valve Rupture or failure	i) QA/QC during Procurements; ii) Availability of spares	MP
10. Instrument corrosion issues	Material of Construction	ED
	i) Corrosion inspection; ii) QA/QC during Procurements; iii) Availability of spares	MP
Threat: Sabotage, Arson, theft		
1. Worker strikes leading to operation disruptions; 2. Intentional or unintentional sabotage; 3. Arson; 4. Piping cut during 5. Pilferage or theft	i) Authorized entry to tank farm (access control); ii) Peripheral fencing; iii) CCTV monitoring; iv) Security deployment for onsite monitoring	SA; RC

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
Threat: Piping Rupture/Leak		
1. Piping cracks due to low temperature.	i) Material of Construction; ii) Compliance to Engineering Standards during Tank Design	ED
	i) QA/QC during Procurements / Hydro testing	MP
2. Pump Leak, Pump seal leaks	i) QA/QC during Procurements; ii) Inspection as per International Standards	MP
3. External impacts on piping	Buried / protected piping	ED
	Permit to Work (PTW) System	SOP
4. Gasket leaks, flammable liquids release	Onsite/ Offsite Functional Testing	SOP
5. Piping leaks due to cracks from line vibrations	i) Compliance to Engineering Std.; ii) Transient Analysis, Stress Analysis during design; iii) Vibration Monitoring	ED
	Inspection and Maintenance	PM
Threat: Degradation of Containment		
1. Gutter formation leading to excessive corrosion	i) Regular drainage of water from tank bottom; ii) pH level monitoring for drained water; iii) Internal visual inspection for tanks; iv) Geospatial Settlement Monitoring; v) Biocide injection at tank bottom; vi) Tank bottom internal coating; vii) UT scanning of whole bottom for tanks	MP
2. Sand accumulation on tank bottom		
3. Corrosion due to corrosive material stored and Sulphate Reducing Bacteria (SRB) formation in tanks		

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
	instead of cross banded pattern	
4. Tank plate joints deformation due to poor welding, soldering; 5. Tank outer/ inner Shell Distortion; 6. Poor Fabrication in tanks	i) Compliance to Engineering Standards; ii) Site Acceptance Test	ED
	i) Inspection and Maintenance; ii) Ultrasonic testing (UT) Inspections and Visual Inspections	MP
7. Subsidence of soil beneath tanks	Soil surveys and foundation design	ED
8. Earthquakes and Hurricanes	Earthquake resistance design	ED
Threat: Static Electricity		
1. Rubber Seal Cutting	i) SOP; ii) Inspection and Maintenance	PM
2. Charge generated from piping, filtering, mixing or agitating	Ensure Management of Change (MOC) is followed for any changes in tank content	ED
3. Improper Tank Loading/ unloading operation	Follow API RP 2003 guidelines for tank loading and unloading	SOP
4. Water washing leading to electrostatically charged steam; 5. Loading from top of tank	i) Tank purging with inert gas during maintenance; ii) All conductive parts earthed; iii) Safe filling process with pressure and flow limits; iv) Avoid falling liquid into tanks from height; v) Use of antistatic additives; vi) Continuous gas testing during maintenance;	SOP
6. By bubbling and agitating inert gas blown into the tank, a strong electrostatic charge can be generated.	i) Bonding and grounding for tank conductors; ii) Use of antistatic additives	ED

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
7. Crude Oil Washing (COW)	i) Oxygen levels maintained below 5%; ii) Continuous monitoring of pressure, oxygen level during washing; iii) Avoid use of re-circulated water; iv) Continuous draining	SOP
8. Improper bonding and grounding	i) Ensure bonding is maintained through continuous testing; ii) Avoid falling liquid into tanks from height	SOP
	i) Inspection and maintenance of bonding and grounding; ii) Check bonding and grounding before and during tank loading/ unloading	PM
Threat: Others		
1. Open Flames	Flares located at Safe distance away from tanks	ED
	Avoid Open Flames during tank maintenance	SOP
2. Tank containment Auto-ignition	Use of EX-rated equipment based on HAC	ED
	i) Inspection and maintenance of bonding and grounding; ii) Check bonding and grounding before and during tank loading/ unloading	MP
3. Natural Disasters	Disaster Management Plan available	ED
4. Runaway Reactions	Compliance to Engineering Standards	ED
	i) Ensure MOC process in followed for any changes in tank content; ii) Consider	SOP

CAUSE	THREAT PREVENTION	PREVENTION CATEGORY
	impurity settlement time during tank loading	
ED – Engineering Design; PM - Preventive maintenance; MP - Maintenance Procedure; SOP - Safe Operating Procedure; SA - Security Aspects; RC - Regulatory Compliance; ESP - Electrical Safety Procedures; SCR - Safety Critical Role		

2.2.External Floating Roof Tank Accidents involving Boilover

Boilover are rare phenomena- there are only about 50 boilover recordedincidents in the last 50 years which means it is not frequent like other process failure events, but it is one of the most devastating incidents associated with storage tanks. Incidents like Czechowice-Dziedzicerefinery boilover in 1971 resulting 37 fatalities is the example of the extent of damage and destruction that boilover incidents can cause[17]. Although at present time, there are some techniques availableto prevent the occurrence of such an event, and also there are established fire-fighting capabilities which can counter a boilover but these incidents area huge challenge for the oil and gas industry. Some previous boilover accidents associated with storage tanks are presented in Table 2 to analyze the extent of damage which could result from a Tank Fires and Boilover accidents.

Table 2: Notable historical Tank Incidents

EVENT DETAILS	EVENT DESCRIPTION
22-Nov-02; Port of Mohammedia, Morocco	Rain and floodwater led to small fire which escalated to storage tank farm multiple storage tanks went on fire and finally resulted in tank explosion. Extensive devastation caused, two fatalities and three people missing[18]
19-Jan-04; Skikda, Algeria	Leak got ignited and led to thisLNG Plant explosion. Three liquefaction trains were destroyed by this incident, also escalated tonearby power station, adjacent industrial facilities. 27 causalities, seventy-two injured and seven missing [2]

EVENT DETAILS	EVENT DESCRIPTION
2nd July 2008; Hardin, Tx, USA	Oil tank hit by lightning got ignited. Fire escalated to adjacent tank. No causalities reported [19].
23rd Oct 2009; Cataño, Puerto Rico	Tank overfilling in CPC refinery led to a large vapour cloud formation which got ignited, resulted in a huge explosion. Seventeen tanks exploded; Total 21 tanks were destroyed. Three injuries reported and significant damage to neighboring areas. 200 residential houses impacted [20]
29 -Oct- 2009; Sangane, Jaipur, India	Leak from tank resulted in a jet of Motor spirit. Delayed leak detection resulted in vapor cloud explosion. Fire continued for 11 days; facility completely destroyed. 2 km area impacted. Eleven fatalities reported with several injured [21]
25-Aug-2012; Falcon state, Punto Fijo, Venezuela	Natural gas leak from corroded pipe led to a vapour cloud explosion. Two tanks destroyed. shock waves from explosion lead to damage of over 1600 surrounding buildings. More than 50 causalities reported and 150 people injured. [22]
21-Mar-14; Mendoza, Argentine	Six oil tanks exploded in depot that affected the entire complex. Seventeen people were reportedly injured from the incident[23]
21-May-14; Lukoil, Komi, Russia	A fire outbreak at Usinskoye field oil treatment facility near Usinsk. No causalities reported; one fireman injured [2]
22-Mar-2018; Prague, Czech Republic	A large storage tank exploded during maintenance resulted in fire, tank was destroyed. Six persons were killed and two persons injured[24]
29-Mar-2021; West Java, Indonesia	Huge explosion after a fire incident. Balongan refinery shut down. Suspected cause is lightning. One casualty and fifteen injuries reported. About 1,000 evacuated from neighboring areas[25]
5-Jun-2017; City of Linyi, China	Accident triggered by an explosion of LNG tanker. Several fuel storage tanks were set ablaze. Eight people killed, nine injured, and nearby areas evacuated [26]

EVENT DETAILS	EVENT DESCRIPTION
7-Oct-2018; Goyang, South Korea	A massive fire resulted from a gasoline tank explosion at a storage terminal. Before the tanks could be emptied a second explosion took which brought the flames back. No causalities reported [27]
26-Mar-2021; Jizan, Saudi Arabia,	A projectile hit an oil product distribution terminal in Jizan, Saudi Arabia. The incident was part of missile and drone attacks on Saudi Arabia Oil and Gas facilities by the Houthi militant group active in Yemen. In similar incident Aramco's Riyadh refinery was also attacked by drones in the same month [28]

2.3.Crude Oil Burning rates from Experiments

The characteristics associated with burning of a fuel on water surface is one of prime factor to study boilover[29]. Several experiments conducted in the past were aimed at establishing the burn rates of multicomponent fuels such as crude oils to studythe occurrences thatarise in real-lifesituation. It was established through these tests that the initially the burning rate increases with depth of fuel layer then finally ends up at a constant value[30]. The constant values are directly related to the pool diameter (or diameter of the experimental vessel)[31]. For fuel layer of lower depth, the water absorbs more heat resulting in reduced burning rate[32]. The results obtained from field experiments is presented in Table 3.

Table 3: Findings from Experiments conducted to study Boilover

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1991, Experimental Study of Boilover in Crude Oil Fires (Hiroshi Koseki, et. al)[32]		
1) To investigate the influence of crude oil layer thickness on boil-over; 2) To measure of the residue leftover in pan; 3) To assess the efficacy of burning as a means of removing crude oil spills using above information. Kerosene with lower range of boiling points was used for understanding of the boil over phenomenon.	Experiment was conducted in Fire Research Institute of Japan. Steel pans of various diameters ranging from 0.3 m to 2.7 m were used to heat Arabian light crude oil. Oil layer thickness ranging from 10 mm to 100 mm was used over water. Increase in fuel thickness was directly proportional to the intensity of boilover. With increased of oil layer from 40 mm to 50 mm, an approximately tenfold riseof unburned remanent was observed. Liquid and gas temperatures, burning rates, and radiative heat outputs were presented.	Burning rates, the external radiation values and the regression rates for hot zone were measured. Over total range from 0.3 m to 1 m, hot zone regression rate was 3mm/min, (independent of pan diameter). When the fuel thickness is constant, the percentage increase of the burning rate during boil over was inversely proportional to pan diameter. During Boilover, rate of burning and external radiation rapidly increased. Burning rates considerably increased for initial fuel levels >50 mm, with ten timesrise in the remanent residue for 100 mm oil layer and seven times rise in leftover fuel quantity. Highest burning intensity was observed at the beginning with maximum fuel thickness. A hot zone with a layer of 5-10 mm was required for boilover.
1995, Experimental study for observing premonitory phenomena in boilover using liquid pool fires supported on water (W. C. Fan et. al)[33]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1) Understanding the physical process involved in boilover; 2) To give recommendations for constructing additional practical setup to forecast the characteristics associatd with oil-tank fires. 3) Conduct noise analysis to demonstrate the feasibility and basic concepts of predicting boilover from micro-explosion noise.	The phenomena of boilover from oil-tank fires over water have were studied experimentally. The burning of Liquid fuel on water were studied in three steps: the quasi-steady stage, thepremonitory boilover stage, and the boilover stage. At each boilover stage, burning aspects of fuel, flame structure, and thermal formulation of the oil and water layer were investigated. Water simmer at the oil-water interface and microexplosion noise from combustion, both were thoroughly investigated and analyzed.	1) There are three stages to boilover process: the quasi-steady stage, thepremonitory boilover stage, and the boilover stage; 2) It was found that two types of microexplosion noise that occur inburning process for liquid fuels: microexplosion noise from combustion, which is released during the premonitory boilover stage and the vapour explosion noise emitted during the boilover period. 3) Most common premonitory occurrences of boilover are the combustion micro-explosion. The thermal process, simmering status at the oil and water interface, and during combustion period are all linked to the noise characteristic. Its unique qualities, such as the form of its spectrum, allow it to foresee the development of a boilover event in large crude oiltank fires at far.
2007, Study of Boilover associated with Liquid Pool Fires Supported on Water Experiment Part I: Effects of a Water Sublayer on Pool Fires(M. Arai et. Al)		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
To better understand the impact of the boiling water sublayer on boilover, series of tests were conducted for small-scale pool fires and conclusions were drawn based on their qualitative observations.	A burner system was used that allowed the fuel's burning surface to be fed into the flame, keeping the fuel/water interface fixed to the container's border. A total of 16 fuels were investigated, ten single components and six multicomponent. The researchers tracked the liquid's path using flow visualization. A pan-arc experiment with an ethylbenzene diameter was also shown.	(i) Boilover are associated with all fuelswhich has a higher boiling point compared to water; (ii) As combustion progresses, average flame height and irradiance fall. The temperature of the fuel layer becomes more homogeneous and eventually drops, lowering the mass burning rate; (iii) Pool fires burn faster when a boilover occurs; (iv) Small pool fires require more external radiant heat; (v) A fire-ball-like flame appears following a frenzied boiling and violent foaming. As a result, flame goes out and unburned fuel remains along the fuel/water interface.
2011, Study of Boilover associated with Liquid Pool Fires Supported on Water Experiment Part II: Effects of In-depth Radiation Absorption (M. Arai et. Al)[34]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1. To measure the quantum of radiation that travelled through the fuel layer in relation to the thickness. 2. To estimate the liquid sublayer's in-depth radiation absorption and 3. To create a model for predicting the TWSB(thermal wave signal).	Using seventeen different liquid fuels, a small-scale pool-fire system was built and tested(single and multicomponent). As part of the model's comprehensive implementation, radiation absorption in relation with thethickness of fuel-layer was investigated in toluene and Alberta Sweet crude oil. In-depth absorption causes inverted temperature profiles to form in the liquid, according to the model's predictions. The presence of expected Rayleigh convection observed in fuel layer was establishedby use of holographic interferometry.	One dimensional setup was used for assessing TWSB associated with the burning on a water sublayer usingToluene, Alberta Crude and N-decane(i) The model, which consists of a conduction terminology, an unstable heat terminology, in-depth radiation absorption terminology, can reliably estimate TWSB for 100s derived from small-scale experiments presented.(ii) The effects of in-depth radiation integrated with Rayleigh convection (RC) on TWSB was found substantial, according to model estimates and measurements, while the influence from heat loss through minor wall. (iii) Additional knowledge of the thermal and physical mechanisms that create water vapour bubbles at the fuel-water contact is required to completely comprehend the mechanism of boilover.
2017, Small scale experimental study on the boilover characteristics (Depeng Kong, et. al)[35]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1. To study the occurrence and features of a boilover fire. 2. Changes in bulk burning rates and the partitioning of the burning process are investigated. 3. Using the pseudo steady stages of boilover as examples, demonstrate relationship between flame height and mass burning rate. 4. Based on burning rate and flame expansion, forecast the time of the boilover and the severity of the boilover.	Crude oil was used to conduct several small-scale experiments in this study.An open fire test chamber was used to investigate the effects of crude oil boilover fire. The experiment made use of three crude oil-filled steel trays, each measuring 0.1 meters in diameter, 0.15 meters in diameter, and 0.2 meters in diameter. During the whole combustion process, three critical parameters were taken and recorded: flame height, mass burning rate, and distribution of fuel temperatures. The combustion process has four main stages: growth, quasi-steady state, boil-over and decay, according to the findings.	(i) Boilover burning can be classified into four stages on the basis ofincreasing mass burning rate: namely the growth stage, quasi-steady stage, boilover-decay stage. (ii) At quasi-steady and boilover stages. The mass burning rate rises as the pool dia. grows. (iii) Depending on the initial thickness of the liquid, the constant mass burning rate is lower depending on initial thickness of the fuel. (iv) The pool fire and constant mass burning rate are linked and occur at around the same time. (v) The height of flame is determined by the mass burning rate. (vi) thickness of first fuel layer is proportional to the time it takes for a boilover occurrence(vii) The magnitude of boilover is proportional to the depth of the initial layer of fuel and is proportional to the size of the pool. (viii) The ratio of greatest flame height and constant flame height is related to boilover intensity, but This ratio is substantially lower than the intensity of the boilover.

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
2021, Experimental Study on hazard characteristics and safety distance for small-scale boilover fire (Depeng Kong et. al)[29]		
1. To conduct number of small-scale boilover experiments. 2. to evaluate how the size of the pool affected the outcome., beginning fuel layer thickness, and fuel type on boilover danger features (boilover initiation time, boilover intensity, and boilover fuel splash coverage ratio).	The effect of pool widths, beginning fuel layer thickness, and types of fuel and characteristics of boilover were investigated through a series of tests.The boilover intensity was measured by mass loss rate, increased with the fuel layerdepth but decreased with pool diameter. The thermal mechanism of the boilover occurrence was used to investigate these events.	Following conclusions were drawn: (1) Depending on the development of heat radiation with flame, the small boilover fire's burning process was categorized infour different stages namely, start, stable, boilover, and decay stage. (2) Boilover commencement time, as measured by flame expansion, shows a mild decreasing trend with the pool dia. while being positively related to initial fuel layer depth. (3) Boilover intensity increased with depth of the initial layer of fuel and decreased with pool diameter, as determined by mass loss rate. (4) The ratio of boilover splash coverage to distance is normally distributed exponentially.
2020, Experiment on Hot-zone boilover suppression using floating objects in crude oil tank fires (Tzu-Yan Tseng et. al)[36]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
Using large and small scale testing, the effect of floating perlites on preventing the formation of hot zones and the incidence of hot-zone boilover was explored in this work.	This research examines the mechanism using floating perlites with three layers (0, 1 and 2 layers) for large pool fires in three series of trials. The first series looks on the role of perlites in the establishment of hot zones in crude oil flames with a diameter of 1 metres; The perlites influence on heat release rate (HRR) and combustion efficiency is investigated in the second series; and Perlites' blocking effect on radiation heat feedback is the subject of the third series.	(1) dependingon the initial depth of the fuel, floating items such as perlites might delay or prevent the formation of a hotzone boilover.(2) The perlites act as a nucleation location and a barrier layer for the heat, reducing radiation feedback and resulting in local strong boiling. (3) The presence of perlites and a vapor layer, which is aided in part by heterogeneous nucleation, heat transfer to the fuel and water beneath it is reduced..(4) The difference between the fuel regression rates and heat wave determines how rapidly hot zones form.
2019, Small scale experiment study on burning characteristics for in-situ burning of crude oil on open water (Depeng Kong, et. al)[37]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1. To further research the burning attributes of crude oil in-situ burning on water surface and the dissimilarity from pool fire in a limited vessel, the boundary conditions of in-situ burning of crude on water surface and the dissimilarities from pool fire in a limited vessel with oil were simulated.	In specifically arranged experimental built that could mimic the end-point conditions of a real ISB operation on water, a series of tests were undertaken. A series of tests with various oil pool widths were done to evaluate the burning properties from in-situ burning of crude on water surface of 50 mm, 100 mm, and 150 mm layer depth and three initial oil layer depth of 5 mm, 10 mm, and 15 mm.	1. A fire in an oil pool has been reported to boil over on open water. Because the end-point conditions of pool fire on water surface differ from those of a steel vessel, a pool fire on water surface has a considerably high boilover onset time, anextended boilover extent, and a much higher average flame height of boilover than an pool fire in a steel vessel with the same size water sublayer.2. Burning efficiency is foremost criteria in the ISB method for cleaning up oil spills. In laboratory settings, the first oil layer thickness, which can be characterised as the oil layer's thermal insulation, grows with oil layer initial thickness for certain oil pool diameter.
2020, Small-scale in-situ burning (ISB) experiments with chemically confined crude oils on water (Ulises Rojas-Alva, et. al)[38]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1. To scrutinize the ISB efficacy of two chemically confining crudes and one forth artificial emulsions for water-in-oil. 2.Benchmark tests with physical confinement for comparisons.	In a custom-built laboratory equipment, small-scale tests were conducted to investigate the in-situ burning (ISB) behavior of crudes those are chemically contained using vessels. ThickSlick 6535 and OP40, two commercially available herding agents, were used to hardentwounidentical crude oils namely, Garne and Alaska North Slope (ANS), as well as thecorresponding artificial water-in-oil emulsions.	The following are the most important findings. 1. Due to differences in crude characteristics, the conbustion behavior at the time of ISB revealed dependencies depending on the oil type. 2. No clear dependence on the vessel type on ISB were identified at this modest scale. 3. When compared to physical confinement, herders produce quantitatively lower results 4. The BE levels were lower than most similar research in the past because ofdissimilarities in experimental settings and oil pool size.
2020, Experimental investigation on the burning behaviors of thin-layertransformer oil on a water Layer (Jinlong Zhao et. al)[39]		

OBJECTIVES	EXPERIMENT SUMMARY	CONCLUSIONS FROM EXPERIMENT
1. To investigate the burning behaviour of thin-layer transformer oil with varied initial thicknesses on a water surface.2. To provide an overview of the entire burning process is provided, as well as an examination of the effects of the water layer on different types of burning, like the pace at which fuel is consumed and the height to which the flames rise during combustion.	A variety of transformer oil pool fires were lit, each with a varying thickness of beginning fuel. In the course of testing, scientists looked at burning characteristics such as burn rate, flame height, liquid temperature, and the risk of a boilover.	The following are the key findings: 1. Quick growth, steady burn, short boilover, sustained boilover, and fire degradation are the five distinct phases of this process.2.It's worth noting that the thickness of the initial fuel has an impact on the occurrence of the three intermediate phases(II, III, and IV). 3. The steady rate of burning on aopen water surface is moderately higher than that would be withoutthe lower boiling point for the fuel and water mixture.4. During boilover stage, the flame size, burning rate and radiation increases dramatically when compared to steady burning. 5. Due to the dissolution of the layer where boiling takes place by the ensuing water bubbles, the rate of burning and flame size decline rapidly after the first boilover.

3. Key Observations drawn Experiments

The observations made in controlled laboratory conditions can be utilized for boilover predictions in real-time. This is by validating numerical simulations from data obtained during these experiments. The key findings form experimental data are described as

i. Boilover are associated with all fuels with higher boiling point than water.
ii. Boilovers occurrences can be sub-divided into three stage, namely; the quasi-steady stage, the premonitory boilover stage, and the boilover stage.
iii. With constant fuel thickness burning rate during boil over is inversely proportional to pool diameter.
iv. During a boilover, the flame size, burning rate and radiation increases dramatically when compared to steady burning. However, due to the dissolution of the layer where boiling takes place, the rate of burning and flame size is found to decline rapidly after first boilover occurrence.
v. The noise during burning can be utilized to predict time to boilover.
vi. The intensity of boilover is always higher than average flame height. Boilover intensity increases with depth of the initial layer of fuel and decreased with pool diameter, as determined by mass loss rate.
vii. Ratio between boilover splash coverage to distance is normally distributed exponentially.
viii. Introduction of floating items such as perlites might delay or prevent the formation of a boilover.
ix. For some pool fires, oil layer thickness, which acts as oil layer's thermal insulation, grows with oil layer initial thickness.

4. Numerical Simulation Methods – Consequence Assessment

Calculating time to Boilover

The ability to forecast how long it will take for boilover to occur or the time-to boilover from the first ignition point is crucial.The time to boilover can range from several hours to several days[40]. Predicting the time to boilover is crucial for emergency response and fire-fighting. Several predictive methods have been developed to determine time to boilover. Most of these predictive methods used observations on the experimental setup by studying the hot zone formation below ignited oil and the layer of oil over water[41]. The predictive tools, which were used to compare the time to boilover are briefly described in Table 4.

Table 4: Time-to boilover (min)

S/N	Time-to boilover equation	Ref.	Abbreviation
1.	$t_B = \frac{H_0}{V_{hz}} - k\,(H_o + H_w)$	[31]	t_B= Time to boilover (min) H_o = Fuel Layer thickness initially (m) D = Diameter of the tank (m) V_{hz} = Hot zone velocity (m/min) H_W = Water layer depth (m) k = When the fuel temperature is lower than the ignition temperature, this coefficient is employed, $k = 0$, otherwise $k = 1$
2.	$t_B = -\ 20.5235\ +\ 557.2043\ \frac{H_0}{\sqrt{D}}$		
3.	$t_B = \frac{\rho_l c_p h_{HC} (T_{HW} - T_a)}{Q_f - m\,[\Delta h_v + c_p (T_{0av} - T_a)]}$	[42]	ρ_l = Fuel density at the temperature T_a (kg/m3) C_p= Specific fuel temperature T_a (kJ/kg K) h_{HC} = Initial fuel tank thicknessbefore start of fire (m) m = Rate of Burning (kg/m^2 s) Δh_v= Temperature for start of evaporation Ta (kJ/kg) T_a= Ambient temperature (K) T_{HW} = Temperature of Heat wave in the course of boilover (K) T_{HW} can be derived from fuel-distillation ratio curve

S/N	Time-to boilover equation	Ref.	Abbreviation
			T_{oav}= Boiling point average of fuel (K) Q_f= Heat transfer to fuel from the surface (~ 60 kW/m^2)
4.	$t_B = \frac{\rho}{m_s+v_2\rho}h_o$	[29]	v_2 = Velocity associated with Heat propagation (m/s) · m = The stable mass burning rate (kg/m^2s) ρ = Fuel density (kg/m^3) λ = Ratio between pool dia. And Initial fuel layer thickness
5.	$t_B = 4.95\lambda + 85.87$		
6.	$t_B = 8.18\ Z_f t_{bo} = \frac{Z_f}{V_{hz}}$	[43]	Z_f = Fuel layer thickness initially (mm) V_{hz}= Hot Zone Velocity (m/s)
7.	$t_B = \frac{\rho_1 Z_f C_p(T_{hz}-T_{st})+(0.001\Delta h_c)}{Q_f+\gamma\rho_1 C_p(T_{hz}-T_{st})}$	[9]	ρ_l = Fuel Density at ambient temperature (kg/m^3) z_f = Fuel thickness in the tank initially (m) C_p = Liquid fuel Specific heat at storedtemperature (J/kg K) T_{hz}= Hot Zone temperature before start of boilover (K)

S/N	Time-to boilover equation	Ref.	Abbreviation
8.	$t_B = \frac{Z_f A \rho_L C_p (T_{hz} - T_{st})}{qA - m_v \Delta h_{lh}}$		T_{st} = Liquid fuel Storage temperature (K) Q_f = The pace at which flame heat enters the fuel measured inper surface unit area (W/m^2) y = Regression rate at Fuel surface (m/s) Δh_c = The amount of heat necessary to raise the temperature and evaporate the fuel's more volatile components. A = Tank area (m2) q = The flux rate from Flametofuel (W/m^2) _ Δh_{lh}= Fuel Latent heat of vaporization (J/kg) mv = The rate of Burning (kg/s)

Recommended Method

The approach that was proposed by [31] to forecast boilovers was the simplest one. When additional data can be acquired for the evaluation, the methods proposed by [42] and [9] should be implemented to get higher accuracy for boilover time prediction.

5. Boilover Consequence Assessment models

(a) Fireball Shape

The shape of a fireball is assumed to be spherical as evident from various available photographs and videos of fireballs.

(b) Fireball Duration (s) & Diameter (m)

In the existing models it can be assumed that all Static fireball models derive the maximum fireball diameter instantaneously and secondly the size of fireball do not change during the full duration that fireball exists. Several researchers have derived relation between fireball diameter as a function of the total amount of fuel in the fireball. Table 5 provides fireball duration and diameter as established through research work[44]. As we can see from Table-5 below, the common value for exponential n is 1/3. Similarly, fireball duration equation relates the total duration of fireball to amount of fuel consumed during the fireball.

Table 5: Fireball Duration and Diameter

S/N	Equation	Ref.	Abbreviation
1.	$t = 0.9M^{0.25}$ $D = 8.664\ M^{0.25}\ t_i^{1/3}$ for $0 \le t_i \le t/3$ $D_{max} = 5.8\ M^{1/3}$ for $t/3 < t_i \le t$	[42]	t = Fireball duration (s) M = Fuel mass inside the fireball (kg) D = Fireball Diameter (m) D_{max} = Maximum value for D t_i= Time instance @i
2.	$t_{bleve} = 0.45\ M^{1/3}$ for $M < 30{,}000$kg $t_{bleve} = 2.6\ M^{1/6}$ for $M > 30{,}000$kg $D_{max} = 5.8\ M^{1/3}$	[45]	t_{bleve}= Combustion duration for Fireball (s). M = initial mass of flammable liquid (kg). D_{max}= Maximum fireball diameter
3.	$t = c_{10}.m^{0.26}$ $r_{fb} = c_g.m^{0.325}$	[46]	$c_{10} = 0.852$ s/kg$^{0.26}$ t = Fireball Duration (s) $c_g = 3.24$ m/kg$^{0.325}$ r_{fb} = Radius of Fireball (m) m = Flammable material mass in kg
4.	$t_{fb} = 1.04\ m_{vap}^{0.253}$ $D_{fb} = 5.95\ m_{vap}^{0.328}$	[9]	t_{fb}= Fireball duration(s) D_{fb} = Fireball diameter (m) m_{vap}= Fuel mass consumed in the fireball (kg)

Recommended Method

From various approaches provided for calculating Fireball duration and diameter, [9]proposed the simplest approach However, . The methods proposed by [42] and [45]should be utilized if sufficient data and time is available and it giver better accuracy for Fireball size and duration.

(c) Fireball Height

The height of fireball is estimated to be about 75% of the total fireball diameter. Number of research work have been carried out for predicting the height of a fireball using data from real-life accidents and fireball dynamics. [42], [45], [46]. The lift-off of the fireball is created by the compacting air stream combined with the turbulent volume rise, which evolves into a spherical shape due to the buoyancy caused by an expansion phase.The methods for predicting Fireball Height are provided in Table 6.

Table – 6: Fireball Height

S/N	Equation	Ref.	Abbreviation
1.	$H = 0.5D$ for $0 \le t_i \le t/3$ $H = \frac{3D_{max}t_i}{2t}$ for $t/3 \le t_i \le t$	[42],	H = Fireball height (m) D = Fireball diameter (m) t_i= Time at any instance i
2.	$Z_{fb} = 0.75\ D_{fb}$	[45]	Z_{fb} = Hight to centre of Fireball from the ground (m) D_{fb} = Fireball duration (s)
3.	$H_{bleve} = 2r_{fb}$	[46]	H_{bleve}= Hight to centre of Fireball from the ground (m) r_{fb} = radius (m)

Recommended Method

For the most accurate results, the approach indicated by [42] should be used to calculate the height of the fireball. On the other hand, if the diameter of the fireball has already been determined, procedures [45]or [46]can be used to predict the height of the fireball.

(d) Radiative Power

Radiative power of fireball is measured in kW/m2. It is also known as the surface emissive power (SEP). various methods have been proposed to measure the SEP as detailed in Table 7. It calculates the percentage of total accessible heat energy radiated by the fireball.

Table 7: Radiative Power

S/N	Equation	Ref	Abbreviation
1.	$E_{max} = 0.0133\eta_{rad}\Delta H_c M^{1/12}$ for $0 \leq t_i \leq t/3$ $E_{max} = E_{max}\left[\frac{3}{2} + (1 - \frac{t_i}{t})\right]$ for $t/3 \leq t_i \leq t$ Radiative Fraction = $\eta_{rad}=0.00325P^{0.32}$	[42]	E_{max} = Maximum radiation power in fireball (kW/m^2) η_{rad} = Radiative fraction (is between 0.2 and 0.4) ΔH_c= Fuel - Heat of combustion (kJ/kg) - lower value M = Total mass of fuel in the fireball (kg)
2.	$E = \frac{f_R m_{vap} \Delta h_c}{\pi D_{fb}^2 t_{fb}}$	[45]	t fb= Duration of Fireball (s) f_R = Radiative heat fraction ranging between 0.3 and 0.4 D_{fb} = Fireball Dia. (m)
3.	$SEP = \Delta H m F_s / (4\pi r_{fb}^2 t)$ Where, Net available Heat (j/kg) $\Delta H = \Delta H_c - \Delta H_v - C_p\Delta T$	[46]	F_{view} = Maximum view factor ΔH = Net heat available (J/kg) ΔHC= Flammable material combustion heat at its boiling point (J/kg) ΔHV= Heat of vaporization for flammable

S/N	Equation	Ref	Abbreviation
	Radiative fraction $F_s = 0.00325(Psv)^{0.32}$		material and at its boiling point (J/kg) CP= At const pressure the Specific heat capacity (J/kg K) ΔT = Temperature differential between ambient temperature and flame (K) F_S= Radiative fraction

Recommended Method

The methods proposed by [46] is recommended to calculate Surface Emissive Power (Radiative Power) from fireballs. Methods proposed by [42] and [45] are typical for calculating Radiative Power for Pool fires and can be used in all types of fires.

(e) View Factor

View factor can be defined as the heat radiated between tow surfaces based on the positioning and orientation of two bodies. Another way to denote view factor is configuration factor or angle factor. Equations for determination of view factor are provided in Table 8. We can determine the proportion of radiated heat that will be transported from one surface to another by computing view factor.

Table 8: Calculating View Factor

S/N	Equation	Ref.	Abbreviation
1.	$F_{max} = \frac{4\pi\,(D^2/4)}{4\pi\left[\frac{D}{2}+d\right]^2} = \frac{D^2}{4\left[\frac{D}{2}+d\right]^2}$ $F_{vertical} = F_{max}\cos\alpha$ $F_{horizontal} = F_{max}\sin\alpha$	[42]	F_{max} = Max. view factor that corresponds to a sphere. (D/2+d) = Distance from centre of fireball to the surface receiving the radiation

S/N	Equation	Ref.	Abbreviation
			α= the angle generated by this surface and the perpendicular line to the fireball's radius surface
2.	$F = \frac{H(\frac{D}{2})^2}{(L^2+H^2)^{3/2}}$ for L< D $F = \frac{L(\frac{D}{2})^2}{(L^2+H^2)^{3/2}}$ for L< D	[45]	F= View Factor (dimensionless) H = Fireball center at a height H (m) L = Distance between point on ground beneath H to the target object (m) D = Fireball Diameter (m)
3.	$F_{view} = \left(\frac{r_{fb}}{X}\right)^2$	[46]	F_{view}= The Geometric view factor (dimensionless) r_{fb} = Fireball Radius (m) X = Distance the radiation source to center of the fire ball (m)

Recommended Method

The methods proposed by[42] and [45] considers distance between point on ground beneath fireball center to the target object and fireball Diameter. Both methods can be sued when L and D values are known. For simpler models [46] can be utilized.

(f) Distance between target and fireball, Transmission coefficient

The catastrophes demonstrated the enormous dangers associated with massive open hydrocarbon flames, which can result in several fatalities. The solid flame model and the point source model have both been used to calculate the amount of heat a fireball loads out on a target [44]. The most widely used model is the solid flame modelfor calculating the thermal radiation received by a target situated at a specific distance from a fireball[47]. According to the solid flame concept, the fire is considered as a static grey body or black body that occupies the apparent space of flames and transmitsheat radiation diffusively from fire surface. Further, it entails determining atmosphere's transmissivity, between the fireball and the target's geometric configuration factor, as well as the flame emissive power.As a result, the fireball's shape and magnitude, as well as its position relative to the target, must be considered.The numerical models for measuring the distance between the target object and fireball is given in Table 9. It is critical to be able to appropriately determine the configuration factor when performing hazard or risk assessments on process vessels or storage tanks that contain flammable liquids or gases. [45].

Table 9: Distance between fireball and target

S/N	Equation	Ref.	Abbreviation
1.	$L = (X_2+Z_{fb}^{2})^{0.5}$ $\tau = \frac{2.02}{(P_w R_T)^2}$ Where, $Pw = 1013.25RH \exp(14.4114 - \frac{5328}{T_{atm}})$ $RT = L – 0.5 D_{fb}$	[45]	L = Distance between target and center of fireball(m) X= Distance between target from fireball center at ground level (m) Z_{fb} = Height of fireball center from ground level (m) τ = Transmission coefficient RT = Distance from fireball to the target (m) Pw = Relative humidity of water in percentage
2.	$X = (X_{bleve}^{2}+H_{bleve}^{2})^{0.5}$ $\tau = 2.02 (P_w r)^{-0.09}$ Where, Pw = relative humidity x vap. Pressure at ambient temp.	[46]	H_{bleve}= Fireball centre height from ground level (m) X_{bleve}= Vertical distance from projected fireball center to ground (m) X = Fireball center distance from the object (m)

Recommended Method

Either of the methods proposed by [45] or [46] can be utilized for calculating Distance between fireball and target.

(g) Heat Flux

The rate of heat transfer per unit area in the direction of the heat flow path is known as heat flux. It refers to the overall amount of heat transmitted by conduction, convection or radiation. Heat Flux from the source to a target is related by surface emissive flux, transmissivity and view factor. Table 10 provides the numerical methods to predict Heat Flux at a given target[49].

Table 10: Heat Flux

S/N	Equation	Ref.	Abbreviation
1.	Heat Flux at target (KW/m^2), $E_R = E\ F\ \delta\tau$	[45]	τ_a = Transmissivity coefficient, dimensionless E= Radiative flux emitted at surface (KW/m^2) F = The view factor, dimensionless
2.	Thermal Heat Flux at given dist. (J/m^{2}s), $\Phi = SEP\ F_{view}\tau$	[46]	Φ = Heat flux received at a given distance (J/m^{2}s) F_{view} = Maximum view factor τ = Atmospheric transmissivity

<u>Recommended Method</u>

Either of the methods proposed by [45] or [46] can be utilized for calculating Distance between fireball and target.

6. Results and Discussion

Contributing factors of fire and escalation events in crude oil tanks were studied through research and data collectionof Hydrocarbon storage tank accident records and data base from the past. Field visits to crude oil storage tank depot were made to interpret the real time incident scale for floating roof tanks. The incident investigation reports and recommendations from past on several process engineering, safety, and fire issues were analyzed and consolidated inTable 2. These threats and preventive measures were finalized after considering the perspectives of several safetyprofessionals, process engineers and fire fighters. From literature review it is concluded that, a full-fledged and violentboilover cannot be predicted based on the results of the trials, which are strongly suggestive despite not beingcompletely instrumented. This can be attributed to the fact that unlike other fire scenarios in process industry, boiloversare escalation event and not primary fire events. It was found that boilover can occur even with a small amount ofwater regardless of the technique used in real-time experiments. This implies that draining off water is not an effectiveprocess toprevent a boilover. Also, maintaining empty tank bottoms cannot guarantee boilovers prevention.Boilovers have been considered in a few specialized Quantitative Risk studies, but they are not included in the majorityof risk assessments conducted for oil industries. At present, there is no consequence modeling simulation packageavailable for modeling a boilover, Boilovers occurrences can take a long time ranging from several hours to few days.It is found that the likelihood of a boilover is high enough to warrant consideration in risk assessments and emergencypreparedness for oil storage facilities and business continuation.

7. CONCLUSION

The purpose of this work was to conduct a literature review of the causes of tank fires leading to boilover in externalfloating roof tanks. Tank fire incident data were collected from different sources. The findings of this study canassist specialists and researchers working in this area for design and construction of floating roof tanks. Additionally, the conclusions of this study can help safety and fire professionals prevent and control fires and explosions in crude oil storage tanks. The writers of this research concentrate on the boilover phenomenon., historical instances and studies aimed towards better understanding the boilover problem, the variables that cause it, and boilover prediction utilizingnumerical simulation approaches. The main attributes of boilovervìz. time to boilover, fireball height, diameter and shape, radiative power, view factor were also discussed. In establishing predicting tools for boilover onset, the study substantially supports the simulation approaches presented by many researchers based on real-time trials.

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