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# **ANALYSIS OF THE CRUDE OIL TRANSFER PROCESS AND ITS SAFETY**

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**Keywords**

oil port terminal, oil transfer, operation process, oil spill, pressure upsurge.

**Abstract**

Considering the operation process of oil port terminal the paper focuses on processes related to the cargo movement inside the pipeline system. Technical parameters during all stages of crude oil transfer process are described. Processes of crude oil loading, discharging and internal recirculation are described. Analyzing the crude oil transfer process and its influence on the oil port terminal and operating environment safety, potential threats of oil spill during oil transfer are identified. The accidental events that can cause oil spill in the terminal are in the paper classified with distinction of internal and external as well as root and contributing causes. Finally, the discussion on protection of marine facilities against hydraulic transient pressure surges that can occur during crude transfer is performed. Some recommendations, including safety culture recommendation, are given.

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## **1 INTRODUCTION**

In the Baltic Sea region, there are many oil terminals, which perform transshipment of crude oil and refined petroleum products. Oil terminals are a key element of the petroleum supply logistics of crude oil to refineries and oil transit. The accident in the oil terminal during unloading/loading of tankers may have a long or short-term consequences for the work of the terminal, that may be associated with the socioeconomic losses and environmental costs consequences.

One of important causes of oil spill, is pressure upsurge inside the pipelines as a hydraulic hammer's consequence. These pressure surges can be generated by anything that causes the liquid velocity in a line to change quickly e.g., valve closure, pump trip, Emergency Shut Down (ESD) closure occurs and subsequently packing pressure. In the paper the particular attention is paid to the pressure upsurge inside the pipelines caused by sudden valve closure on the oil reloading installation in port terminal.

## 2 PROCESSES RELATED TO THE CRUDE OIL TRANSFER INSIDE THE PIPELINE SYSTEM

The operation process of the crude oil transfer has an influence on oil terminal safety and environment safety. Considering system composed of a single pipeline we can distinguish following operational states during its operation process:

- $z_1$  – loading cargo with initially slow rate,
- $z_2$  – laboratory tests of exported crude oil,
- $z_3$  – loading cargo with full rate,
- $z_4$  – loading cargo with reduced rate,
- $z_5$  – unloading cargo with initially slow rate,
- $z_6$  – unloading cargo with full rate,
- $z_7$  – unloading cargo with reduced rate,
- $z_8$  – terminal idle mode, there is no transfer of cargo,
- $z_9$  – internal recirculation process.

We describe below all listed operational states of crude oil transfer process specifying technical parameters.

First, a tanker vessel arriving at oil terminal have to be properly moored for cargo handling process and its position has to be continuously controlled during the unloading/loading time. Moreover the ship's and the terminal's representatives have to discuss all technical issues and procedures before the transshipment process may begin.



*Figure 1.* Loading arms for loading/unloading tankers in the oil terminal [6]



To start the crude oil loading process a piping system line up agreement between tank farm and terminal and between vessel and terminal have to be set. Before tanker loading cargo from the oil terminal, the vessel marine loading arms are connected, for crude oil usually 3 or 4 arms are connected (Fig. 1). Next the line is set by choosing dedicated tanks and pumps ashore and by opening or closing relevant line's valves. Marine terminal leaves per one valve closed on each loading arm. After receiving readiness confirmation for starting loading process from the vessel, the last valves on marine loading arms are opened and the process of crude oil loading with initially slow rate begin (state  $z_1$ ). Cargo starts to flow due to gravity, if needed the pumps start to obtain agreed initial rate.

Technical parameters (pinpoint loading parameters) during initial state of crude oil loading include inter alia:

- initial rate (usually abt. 1000 cbm/h),
- pressure 0,1 – 0,5 Mpa,
- temperature max 35°C.

After some laboratory tests of exported crude oil (state  $z_2$ ) and relevant checks on cargo tanks and lines against leakages and aberrations, the terminal receive agreement from the vessel to increase loading rate to agreed maximum rate and the process of loading crude oil with full rate start (state  $z_3$ ). During loading the parameters and infrastructure integrity have to be inspected on a regular basis and tanker receives cargo from the terminal in accordance with agreed parameters (pressure, temperature, rate).

Below there are given technical parameters of crude oil loading process during state  $z_3$ :

- maximum loading rate (usually approx. 10000 cbm/h),
- pressure 0,3 – 0,4 Mpa,
- temperature max 35°C.

Tanker's tanks are loaded usually to their 95-98% capacities. Final stage of each tank's filling is named "topping". On this stage, for oil spill avoidance reasons, loading rate is decreased to approx. 1000 cbm/h (state  $z_4$ ). When one tank is already full other tank goes to open position to let the cargo pass inside, then the full tank is closed. When the last cargo tank is topped up, tanker asks terminal for pump stoppage and valve closure. When this happens, terminal gives confirmation regarding stoppage and the ships manifold valves are closed. When tankers and terminal's valves on loading lines are closed, the terminal goes into idle mode (state  $z_8$ ).

Technical parameters in the final stage of crude oil loading process are:

- topping rate (usually 1000 cbm/h),
- pressure 0,1 – 0,2 Mpa,
- temperature max 35°C.

Parameters of planned cargo operations stoppages (ex. Line Displacement; One Foot Sample) are:

- maximum pressure limits 1 Mpa,
- cargo temperature limits 1 – 35°C.

The process of crude oil discharging is similar. Before starting the unloading process, a piping system line up agreement between tank farm and terminal and an agreement between vessel and terminal have to be set. Then, the vessel marine loading arms are connected; during unloading process for crude oil usually 3 loading arms are connected. The line has to be set by choosing dedicated tanks and pumps on vessel and by opening or closing relevant line's valves. After fixing the readiness notice between vessel, marine terminal and tank farm, the loading process from the tank farm starts. The last valves on marine loading arms are opened and the pumps on vessel start with initial rate (state  $z_5$ ). If there are no aberrations, after obtained from the vessel agreement to increase discharging rate to agreed maximum rate, the unloading cargo starts with full rate (state  $z_6$ ). During discharging the parameters and infrastructure integrity have to be inspected on a regular basis. In a simplistic way, in the final stage the unloading cargo with reduced rate takes place and tanker finishes discharging cargo, by stripping all cargo tanks (state  $z_7$ ). At the end of the transshipment we are dealing with the process of washing tankers from the sediment COW (Crude Oil Washing). Then the pumps stop, relevant valves are closed and the loading arms are disconnected.

Below there are given technical parameters of crude oil discharging process.

During the state  $z_5$ :

- initial rate (usually 1000 cbm/h),
- pressure 0,1 – 0,5 Mpa,
- temperature max 35°C,

During the state  $z_6$ :

- maximum discharging rate (usually approx. 10000 cbm/h),
- pressure 0,3 – 0,5 Mpa,
- temperature max 35°C,

Planned cargo operations stoppages (ex. Line Displacement) in the state  $z_7$ :

- maximum pressure limits 1 Mpa,
- cargo temperature limits 1 – 35°C.

To start the internal recirculation process (state  $z_9$ ) a piping system line up agreement between tank farm and terminal has to be set. Relevant valves are opened or closed; one valve on each tank has to be still closed. After confirming readiness of both sides, i.e. terminal and tank farm,

the valves on dedicated tanks are opened and the recirculation by gravity commences. Next, relevant checks against line integrity and aberrations are made and cargo pumps start. During recirculation the parameters and infrastructure integrity have to be also inspected on a regular basis. When the process of recirculation is finished the pumps stop and the line valves are closed.

Technical parameters of internal recirculation of crude oil are:

- recirculation rate 5000 cbm/h,
- maximum pressure limits 1 Mpa,
- cargo temperature limits 1 – 35°C.

In terminal idle mode, there is no transfer of cargo, however cargo is still inside shore pipelines.

### 3 SCENARIOS AND CLASSIFICATION OF ACCIDENTS DURING CRUDE OIL TRANSFER PROCESS

For this article needs, we divided oil related incidents into three types. These are oil leakage, overflow and most dangerous oil spill. Types of accidents are concerned with the volume of oil spilled and are strictly related to the states of the operational process (Fig. 2):

- oil leakage – minor incident, that may occur during the state  $z_1, z_2, z_5, z_8$  and  $z_9$ ,
- oil overflow – medium incident something between leakage and spill, that may occur during the state  $z_4$  and  $z_7$ ,
- oil spill – major incident, that may occur during the state  $z_3$  and  $z_6$ .

Most of oil related incidents are not very serious and they are connected to leakages group, however serious accidents also occur.

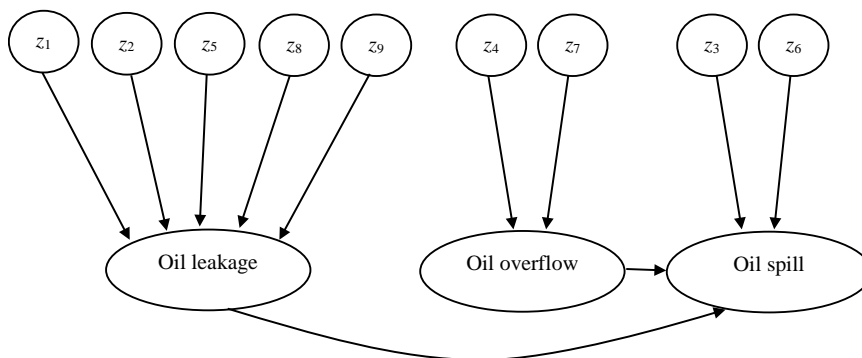


Figure 2. Spill incidences in terms of oil transfer operational states.

The main causes of oil leakage include:

- Disconnecting the ship's manifold from the loading arm during the transshipment due to technical drawbacks or human error (defect) in connecting the arm to the manifold;
- Hydraulic impact due to a sudden valve closure on the ship in case of loading, or a valve closure at the terminal in case of unloading from the ship.

For example, PDVSA, oil company in Venezuela, confirmed that a crude spill occurred from a pipeline, on March 28<sup>th</sup>, 2017. The crude oil leak was a result of a break in the line running from a crude terminal to a single buoy mooring, but it did not affect terminal operations though [9].

Oil overflow may be the result of no stopping loading onto the ship at the right time. Then, the overflowing of tanks and oil spills with P/V valves or mastraiser may occur. As a consequence of inadequate level monitoring the gasoline tank was overfilled in Buncefield, UK, in 2005. The overflow occurred due to the defect of the system that should detect a high level and shut-off the inflow. During that incident more than 250,000 l of gasoline was spilled from an atmospheric pressure storage tank [4]. Oil overflow on shore storage tank can happen also during ship discharging.

Oil spill on board of the ship or on terminal pipeline infrastructure may occur during transfer cargo with full rate, but uncontrolled oil leakage can also result in oil spill and pollution of marine ecosystems. For example, the bunker tanker spilled about 70 tons of fuel at the ATB Vitol oil terminal in Malaysia on August 24, 2016. The spill occurred as the result of a leaking hose during bunkering of the vessel [5].

According to “Oil Tanker Spill Statistics 2016”, oil spills during loading and discharging account for 40% of all small sized spills (below 7 tonnes), classified by operation at time of incident, in 1974-2016. In medium sized spills (7-700 tonnes), 29% occurred during loading and discharging operations. Large spills during oil transfer operations are less frequent and account for 9% of all incident recorded in 1970-2016. Considering these large spills in terms of cause, it can be noticed that 31% are caused by fire or explosion, 26% by equipment failure and 19% by other causes that include heavy weather damage and human error [3].

#### 4 OIL SPILL THREATS RELATED TO CRUDE OIL TRANSFER IN THE TERMINAL

Considering the causes and circumstances of oil spills during oil transfer operations we propose in this paper classification for internal and external reasons.

Internal causes may include:

- technical conditions of oil terminal's infrastructure,
- technical conditions of equipment on tanker vessels,
- human error made by vessel or terminal workers involved in the transshipment process.

Causes associated with technical conditions of oil terminal's infrastructure may include failure of different systems: main oil line, flow line, arms, hoses, hose joints, flange joints, block valves. They can depend on various factors, such as, insufficient maintenance level of pipes, devices, technological appliances and sensors, carried out hot works in sensitive areas. Among human errors we can mention errors made during technological process, maintenance and other activities, abstractedness or measurement errors, errors in setting valves or errors related to insufficient technological knowledge.

Sometimes oil spills during the crude oil transfer can be caused by both human error and mechanical damage. Pressure upsurge inside the pipelines as a hydraulic hammer's consequence can be caused by:

Pump startup – a starting pump can generate high pressures;

Pump power failure – it can cause a pressure upsurge on the suction side and a pressure downsurge on the discharge side;

Valve opening and closing – sudden valve closure changes the velocity quickly and results in a pressure surge. The pressure surge resulting from a sudden valve opening is usually not as excessive. Closing a valve at the downstream end of a pipeline creates a pressure wave that moves back toward the reservoir; improper operation or incorrect design of surge protection devices [2].

Accidents may also occur during the crude oil transfer process due to following external causes:

- technical conditions of oil terminal's infrastructure, associated with abrupt temperature changeover within arrangement: pipeline-liquid-ambient, damage caused by other objects operating in the vicinity of pipelines (ashore/sea), damage to installation and technological appliances due to external forces,
- human factor including terrorism,
- weather condition such as thunderstorm, winds, icing, very high or low temperatures.

Causes of oil spills can be also divided into two other categories. These are generic failures associated with mechanical component of the facility or terminal and specific operating failures prime cause of which is human error. Specific operating failures can include also accidents.

Causes of oil spills in investigation reports are often classified as root causes and contributing causes or factors. Contributing factors can be associated with environment, equipment, safety policy and management, work practice, supervision, training. Contributing factors can be also classified as behavioral, medical, task errors and other. Root causes can be also grouped to immediate causes (unsafe acts, unsafe conditions and miscellaneous causes) and contributing caused (safety management performance, mental and physical condition of worker) [7]. Scheme of different classifications of oil spill causes is presented in Figure 3.

The effects of accidents, which occur at time of oil transfer, can be divided in following categories:

- damage to oil terminal's infrastructure and/or ship,
- short or long term breaks in the functioning of the oil terminal,
- endanger to human health and life,
- environmental pollution that is the most important and financially significant for the polluter.

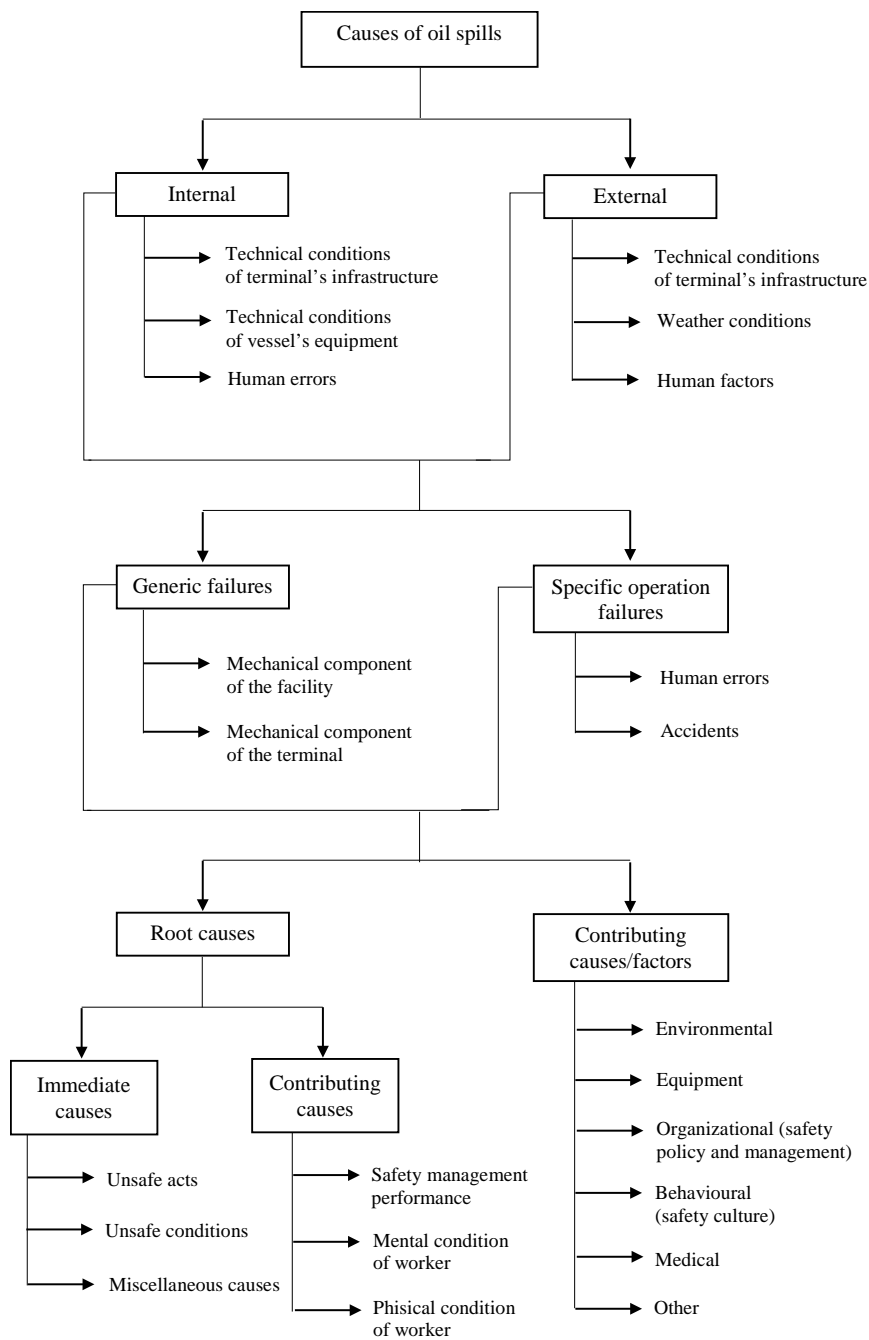


Figure 3. Types of oil spill causes.



## 5 PREVENTION OF PRESSURE UPSURGE INSIDE THE PIPELINES

One of important causes of oil spill, mentioned before, is pressure upsurge inside a pipeline generated by an abrupt change in the rate of flow of liquid in the line i.e. as a hydraulic hammer's consequence. A hydraulic hammer can be caused by the ship's breakaway couplings when the ship disconnects or from an Emergency Shut Down (ESD) valve closure. Both can cause damage to loading hoses or arms, loading buoys, and feed pipework. Sudden valve closure on the reloading installation may occur e.g. on a ship that has all the cargo tanks full. Such situation may take place when there is no space to accept additional volumes of crude oil and there is not able to pass the terminal to stop the transshipment for example by communication errors. In this case, if there is an emergency system to stop handling, not to cause overflow tanks and bottling, the ship decides to close the valve connecting it to the mainland, resulting in the so-called "hammering" resulting in discontinuity of installation and spill [2].

The pressure surge in the pipeline may result in pressure stresses or displacement stresses, and as a consequence it may cause a rupture leading to an extensive oil spill. According to [10], a pressure surge during tanker loading can occur as a result of:

- closure of an automatic shut down valve,
- slamming shut of a shore non-return valve,
- slamming shut of a butterfly type valve,
- rapid closure of a power operated valve.

To protect terminal from the potential damage that can be caused by pressure surges, some pressure relief systems are often used. Excessive surge pressures result from a sudden change in fluid velocity and, without surge relief, they can damage pipes, other piping components, equipment and personnel. These pressure surges can be generated by anything that causes the liquid velocity in a line to change quickly (e.g., valve closure, pump trip, ESD closure occurs) and subsequently packing pressure. The task of crude oil surge-relief system is to protect marine facilities against hydraulic transient pressure surges that can occur during loading and unloading of crude oil to and from vessels. Such system should be able to open very quickly high capacity valves to remove surge pressures from the line and then return to the normal state. Typical tank and pressure vessel systems are required to release pressure without passing large volumes of liquid. These valves are often fully open to allow the entire stream flowing. Closing of these valves should also be done quickly but without causing additional pressure surge. To prevent hydraulic shock and secondary surge during a valve closing, some surge relief systems include damping or slowing systems on valve closing [1].

Investigation reports after oil spills in ports or terminals indicate also a problem of organizational and safety culture. We also analyzed the investigation report on a refinery explosion caused by a raffinate splitter tower overflow.

In order to prevent oil spills accidents following recommendations can be given:

- adequately addressed controlling major hazard risk,

- creating an effective reporting and learning culture after oil spill incidents,
- incorporating human factor considerations in its training, staffing, and work schedule for operations personnel,
- training courses including abnormal and emergency situations and procedures of reaction in such situations,
- proper communication (eliminating problems associated with communication) between operators from the vessel and terminal responsible for oil transfer,
- providing effective safety culture leadership and oversight,
- providing adequate resources to prevent major accidents,
- avoiding excessive cost-cutting.

## **6 CONCLUSIONS**

The paper describes operations during oil transfer process in a terminal and associated with them threats and potential oil spill accidents. Various classifications of causes of oil spill accidents have been proposed in the paper, which may help to identify oil spill threats. Determining the causes of oil spill accidents and identification of potential spill sources can help to avoid or mitigate the effects of potential spills during oil transfer in a terminal in the future. As a continuation of the outlined problem, recommendations and procedures to prevent oil spill accidents will be given. In this scope, training on recognizing and handling abnormal situations during oil transfer will be proposed.

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HAZARD project has 15 full Partners and a total budget of 4.3 million euros. It is executed from spring 2016 till spring 2019, and is part-funded by EU's Baltic Sea Region Interreg programme.

HAZARD aims at mitigating the effects of major accidents and emergencies in major multimodal seaports in the Baltic Sea Region, all handling large volumes of cargo and/or passengers.

Port facilities are often located close to residential areas, thus potentially exposing a large number of people to the consequences of accidents. The HAZARD project deals with these concerns by bringing together Rescue Services, other authorities, logistics operators and established knowledge partners.

HAZARD enables better preparedness, coordination and communication, more efficient actions to reduce damages and loss of life in emergencies, and handling of post-emergency situations by making a number of improvements.

These include harmonization and implementation of safety and security standards and regulations, communication between key actors, the use of risk analysis methods and adoption of new technologies.

See more at: <http://blogit.utu.fi/hazard/>

