Comparative study on the financial implications of a fire fighting intervention on an oil reservoir

I Voicu, E D Juganaru, V F Panaitescu and M Panaitescu
Department of Engineering Sciences in the Mechanical and Environmental field, Electromechanics Faculty, Constanta Maritime University, Constanta, No. 104, Street Mircea cel Batran, Romania

E-mail: dana.mitu@yahoo.com

Abstract. In this paper, the authors determine by calculation, for a storage reservoir design for petroleum products, with a volume of 50,000 m$^3$, the required amount of foam that will be used to extinguish a fire that broke out in it. The reservoir for which the calculation is made is in the park reservoir within S.C. Oil Terminal S.A. Constanta - South Platform. The paper presents the constructive characteristics of the reservoir, for which the calculation is made, the constructive characteristics of the special extinguishing installation, the physico-chemical characteristics of the petroleum substances (gasoline, crude oil), as well as the physico-chemical characteristics of the foaming liquid used for extinguishing the fire. The calculation is made on the basis of the Norm on the fire safety of buildings, Part II Extinguishing Installations Indicative P118/2-2013, as well as on the basis of information from the Methodology for calculating the forces and means necessary for extinguishing fires.

1. Introduction
In this paper, the authors conduct a comparative study on the financial costs of a firefighting operation carried out using the fixed extinguishing system, for two types of petroleum products (crude oil and gasoline), extinguishing the fire with the same type of fire foaming liquid.

The reservoir (50,000 m$^3$) is located inside S.C. Oil Terminal S.A. Constanta - South Platform and the calculation is made on the basis of the Norm on the fire safety of buildings, Part II Extinguishing Installations Indicative P118/2-2013, as well as on the basis of information from the Methodology for calculating the forces and means necessary for extinguishing fires.

2. General information
S.C. Oil Terminal S.A. (figure 1), is a company of national importance that is part of the service sector, in the field of petroleum products. The total area of the company is 221 hectares; it consists mainly of three platforms, which share the activities of receiving, unloading, storage, conditioning and delivery of crude oil and petroleum products, petrochemicals and liquid chemicals for import, export and transit. The three platforms provide a total storage capacity of 1.7 million m$^3$, a turnover of 24 million tons of crude oil per year and about 10 million tons of petroleum products per year [2].
2.1. Technical data on the tank
The tank for which the calculation is made is located in a fleet of 3 (three) tanks (figure 2), each with a volume of 50,000 m³. It is made of a non-combustible material (metal), resistant to corrosion of the product contained. On the outside is inscribed the type of oil product that is stored, as well as its volume. The tank is equipped with a system for determining the level of filling, ventilation valves and flame arrestors. It is tied to the ground belt to avoid the formation of static electricity [4].

From a constructive point of view, this is a cylindrical, vertical tank with an external floating lid, with a diameter of 60.9 m and a height of 17.2 m.

2.2. Stored products
The physico-chemical characteristics of the stored products mean that each tank is designed and built with the purpose of storing a limited number of products.
2.2.1. Physico-chemical characteristics of crude oil, [2]

- boiling temperature: 25 – 525[^C];
- flow temperature: -15 ... + 20[^C];
- density: 800 - 970 [kg / m^3] at a temperature of 15[^C];
- water solubility: insoluble;
- appearance and odor: black-brown viscous liquid, with a characteristic odor of petroleum product;
- vapor density (air = 1): 3-4;
- water content + impurities: max. 1 % of the volume;
- chloride content: max. 0.3 % by weight;
- sulfur content: max. 0.1 - 0.8 % by weight;
- chemical incompatibilities: incompatibilities with oxidants;
- hazardous decomposition products: by oxidative thermal decomposition, it can produce various hydrocarbons and their derivatives as well as partial oxidation products: carbon dioxide, carbon monoxide and sulfur dioxide;
- conditions to be avoided: heating and ignition sources, as well as contact with strong oxidizing agents.

2.2.2. Physico-chemical characteristics of gasoline, [2]

- boiling point:
  - initially 39[^C];
  - after 10 % distillation: 60[^C];
  - after 50 % distillation: 110[^C];
  - after 90 % distillation: 170[^C];
  - final boiling point: 204[^C];
- density: < 760 [kg/m^3];
- water solubility: insoluble;
- appearance and odor: mobile liquid, with a specific odor recognized at more than 10 ppm in the air;
- vapor density (air = 1): 3-4;
- chemical incompatibilities: petrol for cars can react with oxidizing materials such as: peroxide, nitric acid, perchlorate;
- hazardous decomposition products: oxidative thermal decomposition of automotive petrol can produce carbon monoxide;
- conditions to be avoided: heating and ignition sources.

2.3. The foaming liquid

Low-foaming foams are used to extinguish flames in flammable product tanks; in this case the foaming liquid used to extinguish the fire is Fomtec AFFF 6 % which is a concentrated foaming agent (AFFF) with aqueous film formation, containing fluorocarbon surfactants and hydrocarbons mixed with various solvents, preservatives and stabilizers. [5]

The foam forms an aqueous film that removes the oxygen reserve, causing the fire to go out. The expanded foam from which the film is drained forms a stable blanket that inhibits the release of flammable vapors and cools the fuel-soaked surface by extinguishing the fire and preventing it from re-igniting.

The low tension on the surface of the water content of the foam allows the aqueous film which, although heavier than fuel, to float on its surface.

Fomtec AFFF 6 % must be used in a concentration of 6 % in proportionate solution (6 parts concentrate and 94 parts water) willow water, fresh or salt. It can be stored as a premixed solution in drinking water. [5]
Fomtec AFFF 6% is used to extinguish fires of class B fuels, hydrocarbons such as: oil, gasoline, diesel, fuels used in aviation.

The fire performance of Fomtec AFFF 6% (table 1) has been tested and recorded. The foaming properties depend on the equipment used and other variables such as water and ambient temperatures. The average bending is 7:1, the average 1/4 drainage time is 2:30 minutes using the UNI 86 test nozzle.

Table 1. Technical characteristics of Fomtec AFFF 6% foaming liquid. [5]

| Technical specifications               |
|---------------------------------------|
| Appearance                            |
| clear yellowish liquid                |
| Specific gravity at 20 °C             |
| 1,005 +/- 0.01 [g/ml]                 |
| Specific gravity at 20 °C             |
| < 20 [cSt]                            |
| pH                                    |
| 7.5 +/- 1.0                           |
| Freezing temperature                  |
| - 3 [°C]                              |
| Storage temperature                   |
| - 2 [°C]                              |
| Suspended sediment (v/v)              |
| less than de 0.2 [%]                  |
| Surface tension                       |
| 20.0 [dyn/cm]                         |

2.4. Fixed extinguishing system

The fixed foam extinguishing system consists of pipes attached to the tank to support the generators and aeromechanical foam generators.

The fixed cooling system consists of 3 (three) cooling rings, related supply pipes and water spray nozzles.

Fixed foam fire-fighting installations mainly consist of, [1]:

a) water supply installations;
   b) containers for sparkling wines;
   c) foam generators with air blowing;
   d) dispensers;
   e) water and sparkling pumps;
   f) pipes for foaming solution;
   g) foam spills;
   h) commissioning and control devices.

3. Calculation of the required amount of foam

For the determination of the minimum quantity of low-fold foaming solution, \( q \), required for extinguishing the fire, the following relation was used, from the Regulation on fire safety of constructions, Part II, Extinguishing installations, Indicative P118 / 2-2013 ,as follows, [1]:

\[
q = q_{th} \cdot f_c \cdot f_o \cdot f_H
\]  

(1)

where:

- \( q \) – represents the minimum quantity of foaming solution [l/min·m²];
- \( q_{th} \) – nominal quantity of foaming solution [l/min·m²];
- \( f_c \) – correction factor for the foam solution class;
- \( f_o \) – correction factor for the protected object type;
- \( f_H \) – correction factor depending on the distance of the nozzles for external systems;

From a constructive point of view, the tank is cylindrical, vertical, with external floating cover, and it is assumed that at the time of the fire the cover is not dropped, so that the fire manifests at the top, on its entire circumference, the burned area being 191.2 m² (the distance between the lid and the tank jacket being 100 cm).
According to the norm mentioned above, the minimum quantity of foaming solution, \( q \), necessary for extinguishing the fire, is determined with relation (1), where:

- nominal quantity of foaming solution, \( q_{th} = 4.0 \frac{[l/min\cdot m^2]}{} \);
- the correction factor for the foaming solution class is \( f_c = 1.1 \), because the foaming solution's quenching performance class is 1B;
- correction factor for the type of protected object, \( f_o = 3 \) at 20 minutes;
- correction factor depending on the distance of the nozzles for external systems, \( f_H = 1.25 \) for nozzles located at > 5 m from the protected surface;

According to the mentioned norm, the minimum quantity of foaming solution calculated, \( q = 16.5 \frac{l/min\cdot m^2}{}, \) so for an area of 191.2 m\(^2\), results a total amount of foaming solution, \( q_t = 3,154.8 \frac{l/min}{}, \) for the entire protected area.

Given that for floating tank tanks the foam overflows of fixed installations are evenly distributed on the contour of the tank and that the distance between the overflows on the contour must not exceed 26 m and that the circumference of the tank for which the calculation is made is of 191.22 m, it results that 8 (eight) overflows will be mounted on the contour of the tank, each having a flow rate of 400 l/min.

A foam overflow model PX - 5 (figure 3) with a flow rate of 400 l/min was chosen. [6]

![Figure 3. Foam spill PX – 5. [6]](image)

4. The general scenario

Tank no. 38, for which the calculation is made, is located, in a park of 3 (three) tanks, each having the same volume, on the site of S.C. Oil Terminal S.A. - South Platform. In order to carry out the comparative study, two scenarios were imagined, which correspond to each oil product in the tank.

The time elapsed from the outbreak to the observation and announcement, for the industrial objectives with process in three shifts is between 1 and 3 minutes, for the two scenarios the most unfavorable option was chosen.

The free fire development time for both scenarios is 10 minutes.

Extinguishing time, \( T_s \), for both scenarios, is calculated with the following relation, [7]:

\[
T_s = \frac{T_f A t_{60}}{N t_q u} \quad [\text{min}]
\]

where:

- \( T_f \) - duration of an extinguishing operation, for extinguishing combustible liquids in tanks, with fixed installations for the production of foam, \( T_f = 20 \text{ min} \);
- \( A \) - burned area, \( A = 191.2 \text{ m}^2 \);
- extinguishing intensity, for vertical tanks with floating lid, \( i_s = 0.25 \text{ l/s} \cdot \text{m}^2 \);
- number of cutting heads, number of foam spills, \( N_{\text{H}} = 8 \);
- nominal foam flow rate, nominal flow rate of foam overflow \( \dot{Q} = 400 \text{ l/min} \);

Thus, the extinguishing time, \( T_e = 17 \text{ min } 55 \text{ seconds} \).

4.1. Scenario I, “crude oil” product

According to the Methodology for Calculating the Forces and Means for Extinguishing Fires, the mass of burnt crude oil is, \( m = 1.2 \text{ kg/m}^2 \cdot \text{min} \).

It is considered that the density of crude oil in the tank has the value, \( \rho = 0.9 \text{ kg/m}^3 \).

The price of a barrel of crude oil is $ 50 for a barrel, and a barrel has 159 liters and the results are presented in table 2.

### Table 2. Mass, volume and price of crude oil.

| Time [min] | Mass of crude oil [kg/m²·min] | Area [m²] | Mass of crude oil [kg/m²·min] | Volume of crude oil [l/m²·min] | Price of burnt oil [$] |
|------------|-------------------------------|-----------|-------------------------------|-------------------------------|----------------------|
| 1          | 1.2                           | 191.2     | 229.44                        | 254.93                        | 80.17                |
| 2          | 2.4                           | 191.2     | 458.88                        | 509.86                        | 160.34               |
| 3          | 3.6                           | 191.2     | 688.32                        | 764.80                        | 240.51               |
| 4          | 4.8                           | 191.2     | 917.76                        | 1,019.73                      | 320.68               |
| 5          | 6                             | 191.2     | 1,147.20                      | 1,274.66                      | 400.85               |
| 6          | 7.2                           | 191.2     | 1,376.64                      | 1,529.60                      | 481.02               |
| 7          | 8.4                           | 191.2     | 1,606.08                      | 1,784.53                      | 561.20               |
| 8          | 9.6                           | 191.2     | 1,835.52                      | 2,039.46                      | 641.37               |
| 9          | 10.8                          | 191.2     | 2,064.96                      | 2,294.40                      | 721.54               |
| 10         | 12                            | 191.2     | 2,294.40                      | 2,549.33                      | 801.71               |
| 11         | 13.2                          | 191.2     | 2,523.84                      | 2,804.26                      | 881.88               |
| 12         | 14.4                          | 191.2     | 2,753.28                      | 3,059.20                      | 962.05               |
| **13**     | **15.6**                      | **191.2** | **2,982.72**                  | **3,314.13**                  | **1,042.22**         |
| 14         | 14.7                          | 180.5     | 3,305.33                      | 3,672.59                      | 1,154.95             |
| 15         | 13.8                          | 169.9     | 3,609.49                      | 4,010.54                      | 1,261.23             |
| 16         | 13                            | 159.2     | 3,895.19                      | 4,327.98                      | 1,361.06             |
| 17         | 12.1                          | 148.6     | 4,162.42                      | 4,624.91                      | 1,454.44             |
| 18         | 11.2                          | 137.9     | 4,411.20                      | 4,901.33                      | 1,541.37             |
| 19         | 10.4                          | 127.3     | 4,641.51                      | 5,157.24                      | 1,621.85             |
| 20         | 9.5                           | 116.6     | 4,853.37                      | 5,392.64                      | 1,695.87             |
| 21         | 8.6                           | 106       | 5,046.77                      | 5,607.52                      | 1,763.45             |
| 22         | 7.8                           | 95.3      | 5,221.70                      | 5,801.89                      | 1,824.58             |
| 23         | 6.9                           | 84.7      | 5,378.18                      | 5,975.76                      | 1,879.25             |
| 24         | 6                             | 74        | 5,516.20                      | 6,129.11                      | 1,927.48             |
| 25         | 5.2                           | 63.4      | 5,635.75                      | 6,261.95                      | 1,969.25             |
| 26         | 4.3                           | 52.7      | 5,736.85                      | 6,374.28                      | 2,004.58             |
| 27         | 3.4                           | 42.1      | 5,819.49                      | 6,466.10                      | 2,033.46             |
| 28         | 2.6                           | 31.4      | 5,883.67                      | 6,537.41                      | 2,055.88             |
| 29         | 1.7                           | 20.8      | 5,929.38                      | 6,588.20                      | 2,071.85             |
| 30         | 0.8                           | 10.1      | 5,956.64                      | 6,618.49                      | 2,081.38             |
| **31**     | **-**                         | **-**     | **5,956.64**                  | **6,618.49**                  | **2,081.38**         |
The results obtained show that in the first 13 minutes, until the fixed fire extinguishing installation, with which the tank is equipped, comes into operation, the volume burned is 3,314.13 liters, the equivalent of $1,042.22. 18 minutes after the commissioning of the fixed extinguishing system, the fire is extinguished, the volume burned during this time being 3,304.36 liters, the equivalent of $1,039.15.

The total volume burned is 6,618.49 liters, the equivalent of $2,081.38.

4.2. Scenario II, petroleum product “gasoline”

According to the Methodology for Calculating the Forces and Means for Extinguishing Fires, the mass of burned gasoline is, \( m = 2.9 \text{ kg/m}^2\cdot\text{min} \).

It is considered that the density of gasoline in the tank has the value, \( \rho = 0.75 \text{ kg/m}^3 \).

The average price of gasoline is considered to be $1.222 per liter and the results are presented in table 3.

| Time [min] | Mass of gasoline [kg/m²·min] | Area [m²] | Mass of gasoline [kg/m²·min] | Volume of gasoline [l/m²·min] | Price of burnt gasoline [$] |
|-----------|-------------------------------|-----------|-------------------------------|-------------------------------|---------------------------|
| 1         | 2.9                           | 191.2     | 554.48                        | 739.30                        | 903.43                    |
| 2         | 5.8                           | 191.2     | 1,108.96                      | 1,478.61                      | 1,806.86                  |
| 3         | 8.7                           | 191.2     | 1,663.44                      | 2,217.92                      | 2,710.29                  |
| 4         | 11.6                          | 191.2     | 2,217.92                      | 2,957.22                      | 3,613.73                  |
| 5         | 14.5                          | 191.2     | 2,772.4                       | 3,696.53                      | 4,517.16                  |
| 6         | 17.4                          | 191.2     | 3,326.88                      | 4,435.84                      | 5,420.59                  |
| 7         | 20.3                          | 191.2     | 3,881.36                      | 5,175.14                      | 6,324.02                  |
| 8         | 23.2                          | 191.2     | 4,435.84                      | 5,914.45                      | 7,227.46                  |
| 9         | 26.1                          | 191.2     | 4,990.32                      | 6,653.76                      | 8,130.89                  |
| 10        | 29                            | 191.2     | 5,544.8                       | 7,393.06                      | 9,034.32                  |
| 11        | 31.9                          | 191.2     | 6,099.28                      | 8,132.37                      | 9,937.76                  |
| 12        | 34.8                          | 191.2     | 6,653.76                      | 8,871.68                      | 10,841.19                 |
| 13        | 37.7                          | 191.2     | 7,208.24                      | 9,610.98                      | 11,744.62                 |
| 14        | 35.6                          | 180.5     | 7,987.89                      | 10,650.52                     | 13,014.94                 |
| 15        | 33.5                          | 169.9     | 8,722.94                      | 11,630.58                     | 14,212.57                 |
| 16        | 31.4                          | 159.2     | 9,413.37                      | 12,551.16                     | 15,337.52                 |
| 17        | 29.3                          | 148.6     | 10,059.2                      | 13,412.26                     | 16,389.78                 |
| 18        | 27.2                          | 137.9     | 10,660.4                      | 14,213.87                     | 17,369.35                 |
| 19        | 25.1                          | 127.3     | 11,217                        | 14,956.00                     | 18,276.23                 |
| 20        | 23                            | 116.6     | 11,728.99                     | 15,638.65                     | 19,110.43                 |
| 21        | 20.9                          | 106       | 12,196.37                     | 16,261.82                     | 19,871.94                 |
| 22        | 18.8                          | 95.3      | 12,619.13                     | 16,825.50                     | 20,560.76                 |
| 23        | 16.7                          | 84.7      | 12,997.28                     | 17,329.70                     | 21,176.90                 |
| 24        | 14.6                          | 74        | 13,330.82                     | 17,774.42                     | 21,720.35                 |
| 25        | 12.5                          | 63.4      | 13,619.75                     | 18,159.66                     | 22,191.11                 |
| 26        | 10.4                          | 52.7      | 13,864.07                     | 18,485.42                     | 22,589.18                 |
| 27        | 8.3                           | 42.1      | 14,063.77                     | 18,751.69                     | 22,914.57                 |
| 28        | 6.2                           | 31.45     | 14,218.87                     | 18,958.48                     | 23,167.27                 |
| 29        | 4.1                           | 20.8      | 14,329.35                     | 19,105.79                     | 23,347.28                 |
| 30        | 2                             | 10.1      | 14,395.22                     | 19,193.62                     | 23,454.61                 |
| 31        | -                             | -         | 14,395.22                     | 19,193.62                     | 23,454.61                 |
The results show that in the first 13 minutes, until the fixed fire extinguishing system with which the tank is equipped, comes into operation, the burned volume is 9,610.98 liters, the equivalent of $11,744.62. And in 18 minutes after the commissioning of the fixed extinguishing system, the fire is extinguished; the volume burned during this time, being 9,582.64 liters, the equivalent of $11,709.98.

The total volume burned is 19,193.62 liters, the equivalent of $23,454.61.

5. Conclusions
According to the calculations made in the previous chapter, it results that the burnt crude oil has a volume of 6,618.49 liters, the equivalent of $2,081.38, and the burnt gasoline has a volume of 19,193.62 liters, the equivalent of $23,454.61.

To extinguish the fire produced, in both variants, the fixed extinguishing system uses a volume of 3,407.18 l for 18 min - sparkling liquid, the sparkling liquid having a price of $10,304.64.

It is observed that the price of burnt gasoline in 30 minutes is double the price of the sparkling liquid, and the price of crude oil is 5 (five) times lower than the price of the sparkling liquid.

But in the end, the financial value of firefighting operations is not so important because the effects of an uncontrolled burning of petroleum products can have irreversible effects on the fauna, flora and health of the immediate population. By combustion, a multitude of pollutants are released into the atmosphere, such as: nitrogen oxides, sulfur oxides, various products of incomplete combustion and solid particles in suspension.

6. References
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