ANALYSIS METHOD OF FIRE HAZARD OF FUEL OIL AND DIESEL OIL SYSTEMS IN SEA VESSELS ENGINE ROOMS

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Abstract

This paper presents theoretical model for fire hazard analysis in fuel oil and diesel oil systems in engine rooms. The model is based on the probabilistic calculus and covers a 'fire tree' and formulas to calculate fire frequencies. Preliminary assumptions and initial frequencies calculation parameters have been adopted on the basis of statistical data.

Fire sources identification involves selection of definite number of system elements, the damages of which may result in flammable liquid leakage and self-ignition. Such elements as, inter alia, pipelines joints and sections, valves and system equipment, are taken into consideration.

With the use of the model, it is possible to calculate individual fire frequencies for individual self-ignition sources, and synthetic risk in systems and specific rooms. The calculations account for a possibility of introducing construction changes of safety equipment that influence the risk, e.g. number of detectors, fire extinguishing nozzles (fire extinguishers), leakege protection, etc. The method can be used to analyze the influence of fire construction protection on the risk (so-called 'risk sensitivity' testing) in the phase of creating requirements. However, for its quantitative verification statistical data concerning engine rooms fire hazard is essential. It may be assumed that creating an adequate calculation model for the purpose of a general fire hazard analysis of an engine room (of a vessel) is a significantly bigger challenge.

Keywords: *fire hazard, safety of sea vessel, safety of vessels engine rooms*

1. Introduction

Fire hazard concerning engine rooms of sea vessels, which is expressed with a frequency rate, is calculated as an average of 1/1000 ship years, with the frequency of fuel oil and diesel oil systems fires caused by self-ignition at 60% [3, 4]. The research [3, 4] shows that the main cause of self-ignition are vibration-based damages of system elements. In order to prevent fires, an international team of specialists from the Committee for Fire Protection of the International Maritime Organization (IMO) have drawn up new requirements, which have been verified with a theoretical method of analysis of fire hazard of fuel oil and diesel oil systems.

2. Preliminary assumptions

Fire hazard theoretical analysis concerns fires caused by self-ignition of flammable liquids in fuel oil and diesel oil systems. It involves the following issues:

- identification and classification of potential fire sources (liquid leakage and ignition),
- adoption of fire occurrence tree,
- calculations of relative frequencies (probability) of various types of fires.

3. Identification and classification of fire sources

Fire sources identification involves selection of definite number of system elements, the damages of which may result in flammable liquid leakage and self-ignition. Such elements as, inter alia, pipelines joints and sections, valves and system equipment, are taken into consideration.

The following constitute systems (of machines) that may contain potential leakage sources:

- engine injection systems,
- supply pumps, filters and fuel oil and diesel oil boilers,
- fuel oil and diesel oil centrifuges,
- boiler burners,
- inert gas generators,
- waste oil incinerating plants, and
- transport pipelines.

Sources of leakages are regarded as fire sources when they are at a specific (established) distance from the source of ignition.

The following are potential sources of ignition:

- outlet exhaust pipes,
- turbo compressors,
- electrical equipment,
- boilers and incinerating plants,
- heating oil boilers,
- starters,
- other (e.g. hot works area).

Potential fire sources are classified and marked according to factors (construction and operational parameters) that influence occurrence and development of fire (hazard). Basic hazard factors are as follows:

- type of a system and its operation outline,
- localizing fire source in a system,
- parameters and properties of flammable liquids,
- localizing fire sources in an engine room,
- geometry of system elements (inter alia, flow section),
- characteristics of typical ignition sources (inter alia, temperature, distance to the leakage source and its shape),
- characteristics of fire protection system (inter alia, liquid dispersion reduction, a number of proper fire detectors, equipment and nozzles of fire-extinguishing system).

Identification of fire sources is based on statistical data concerning real fires, i.e. frequency and causes of their occurrence. To determine the overall number of potential fire sources, a condition that the estimated and real relative fire frequencies are equal (or similar) is taken into consideration.

4. Adoption of a fire event tree

To adopt a fire event tree, the following original scenario (sequence of events is assumed:

1. leakage of flammable liquid,
2. flammable mixture and ignition source interaction,
3. fire break out (ignition),
4. fire detection (detector activation),
5. preliminary fire fighting (without cutting off liquid supply),
6. power cut-off,
7. full scale fire fighting (use of fixed fire-extinguishing system).

Depending on which possibility of an event has been chosen (yes or no), the original sequence is expanded as secondary events branches, the time limit of which is a fire of various scales (or no fire). Fig. 1 presents a model tree of occurrence and development (course of events) of a fire.

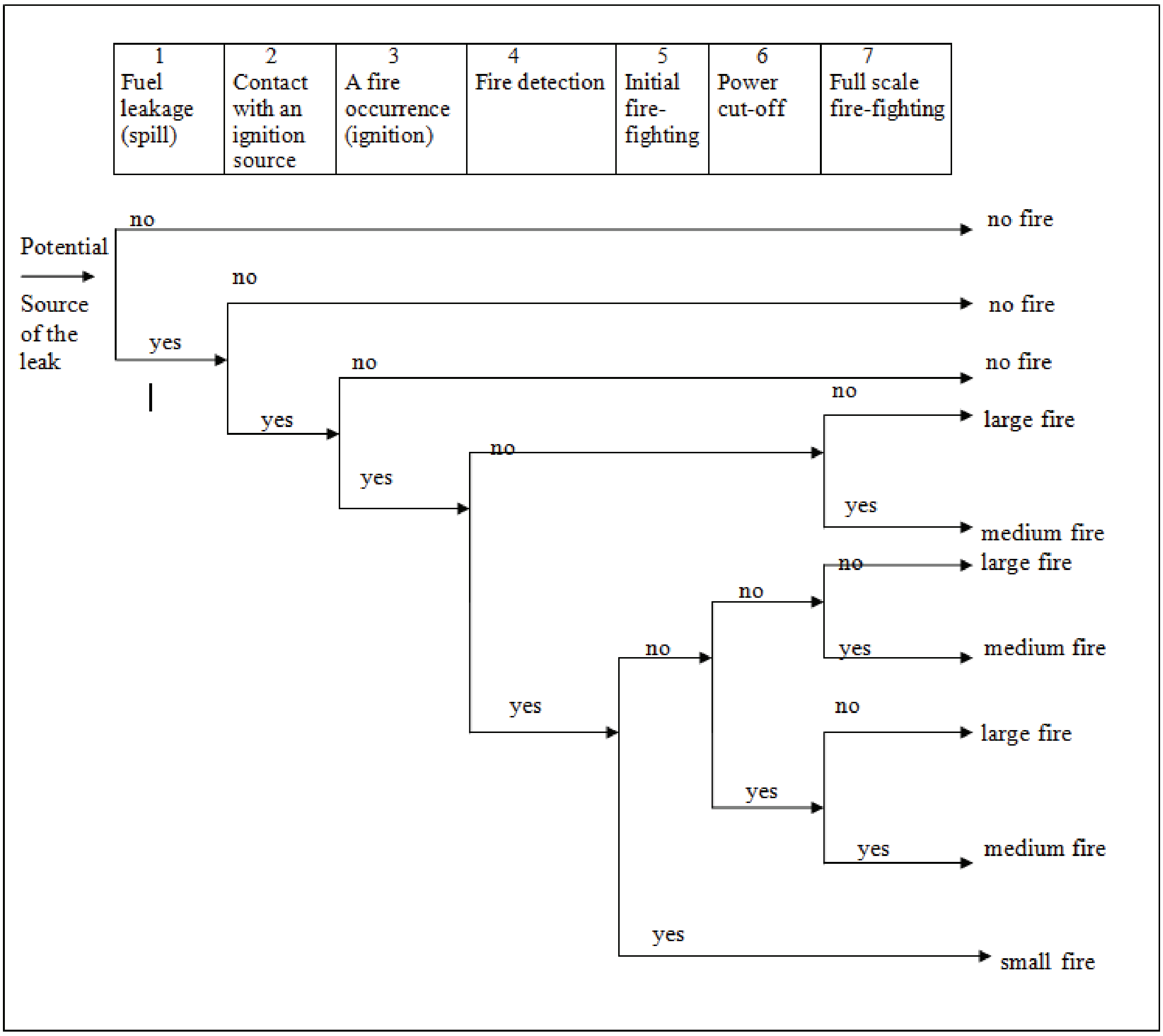

Fig. 1. A tree of occurrence and development of a fire

5. Frequency of flammable liquids leakages

Frequency of flammable liquid leakages in vessel installations is determined on the basis of probability of damages occurrence in elements which constitute a potential leakage source [4]. Adopted damage frequency values per year (7 200 h) are presented in Tab. 1.

Tab. 1. Frequency of damages

Construction elements	Frequency of damages	
	1/hour	1/year
Joints Valves Accessories	0.57×10^{-6} 1.52×10^{-7} $0.25 \times {}^{10\text{-}7}$	4.10×10^{-3} 1.09×10^{-3} 1.80×10^{-4}

6. Probability of sprayed liquid interaction with an ignition source

Probability of sprayed flammable liquid (leakage) interaction with an ignition source is calculated with the following formula:

$$Pit = \frac{R\max - \lambda}{R\max} \cdot \frac{2\phi + \omega}{360} \cdot 0.5 \cdot f, \tag{1}$$

where:
*R*max - spray reach,
λ - reduced distance between a leakage point and a source of ignition,
λ = 1.5 - for the real distance L<3 m,
λ = 4.5 - for L>3 m,
ϕ - liquid spray cone angle in horizontal plane (Illustration 2),
ϕ - 40 - for flanged joints,
ϕ = 15 - for bolted joints,
f - coefficient of splash protection,
f = 0.0625 - 0.125 - depending on L,
ω - coefficient of shape (2D) projection of ignition source onto a plane perpendicular to the leakage direction,
ω = 60 - 120 - for engines and boilers,
ω = 30 - 60 - for other ignition sources depending on L,

The spray reach has been calculated with the following formula:

$$R\max = \frac{Vo^2}{2g} \cdot \sin 2\theta, \tag{2}$$

where:
Vo - liquid leakage velocity,
2θ - spray cone angle in horizontal plane,
g - gravitational acceleration.

7. Probability of ignition

Probability of ignition during an interaction between liquid splashed during leaking and the source of ignition, is calculated with the following formula:

$$\text{Pi} = \text{pit} \cdot \text{Ct}, \tag{3}$$

where:
C_t - coefficient taking into consideration a temperature of the liquid,
Ct = 0.4 - 1 - at 80 - 130ºC,
p_{it} - coefficient taking into consideration the distance between a source of leakage and a source of ignition,
$p_{it} = 1.0 \cdot 10^{-2}$ - for engines and boilers, and
$p_{it} = 1.0 \cdot 10^{-3}$ - for other sources of fire for L<3 m,
$p_{it} = 5.0 \cdot 10^{-3}$ - for engines and boilers, and
$p_{it} = 5.0 \cdot 10^{-4}$ - for other sources of ignition for L>3 m.

8. Probability of fire detection

Probability of fire detection is calculated with the following formulas:

$$\text{Pd} = 1 - (1 - \text{pdet}), \text{ for nd} \geq 1, \tag{4}$$

$$\text{Pd} = \text{pdet} \cdot 0.5, \text{ for nd} = 0, \tag{5}$$

where:
p_{det} - coefficient of fire detection (0.8),
n_d - a number of fire detectors.

9. Probability of fire extinguishment

Probability of fire extinguishment with the use of proper equipment (fire-extinguisher) is calculated with the following formulas:

$$Pg = Pgi\ k, \tag{6}$$

$$P_{gi} = 1 - [1 - \exp\{-(\frac{E4}{b})^a\}]^{ng}, \tag{7}$$

where:
E4 - radiant heat at a distance of 4 m from the centre of a flame [kJ/m^2 · h.],
a = 3,4 b = 16.33 x 10^3 – fixed coefficients,
ng - a number of fire-extinguishers,
k - operator's safety coefficient.

Effective range of fire-extinguisher (4 m) and operator's safety coefficient (k = 0.99 – for $E4$ < 1000, k = 0.1 – for $E4$ < 5000) are taken into consideration for calculations.

Probability of fire extinguishment with the use of fire foam from fixed foam system nozzles is calculated with the following formula:

$$P_f = 1 - [1 - \exp\{-(\frac{E10}{b})^a\}]^{nd}, \tag{8}$$

where:
E10 - radiant heat at a distance of 10 m from the centre of a flame,
nd - a number of nozzles.

Illustration 2 presents a relation between radiant heat and a radius of a flame expressed with an empirical formula.

The radius of the flame 's base is calculated with the following ratio:

$$\pi R^2 = \frac{A(0,2)^2 \cdot V_o}{V_B}, \tag{9}$$

where:
R - radius of a flame (Illustration 4),
A - section of a pipeline supplying flammable liquid,
V_o - liquid (leakage) outflow velocity,
V_B - burning velocity (0.28 ·10^{-4} m/s).

In a geometric model of the flame's shape, it is assumed that the leakage was a result of a crack or loose joint of a pipeline. It has been assumed that a fire of an overflow area corresponds to 20% of damage and that the amounts of leaking liquid and burning liquid are equal.

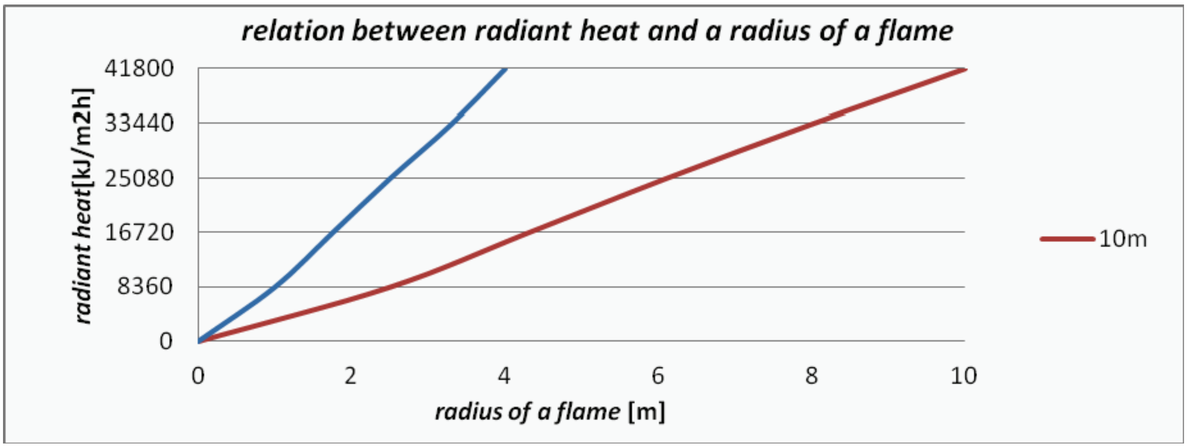

Fig. 2. The relation between radiant heat and a radius of a flame (for leakages caused by cracks or lack of tightness in joints of pipelines)

The probability of efficient initial fire extinguishing (small fire) is calculated with the following formula:

$$P_e = 1 - \left(1 - P_g\right) \cdot \left(1 - P_f\right). \tag{10}$$

The following values of probability of efficient large fire extinguishing (full scale) with the use of a fixed fire-extinguishing system are adopted:
$P_s = 0.99$ - after fuel cut-off,
$P_s = 0.9$ - without fuel cut-off.

The value of 0.99 for the probability of efficient fuel cut-off is adopted.

10. Conclusions

The theoretical method for analyzing risk hazard described in this paper is based on a probabilistic model. Its preliminary assumptions and initial parameters for fire frequency calculations are adopted on the basis of statistical data for real fires. With the use of the model, it is possible to calculate relative frequencies of fires of a various scale for individual fire sources in fuel oil and diesel oil systems as well as to calculate total fire hazard for machines and spaces, and their contribution to general hazard concerning engine rooms.

The accuracy of fire frequencies calculations is approximate and when applied to quantitative assessment of hazard the credibility of results is limited. The fundamental simplification of the model is that the influence of human factor is not taken into consideration.

For the purposes of searching for possibilities of construction influence on fire hazard, qualitative assessment is sufficient. It is so-called sensitivity analysis that is based on relative fire frequency calculations for various types of protection (e.g. with the use of liquid splash protection, various number of fire detectors and fire extinguishing nozzles).

In this respect, the model described in this paper has been used to verify requirements for fire protection of fuel oil and diesel oil systems in creatively chosen engine rooms [2]. It may be assumed that creating an adequate calculation model for the purpose of a general fire hazard analysis of an engine room (of a vessel) is a significantly bigger challenge.

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