

## CASE STUDY OF TESTS OF THE ORGANIZATION LASTFIRE OF FER FIRE BRIGADE IN HUNGARY ENVIRONMENT

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**Abstract:** Examining the occurrence frequency of tank fires we can show you the statistical data (published by LastFire project), as the quotient of number of fires and tank-year. The aim of research was fire tasks are fires in three main kinds of tank type: fixed cone roof tanks; open top floating roof tanks and internal floating roof tanks. The project investigates incidents occurred on atmospheric storage tanks having their diameter above 10 meters. We extinguished flammable liquid spill fires of various sizes with heavy foam and medium foam. The size of the liquid surface ranged from 50 square meters to 1,200 (twelve hundred) square meters. The enclosed data show that the shell temperatures developed similarly in the case of both tank sizes. In respect of extinguishing time almost identical data were obtained in both cases with the use of the same foam agent, “gun” type and solution strength.

**Key words:** tanks, fire, flammable liquid.

## Introducing

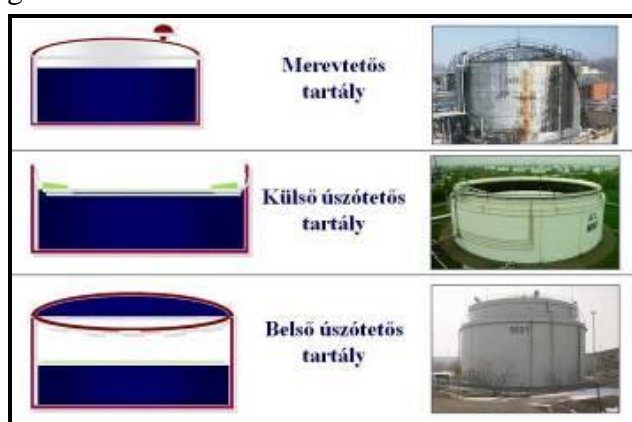
### 1. Atmospheric storage tank fires

When speaking about tank fire we are usually thinking about large atmospheric aboveground storage tanks because it is the most characteristic construction. Beside this it can be declared that the basic rules must mostly be applied also in case of fighting any other kind of fuel fires.

#### 1.1 Types of atmospheric storage tanks

If the topic of the examination is firefighting it is reasonable to categorize the large atmospheric storage vessels according to their roof construction. Therefore, there are three main kinds of tank type (Fig 1):

- Fixed cone roof tanks
- Open top floating roof tanks
- Internal floating roof tanks.



**Fig 1** The three main kinds of tank type

The fixed cone roof tanks are usually used for the storage of “black”, heavy products, such as heating oil, vacuum distillation and bitumen. For the storage of lighter, more volatile products open top and internal open top floating roof tanks are used. (BP Process Safety Series, 2008)

#### 1.2. The most typical tank fires

When examining the fire types involving storage tanks it can be determined that the most important factor, having also impact on the intervention opportunities, is the construction of the vessel.

Examining the occurrence frequency of tank fires in general I show you the statistical data from LastFire project update - Large Atmospheric Storage Tank Fire Project (2006), published by LastFire project, as the quotient of number of fires and tank-year. The project investigates incidents occurred on atmospheric storage tanks having their diameter above 10 meters.

According to their finding the average probability of tank fires is  $3,84 \times 10^{-4}$ . Exceeding this average probability there are fires, with the highest frequency, on open top floating roof tanks with the probability of  $6,51 \times 10^{-4}$  (source: LastFire project update - Large Atmospheric Storage Tank Fire Project, 2006).

However, when evaluating this data it has to be taken into account that the largest storage capacity tanks are built in this construction form because of the difficulties faced when covering such big diameters with a fixed cone roof. This finding is supported by another

source (István, 2005) that says that in case of tanks above 40 meters dia the general frequency of tank fires is  $1,5 - 1,6 \times 10^{-3}$ / tank-year.

The frequency of fires in case of fixed cone roof ( $2,28 \times 10^{-4}$ ) and internal floating roof tanks ( $1,46 \times 10^{-4}$ ) is lower. Examining the spatial form and dimension of the flames some typical tank fire types can be identified.

**Tab 1** The probability of the occurrence of tank fire types by LastFire project update - Large Atmospheric Storage Tank Fire Project (2006)

Tank fire type	Frequency
Rim seal fire	$3,19 \times 10^{-4}$
Vent fire	$3,24 \times 10^{-5}$
Pipe, flange, valve fires	$2,65 \times 10^{-5}$
Bund fire	$1,99 \times 10^{-5}$
Pool fire on tank roof	$1,32 \times 10^{-5}$
Full surface fire	$8,60 \times 10^{-5}$
Vapour explosion	$4,31 \times 10^{-5}$
Cavern explosion	$5,14 \times 10^{-5}$
Others	$4,63 \times 10^{-5}$

### 1.3 Special tank fire phenomena

During tank fires the appearance and danger of such special phenomena have to be taken into account as a result of which burning flammable liquid leaks into the surrounding area or in lucky cases into the bund.

With the spread of the burning fire into the bund there are together the:

- Frothover
- Boilover and
- Slopover phenomena

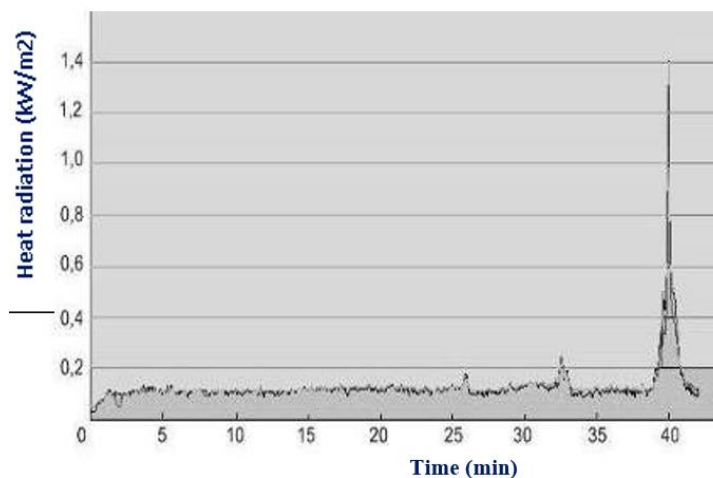
Slopover phenomenon can occur in case of tanks containing fuel on higher temperature than the ambient one (heated, insulated tanks). If a liquid stream is applied into the contained fuel, and the temperature of the contained fuel exceeds the boiling point of the liquid, the evaporating liquid causes a sudden pressure increase in the tank, and as a result splitting or explosion of the tank occurs.

Boilover phenomenon can occur if the water at the bottom of a tank, from the heat wave due to a longer surface fire, reaches its boiling point and evaporates; then its volume increases 1.700 folds. As a result of the sudden volume expansion the vapour stream throws the hot burning fuel up and it spreads in the vicinity of the tank increasing the fire surface and its heat radiation. (Fig 2)

In case of boilover the time factor also has extraordinary importance. The sinking speed of the 100 – 115 °C layer-temperature, which is characteristic of the given fuel, defines the expected time of the boilover. If this heat wave reaches the water layer at the bottom the boilover occurs.

Frothover is a phenomenon when the dissolved water content of the fuel boils and as a result burning fuel overflows the tank. Some of the professional literatures (BP Process Safety Series, 2005, LastFire project update, 2006) do not make difference between the two types of boilover, while the others (István, 2005, Pimper, 2005, Koseki, 1994, Kuncz, 1978) clearly dissociate the two mechanisms.

If the firefighting foam immediately evaporates on the hot, burning fuel layer the phenomenon of slopover occurs. The burning flammable fuel suddenly froths and the hot burning fuel overflows the tank.



**Fig 2** Development of heat radiation during slopover (Pimper, 2009)

Besides the reviewed phenomena there are some external effects that might be the cause of the spread of fire to the bund, such as earthquakes, terrorist attacks or other incidents in the surrounding area. The spread of fire to the bund might also occur as a consequence of different defects or technological failures.

## 2. The characteristic of LASTFIRE Group

LASTFIRE (<http://www.lastfire.co.uk>) stands for „Large Atmospheric Storage Tank Fires”. The LASTFIRE Group is a consortium of international oil companies reviewing the risks associated with fires in storage tanks and developing the best industry practice to mitigate the risks.

Since its original inception in 1993 the LASTFIRE Group has become the World’s recognised international industry forum on all aspects of Storage Tank Fire Hazard Management. It is now quoted regularly by legislators as a recognised source of reliable data and guidance.

In addition, through research work, it has increased industry knowledge on incident statistics, boilovers, foam application, detection systems, floating roof structures and tank operation. One of the most valuable aspects of the Group is the interaction with fellow professionals that occurs at the 6 monthly meetings and through regular correspondence.

The Group objective is to extend its membership and continue its role as the recognised international oil and petrochemical industry forum on best practices of Fire Hazard Management of Storage Tanks. The current members are: ADCO; AFS; BP; IDEMITSU; MERO; MOL; NESTE OIL; PETRONAS; QUATAR PETROLEUM; SAUDI ARAMCO; SHELL; TAKREER; TOTAL and ZADCO.

The approach of the LASTFIRE Group is holistic, including incident prevention as well as incident mitigation and response. It addresses any issue including tank construction and maintenance that may have a bearing on fire risk reduction.

Each member company has three designated LASTFIRE contacts, one being a Steering Panel member. The Group communicates regularly and meets twice a year to discuss in-house incidents, research progress, Steering Panel decisions etc. followed by sessions where external speakers are invited to give technical presentations on any relevant subject of interest.

The Steering Panel meet prior to each Group Meeting and at other times as thought necessary to prioritise research projects, set budgets and make decisions on publication of results and guidance documents.

## **2. 1 Standard deliverables available to members of LASTFIRE Group**

### **Incident Database**

The LASTFIRE Statistical Database is developed from information provided by the Members anonymously and compiled by the LASTFIRE coordinators Resoure Protection International. It provides the most rigorously collected information on tank fire incidents and relates it to the relevant tank population to derive probability. Originally based on open top floating roof tanks, it has been extended to include fixed roof and internal floating roof tanks. The statistics provide an essential input into Risk Analyses and Cost Benefit Analyses both for regulatory requirements and for company risk assessments to determine cost-effective and justified response policies.

### **Incident Review**

Annual listing/review of incidents from inside and outside Group and, where possible, details of the causes/failures leading to the incident with lessons learned and any relevant Group recommendations on preventing future similar events.

### **Risk Reduction Options Document (PRO)**

The comprehensive review of potential risk reduction measures can be implemented on site. It is updated annually based on research work, incident experience and feedback from Members therefore reflects true operational experience rather than theoretical capability.

### **LASTFIRE Standards/Specifications**

A test protocol for the evaluation of the firefighting foam and its performance related to the specific requirements of a storage tank fire.

## **3 Industry Research reports and Best Practice Guidance Documents**

### **3. 1 LASFIRE Research Work**

*Boil over Studies.* The group has carried out extensive Boilover Studies with the aim of providing responders with better information on time to boil over, boil over consequences and firefighting foam application strategies.

*Lightning Study* The LASTFIRE Group was requested to comment on the API/EI lightning study related to storage tanks.

*Future Research project* includes important issues such as:

- Vapour Suppression properties of different quality foams
- Foam Application Rate
- Effectiveness of Large Monitor Packages
- Internal Floating roof tank fire extinguishing systems
- Vapour measurements under geodesic domes

MOL Plc. has been a member of the project since 2003 and with active participation has contributed to the researches. The Group represents itself in the Steering Panel and the six-monthly meetings with three representatives.

### 3.2 Researches and tests of FER Fire Brigade

Almost fifty years ago the construction of two industrial establishments was started in Százhalombatta. Together with the units of Danube Refinery and Dunamenti Power Plant, for the protection of the two establishments, an industrial fire brigade was set up and started its development. By our days FER Fire Brigade carries out the provision of the tasks of an industrial fire brigade from four fire stations and on three sites. Besides the ones in Százhalombatta, there are also fire brigades working under the supervision of the company on the sites of Komárom and Algyő.

Beyond the harmonized operation of the three industrial fire brigades of FER there are mutual aid contracts made between FER and the Fire Brigade of Slovnaft Refinery in Bratislava and the Fire Fighting and Technical Rescue Ltd. in Tiszaújváros.

FER Fire Brigade provides safety to its owners and partners with the best available technical solutions in its resources. As a result of conscious coaching and the large number of special supplementary activities our professionals are excellently trained.

With a high-standard and wide-ranging interventional reliability, and with a great many supplementary activities FER Fire Brigade serves the owners' high level protection in a cost-effective system. Our researches and tests are basically connected to the intervention tasks of our operational area and they are completed with different kind of measurements. The most important target areas of our researches are as follows:

- Foam firefighting
  - 1 % mixing rate foam agents
  - Firefighting by high expansion rate (HEX) foam
  - Comparison tests of different foam agents
- Tank fire fighting
  - Extinguishment of large pool fires
  - Special dangers of tank fires (e.g. boilover, slopover, frothover)
  - Model tests
  - Elaboration of the handbook of fighting large storage tank fires
- Overpressure ventilation
  - Fighting cable tunnel fires by using overpressure ventilation
  - Smoke removal
- Handling hazardous materials, flushing and diverting gas clouds
- Response opportunities in case of emergencies with the presence of hazardous gases

During the more than one-century history of the oil industry the hydrocarbon storage tanks have grown out from the ground together with the crude oil refining establishments. After the small storage capacity tanks the large ones also appeared. Parallel with the increase of the stored amount the danger also got bigger and bigger, involving the extent of the danger of fire and explosion. Besides the growing amounts, the appearance of the latest products and the changing technological features, the more and more rigorous safety and environmental expectations also make necessary the continuous development of the special field of interventions.

Therefore, it is no wonder that we put great significance on the issues of the fighting storage tank fires.

The importance of tank fire protection and within its frame tank fire fighting is increased by the fact that it is widely spread within the industry and it needs special preparedness and

resources. In the field of the oil and chemical industry it is almost generally true that in the establishments the authoritative fire- and planning-scenario is the fire of the largest storage tank and its bund.

### 3. 3 Extinction of spill fires

We extinguished flammable liquid spill fires of various sizes with heavy foam and medium foam. The size of the liquid surface ranged from a few square meters to 1,200 (twelve hundred) square meters.

The primary objective during these fire-fighting tests was to appraise the real extinction performance of foam blankets generated with the use of 1% foam agents. We progressed to the next fire-fighting tasks – involving larger surfaces and posing thereby higher challenges – following the convincing experiences gained with smaller fire surfaces (Fig 3).

We put out the flames on the 1,200 square meters surface – representing the largest “spill fire” – several times in scarcely 40-45 seconds with one single foam gun of 10,000 liters per minute capacity mounted in our mobile fire-fighting center built primarily for the purpose of extinguishing tank fires.



Fig 3 Show of fire-flightinf task

Starting from the findings of the previous comparative tests, these tests were conducted with the use of two 1% foam agent types. After evaluating the test results, we have selected the extinguishing agent (STAMEX AFFF 1%) more suitable for us because of its shorter extinction times and properties, and this has been on hand since then in the foam agent containers of our fire-engines (one quick response fire-truck and one mobile fire-fighting center).

### 3. 4 Boil-over test

The storage tank fire was simulated by a 1,2 m diameter, 0,30 m high round tray under the conditions defined in the scope of the LASTFire project. The ratio of crude to water is shown in the Fig 4.



Fig 4 The ratio of crude to water

The phenomena observed are summarized in the list shown (Tab 2).

**Tab 2** Presentation of the phenomena “boil-over”

Time	Processes
0 minute	Ignition of fire
29 minutes 45 seconds	Noise phenomenon indicating ever stronger boiling
30 minutes 05 seconds	Start of boil-out
30 minutes 36 seconds	Start of intensive boil-over
30 minutes 56 seconds	Fire surface reaches maximum size
31 minutes 34 seconds	Minor ejection accompanied by noise phenomenon
31 minutes 44 seconds	More intensive ejection accompanied by noise phenomenon
31 minutes 49 seconds	Most intensive ejection, scattering burning material even outside the area of flame volume
from 32 minutes 36 seconds	Minor noise phenomena indicating ejection
from 36 <sup>th</sup> minute	Extension of fire surface begins to decrease (in lack of combustible material)
by 37 <sup>th</sup> minute	Fire surface less than 1 square meter
by 39 minutes 40 seconds	Fire surface less than 0.1 square meter

During boil-out the fire had spread to an average distance of 2,1 m from the wall of the container in all directions. The largest radial expansion during boil-out was 2,8 m. Burning material was scattered to more than 3 m distance from the tray during ejection. The same meaning have Kelly (2014) a Sprunk et al. (2014). The steps of the process and the extent of the area affected are well illustrated in the enclosed photos (Fig 5).



**Fig 5** The steps of the process and the extent of the area



### 3. 5 Investigation of burn-out rate

In the course of the test series we measured on various smaller surfaces the thickness of material layers burned off per minute in the case of diesel and gasoline fuels. Each test was repeated three times with the results shown in the Tab 3.

**Tab 3** The test series we measured on various smaller surfaces

COMBUSTION VESSEL		BURN-OUT RATE (mm/minute)	
DIAMETER (cm)	SURFACE (m <sup>2</sup> )	DIESEL	GASOLINE (95)
10.0	0.0079	0.88	3.30
26.0	0.0531	1.32	3.30
37.5	0.1104	1.60	3.00
57.0	0.2550	1.70	3.10

We could not perform accurate measurements during tank fire extinction tests due to measuring difficulties and the influence of environmental (such as wind) effects.

### 3. 6 Tests of re-ignition effect

The objective was to investigate the foam breakdown and re-ignition inducing effects of the hot tank shell. We placed the combustible material in a container with a quarter square meter surface and then heated the wall of the container from outside with a gas torch. at the height of the liquid level, while monitoring the temperature. We repeated this test (Fig 6) also in the case of foam blanket covered liquid surface. Gasoline and diesel fuels were used as combustible materials.



**Fig 6** Tests of re-ignition effect

Our findings were as follows:

- The heated wall ignited the gasoline already at a low temperature, but no ignition occurred in the case of diesel fuel even in spite of the diesel layer next to the wall already boiling.
- The foam blanket broke up next to the hot shell and then ignition occurred at this part in the case of gasoline.
- When the torch was removed, the foam blanket/film put out the fire again.
- Continuous heating maintained the blaze and foam breakdown spread out (very slowly).

### 3.7 Full surface tank fire fighting tests

Fire-fighting tests were conducted with two sizes of storage tanks (Fig 7):

- with 50 m<sup>3</sup> tank - 14 times
- with 20000 m<sup>3</sup> tank - 2 times

#### Tank fire fighting tests on 50 m<sup>3</sup> tank

Under varied conditions, with 1 parameter changed each time:

- Pre-combustion time: 1.3, 4.6 & 10 minutes
- Extinguisher: heavy foam jet nozzles: with air induction  
without air induction
- medium foam jet nozzle: 30 l/min capacity
- foam generator: one - 30 l/min capacity



Lánghőmérséklet - benzin

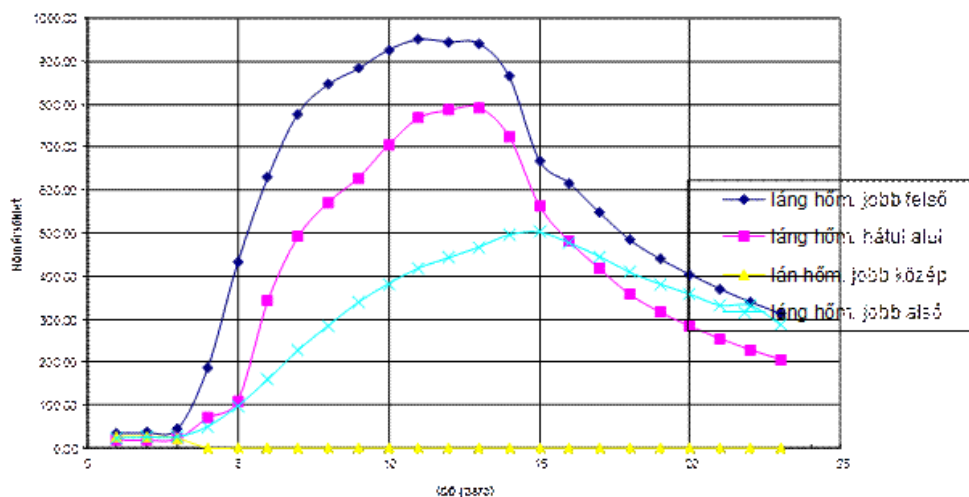


Fig 7 Full surface tank fire fighting tests

### 3.8 Full surface tank fire fighting tests on 20.000 m<sup>3</sup> storage tank

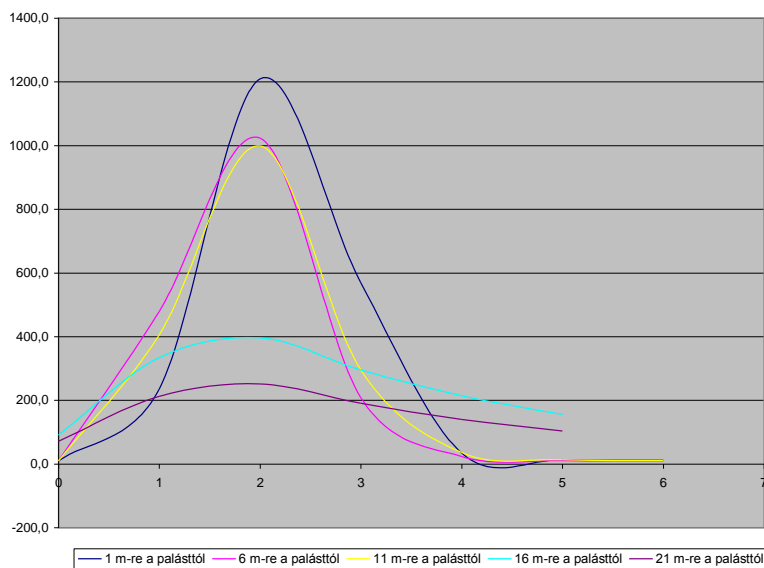
The most important features of the two tests (Fig 8):

- Nominal tank volume: 20.000 m<sup>3</sup>;
- Diameter: 42 m (fire surface: 1385 m<sup>2</sup>), height: 16 m.
- Full surface tank fire fighting;
- The use of foam pourers is excluded;
- Mobile, non-aspirated monitor, 10.000 l/min capacity;



**Fig 8** Firefighting test done on tank No 20.008

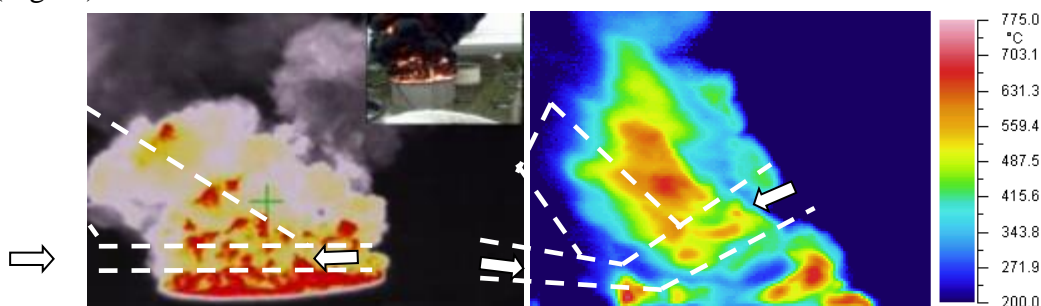
Fig 9 shows the change of the flame temperature above the liquid surface from different distance from the shell in dependence of time.



**Fig 9** Change of the flame temperature above the liquid surface (Pimper, 2005 May 19)

The figures unambiguously justified the thesis that in the inner zone of the flame where there is a lack of oxygen the intensity of burning is smaller and the temperature of the liquid and flame is lower.

Therefore, it is determinable that the most expedient way to apply the foam is to apply it to the centre of the liquid surface. This way the smallest possible damage of the foam can be assured while spreading on the surface. During our tests we took IR shots of the tank and the flame (Fig 10).



**Fig 10** Temperature of the flame (IR shots)

On the bases of the IR shots the vertical layers of the flame can be divided into three zones. Between the hot, flat zone stretching above the tank and the topmost, innermost, hotter, turbulent and oxygen-rich zone there is another one with lower temperature. The application of the foam through this zone, just above the tank shell, provides the smallest possible damage of the foam.

#### 4 Foam flow tests

While fighting large tank fires the task can clearly be separated into two parts by LastFire project update - Large Atmospheric Storage Tank Fire Project: Incident survey for 1984-2005 (2006):

- Extinguishment of the open liquid surface fire,
- Putting out the flames next to the hot tank shell.

The extinguishment of an open liquid surface fire by making an unbroken foam blanket is usually “quite simple”. The task of the responders, depending on the method of foam firefighting (mobile or built-in), is to establish an unbroken, airtight foam blanket. In case of fix, built-in foam pourers it is done by the self-spreading of the foam. In case of mobile equipment it is done by the appropriate use of the foam stream.

Next to the hot tank shell it is extremely difficult to establish an unbroken, airtight foam blanket. The liquid touching the hot shell is continuously boiling; its vapours go through the foam blanket and keep on the flaming. This phenomenon is called “wall effect”; however, its investigation was not the topic of the tests I am speaking about. (István, 2002/2003, 2004)

We measured the foam flow on a 12 m by 50 m, 600 m<sup>2</sup> pool, made of soil.

Total number of the foam flow tests is four:

- 2 „cold”, tests without fire:
  - 1 time with medium expansion rate foam (MEX),
  - 1 time with low expansion rate foam (LEX).
- 2 firefighting tests („hot tests”):
  - 1 time with MEX foam,
  - 1 time with LEX foam.

The expansion rates were: in case of LEX foam 7, 8; in case of MEX foam 31,6 volt. The applied foam ensured 4 l/min/m<sup>2</sup> application rate, calculated on the full surface (Fig 11).

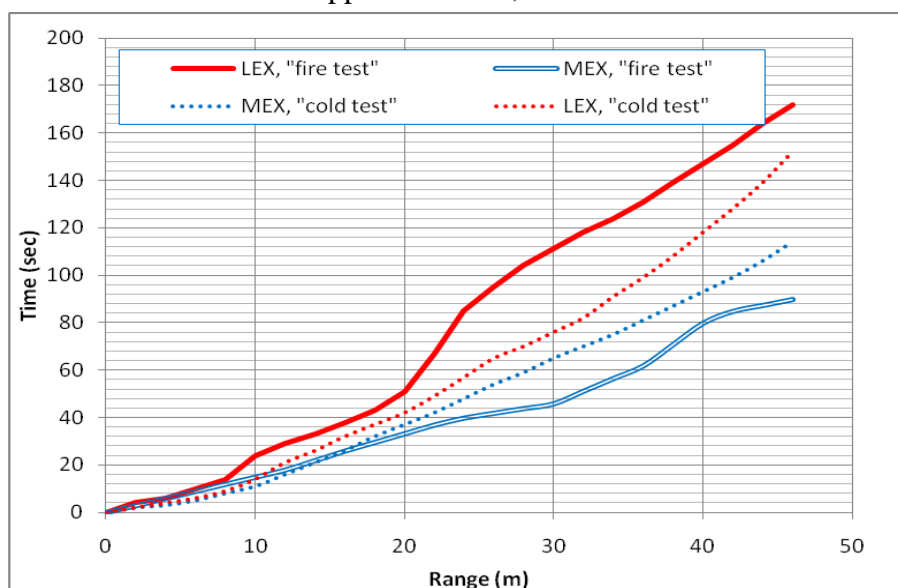


Fig 11 Firefighting and foam flow tests

Fig 12 shows the summarized figures of the foam flow tests. When using low expansion rate foam our previously stated idea, according to which the measured penetration speed, because of the damage of the foam caused by the heat, stays behind the one measured during the cold tests, was justified. However, against our expectation the results of those tests done by medium expansion rate foam showed the opposite. We measured higher penetration speed during the firefighting tests than during the cold ones.

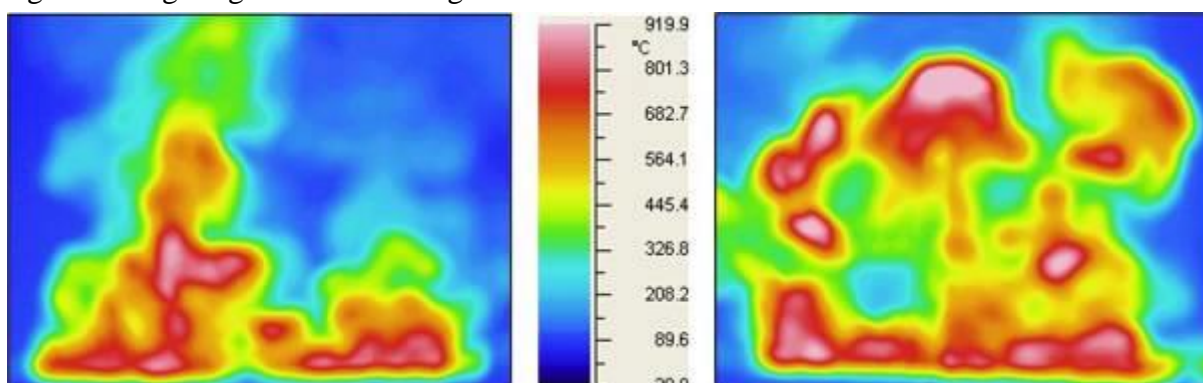


Fig 12 IR measurements

The 1 % mixing rate foam that we used during the tests passed brilliantly the exam in both MEX and LEX form. Based on the results of the recent, high-number firefighting tests it is justified that today's 1 % mixing rate foam agents offer appropriate and cost-effective solution for carrying out the task.

### Conclusion

The processes of extinguishing the fire of a 20,000 m<sup>3</sup> storage capacity tank and a 50 m<sup>3</sup> capacity tank under the same conditions are clearly comparable.

The enclosed data show that the shell temperatures developed similarly in the case of both tank sizes. In respect of extinguishing time almost identical data were obtained in both cases with the use of the same foam agent, “gun” type and solution strength.

The tests conducted on smaller containers with various foam agents have also demonstrated that the selection of foam agent type has a great influence on the time need for extinction. In our tests the film-forming agents provided shorter extinguishing time in all cases, but – at the same time – no detectable difference could be observed in the extinguishing results of foam agents of the same nature, applicable at 1% and 3% mixing ratio.

We proved that the firefighting foams, similar to the applied one, regarding e.g. in type, expansion rate), are capable of flowing to longer distances (over 50 m) without being shot. We experimentally proved that the longer the distance from the foam source is, the lower the penetration speed is.

During the firefighting tests we paid attention also to examining the design and suitability of the fixed and semi-fixed fire protection equipment installed on storage tanks.

We can state that the general practice for the design of shell-cooling sprinklers is not satisfactory. They leave the top section of the shell above the cooling-spraying ring without protection and no protect is provided also for the same section by the positive cooling effect of the stored material mass. We recommend the shell-cooling sprinklers to be re-located to the highest shell section possible in order to enable them both to improve the protection of the shell and to reduce the re-ignition effect of the hot surface – possibly shortening the time needed for putting out the fire and improving the safety of the operation

We used foam agents with various foam-forming capacity during the extinction tests. It became obvious that foam blankets generated by foam generators able to provide higher foam-forming capacities result in faster extinction. We recommend to give preference to this type when selecting foam generators for storage tanks.

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