Journal of Hazardous Materials, 20 (1988) 73–82
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

INVESTIGATIONS OF WATER SPRAYING SYSTEMS FOR LPG STORAGE TANKS BY FULL SCALE FIRE TESTS

W. SCHOEN and B. DROSTE
Federal Institute for Materials Research and Testing (BAM),
Unter den Eichen 87, D-1000 Berlin 45

SUMMARY

This paper presents the results of fire tests using liquid propane as fuel on commercial 4.85 m^3 LPG storage vessels protected alternatively by two types of water spraying systems (WSS). The conventional WSS which consists of one or more pipes above the tanks top is not able even with a spraying rate of 1000 l/(m^2.h) to protect a vessel from bursting when fully engulfed. Therefore an upgraded WSS had been developed. It consists in principle of five pipes sited around the vessel like a cage. With a spraying rate of about 400 l/ (m^2.h) the upgraded WSS is able to protect a vessel from failure. The test parameters and results as well as design aspects of the two WSS are given and discussed in detail.

INTRODUCTION

LPG containments will rupture violently if subject to prolonged fire attack. The consequences are severe. The Federal Institute for Materials Research and Testing (BAM), Berlin, FR Germany, in cooperation with the Technischer Oberwachungs-Verein Hannover, had carried out full scale fire tests on unprotected commercial LPG storage tanks and described the consequences of tank failure (ref.1).

German regulations (pressure vessel order DruckbehV) (ref.2) require save handling and storage of LPG. The Technical Rules Pressure Vessels (TRB) (ref.3) precise these requirements. TRB 610 obliges LPG storage tanks to be sited underground or mounded. Above ground vessels have to be protected for at least 90 minutes from failure in case of full engulfment. TRB 610 recommendations are thermal insulation or water spraying systems (wss) with a spraying rate of 100 l/ (m^2.h) combined with certain safety distances to buildings.

Because of the unknown fire protection efficiency of this measure we performed experiments with different water spraying systems to evaluate the optimal construction and necessary spray rates. The experiments were part of a research program, sponsored by the FRG Federal Department of Research and Development (Bundesminister für Forschung und Technologie).

FIRE TEST FACILITIES AND EQUIPMENT

The tanks used in our series of tests were commercial cylindrical Propane tanks. The main design criteria of the tanks were:

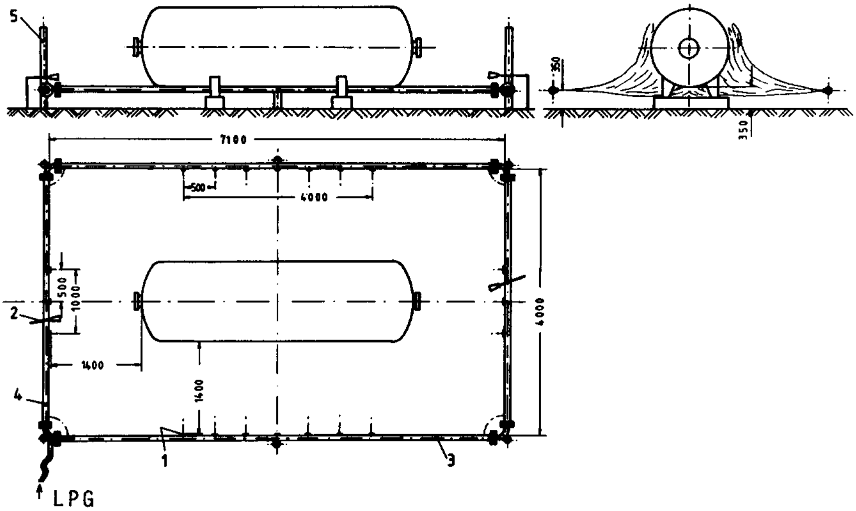
Volume		4.85 m^3
Length		4.3 m
Diameter		1.25 m
Wall thickness		6.5 mm
Material	fine grained steel	StE 36
Maximum allowable filling degree		85 %
Maximum working pressure		16.4 bar
Test pressure		21.6 bar

Each tank had been equipped with several thermocouples (NiCr/Ni) for temperature measurements at different locations (ambient temperatures in 10 cm distance to the tank, outer wall temperature, temperature of the fittings, liquid and vapour space temperatures, water temperature in the spraying system pipes and when leaving the tank surface at the bottom) and pressure measurement devices for the liquid and vapour space overpressure.

In order to vary heat flux into the tank and to ensure an abrupt end of fire engulfment we choosed a burner system working with liquid Propane torch fires (not premixed with air) from a closed circuit pipe around the test vessel (Fig.1). The liquid Propane escapes horizontally or vertically from the pipe and is ignited by two permanently burning flames.

Two types of WSS had been used within the experiments, the conventional and the upgraded WSS. The conventional WSS as can be seen in Fig.2 consists of three pipes above the top of the vessel with spraying rates from 100 $l/(m^2.h)$ up to 1000 $l/(m^2.h)$. This WSS is up to now the main method of fire protection for above ground LPG vessels.

The pipes and nozzles of the upgraded WSS surround the vessel in equal distances like a cage. Additionally four nozzles had been installed at each head of the tank (Fig.3).



(a)

(b)

Fig.1 (a) Burner system, closed-circuit pipe with nozzles for liquid Propane release
(b) Fire test facility in action (4.85 m^3 LPG storage tank, conventional WSS, 1000 $l/(m^2 \cdot h)$

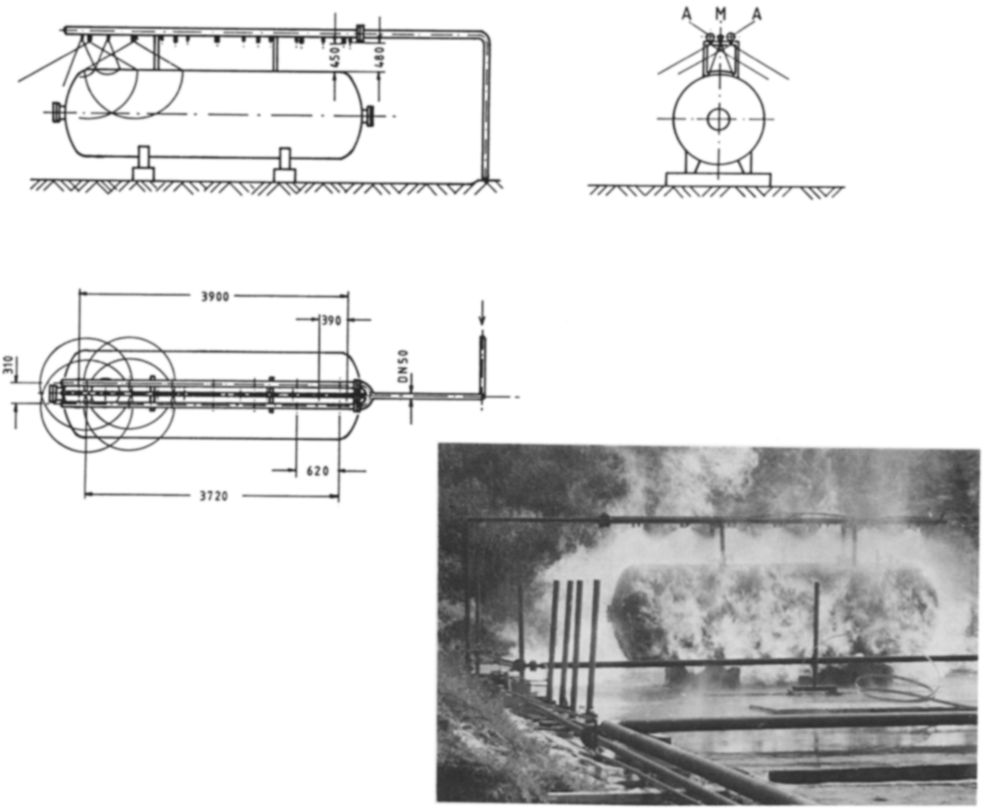


Fig. 2 Conventional water spraying system

TEST PARAMTERS

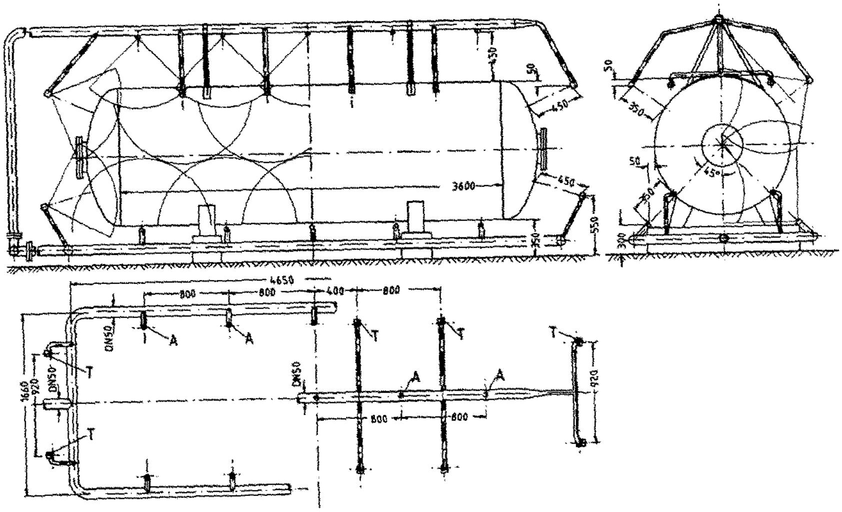
To ensure that a failure of a Propane filled tank with the consequences (BLEVE, destruction of the test facilities) would not occur, fire tests were carried out at first by using water filled vessels.

To verify positive results of the parameter variations we performed at last fire tests on a Propan filled vessel using test conditions with the optimized parameters.

Within the first series of five tests we used the conventional WSS.

Full fire engulfment conditions could be reached by using 14 horizontal torches with nozzles, each with a diameter of 1.5 mm and a resulting gas consumption rate of nearly 80 l liquid propane per minute.

(a)



(b)

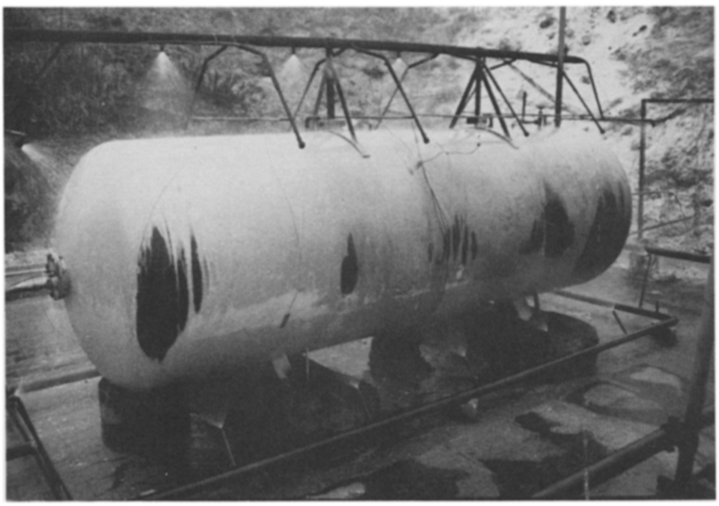


Fig.3 (a) Upgraded water spraying system

(b) Upgraded WSS in action, average spray rate 400 $l/(m^2 \cdot h)$, 4.85 m^3 LPG storage tank after 90 minutes fire angulfment

The next test series was carried out with the advanced WSS because when using the conventional system the temperature rose up within a few minutes to more than 250 °C at the flanges or more than 400 °C at the tank wall. In this series the water spray rate could be varied down to about 400 $l/(m^2 \cdot h)$ in case of the same fire engulfment conditions. This test had been successfully repeated with a LPG-filled tank with filling degrees of 20 % and 85 %.

Within the last series of fire tests on a 4.85 m^3 LPG-vessel the conventional WSS was used again. We choosed a spraying rate of 100 $l/(m^3 \times h)$ and varied the heat flux into the LPG-tank. This could be done by turning up the fire torches to the vertical position. In this case the fire had not any direct contact to the tank wall. The heat flux resulted only from radiation. This test had been successfully repeated with a 20 % filling degree of propane.

MAJOR TEST RESULTS

Using the upgraded water spraying system with a rate of 400 $l/(m^2 \times h)$ a commercial LPG storage tank equipped with a pressure relief valve could be protected 90 minutes from failure.

In the fire test with the 20 % filled tank the inner pressure rose within the first five minutes up to the start to discharge pressure of the pressure relief valve of about 14 bar overpressure (Fig. 4). Within the next 20 minutes the valve closed and opened five times. After nearly 50 minutes the whole liquid phase in the tank had been evaporated.

The vapor space temperature rose up to 100 °C. The liquid propane temperature in the vessel was about 45 °C at its maximum (Fig. 5).

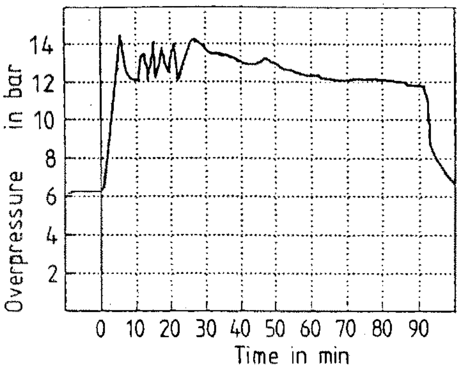


Fig. 4 Pressure-Time-Curve, Upgraded water spraying system

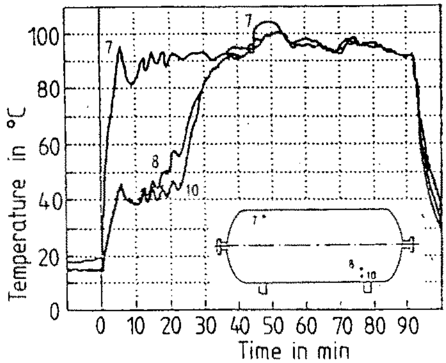


Fig. 5 Temperatures of tank contents

Those parts of the tank wall which had been cooled by the water spraying system had a maximum temperature of 100 °C. At non-cooled local points (in case of wind effects) the wall-temperature rose up to more than 300 °C (Fig. 6).

Using the conventional water spraying system with a spraying rate of 1000 $l/(m^2 \times h)$ the temperature at the head flanges rose up to more than 450 °C within the first 5 minutes (Fig. 7)

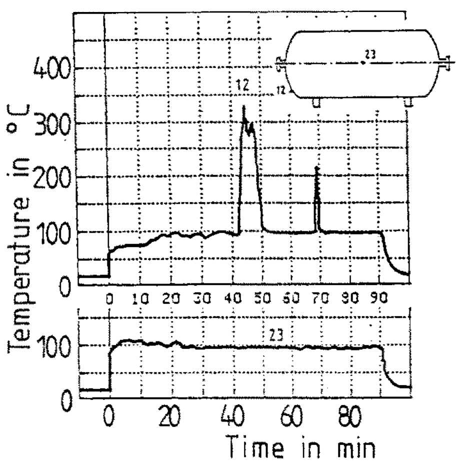


Fig. 6 Tank shell temperatures, upgraded water spraying system

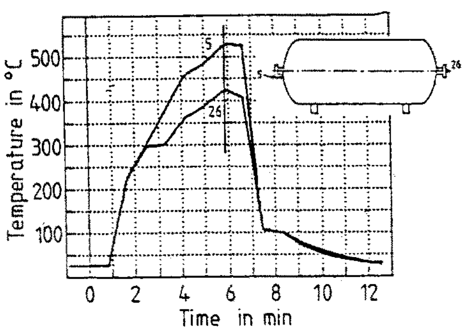


Fig. 7 Flange temperatures, conventional water spraying system

Reducing the effective heat flux into the tank contents from 55 kW/m² down to 12 kW/m² by turning up the fire torches into vertical position (Fig.8) the conventional water spraying system was able to prevent the vessel from failure by using a water spraying rate of about 100 l/(m² x h).

The inner pressure rose up to 14 bar - the working pressure of the pressure relief valve - within the first 26 minutes. This pressure remained until the end of this fire test.

The wall and flange temperatures rose up to 240 °C.

The liquid phase temperature maximum was at about 60 °C near the surface and at about 45 °C near the bottom of the tank. The vapor space temperature rose up to about 87 °C.

SUMMARY

(i) Effectivity limits of conventional WSS. Using the conventional water spraying system with a rate of 100 l/(m² x h) as a fire protection measure the average effective heat flux into the tank contents has to be limited to less than 12 kW/m² by additional measures. In any case one nozzle has to be installed above each head of the vessel.

(ii) Presumptions for the effectivity of the upgraded WSS. The Federal Institute for Materials Research and Testing (BAM), Berlin, FR Germany, had carried out full scale fire tests on LPG storage tanks, one series with non-protected vessels, one series with insulated vessels, and at last the described series with tanks protected by water spraying systems.

The advanced WSS as described above is an effective measure to protect fully engulfed LPG storage tanks from failure within 90 minutes when it would be started immediately at the beginning of the fire engulfment and when all water nozzles are propperly in function. But however pressure and temperature curves show that a thermal insulation of above ground storage tanks is more effective (Fig. 9).

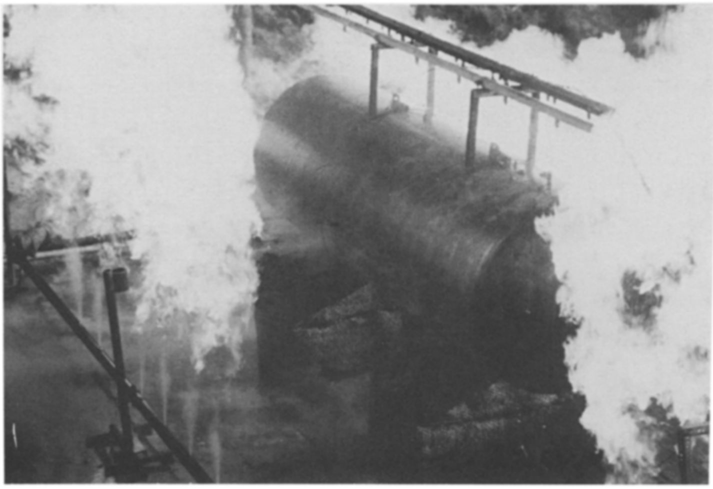


Fig.8 Fire test with vertical torch flames

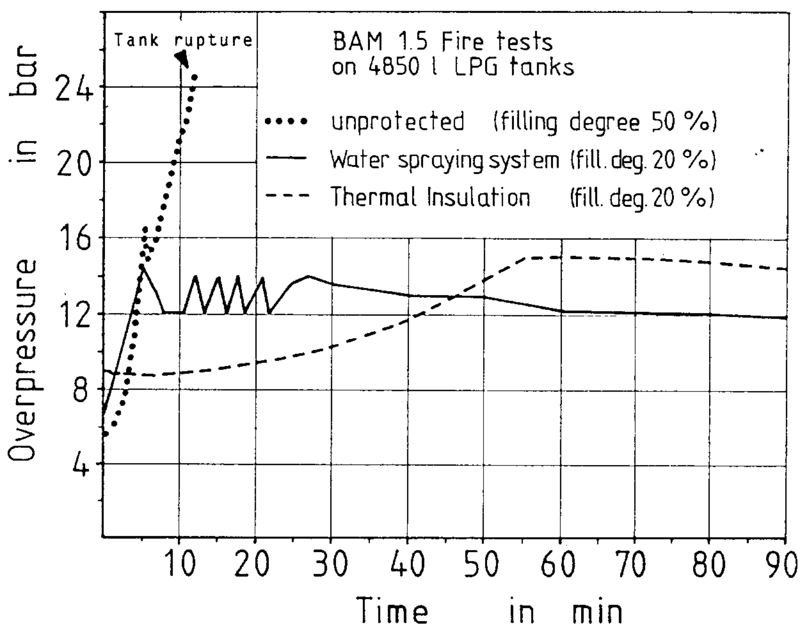


Fig. 9 Comparison of different fire protection measures

REFERENCES

1 B. Schulz-Forberg, B. Droste and H. Charlet, Failure mechanisms of propane tanks under thermal stresses including fire engulfment, Proc. Int. Symp. on Transport and Storage of LPG ans LNG, Brugge, Belgium, May 7 - 10, 1984, Koninklijke Vlaamse Ingenieursveriging, Antwerpen, 1984, Vol. 1, pp 295 - 305
2 Verordnung über Druckbehälter, Druckgasbehälter und Füllanlagen (Druckbehälterverordnung - Druckbeh. V), February 27, 1980, BGBl. I S. 184
3 Technische Regeln Druckbehälter, TRB 610, Druckbehälter, Aufstellung von Druckbehältern zum Lagern von Gasen, Bundesarbeitsblatt 1/1984