CHEMICAL ENGINEERING TRANSACTIONS

VOL. 67, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Valerio Cozzani, Bruno Fabiano, Davide Manca

ISBN 978-88-95608-64-8; **ISSN** 2283-9216

DOI: 10.3303/CET1867034

Gasoline-air mixture Explosion in a Semi-Confined Space with a 90° Bend

Meng Li*, Yang Du, Guoqing Li, Shimao Wang, Chong Liu, Shihao Wei

Chongqing Key Laboratory of Fire and Explosion Safety, Army Logistics University of PLA, Chongqing 401311, China
898556580@qq.com

In this work, experiments data from vented explosions tests using gasoline-air mixtures in a small, open square duct With a 90°bend were performed using high-speed camera. It is found that pressure history in the semi-confined space can be divided into four phases, i.e. constant volume explosion, effusive flow overpressure, disturbance explosion, vibration attenuation. The bend structure has an impact on the flame structure during the explosion. In the confined space, the flame transforms from sphere to brush-like shape. The transformation of flame shape in the pipe can be classified into six stages. When flame propagates to the bend structure, it bypasses the bend along the inner wall of the pipe. Flame velocity and flame front position can be divided into four stages: explosion initial stage, accelerated effusion stage, disturbance explosion stage, and energy attenuation stage. Both changes are consistent with changes in flame morphology.

1. Introduction

The explosion propagation process of premixed combustible gas in a confined space is the basic content of explosion hazard research (Fakandu et al., 2015). In the fields with pipelines, tunnels, cave depots and other works (Qi et al., 2016), the internal structure in confined space is complex and diverse, and there are a certain number of branches (Li et al., 2016), bends (Zhou et al., 2006), etc. It is of great significance to improve the safety of industrial production by conducting research on explosions that occur in confined spaces containing curved pipe structures.

Currently, aiming at the characteristics of explosions occurred when premixed flame propagates through bend, the study focuses on the impact of the bend on the burst intensity and flame velocity (Xiao et al., 2015). An experiment on explosion was made (Phylaktou et al.,1993) from closed steel pipe containing a 90° bend and found that the bend can greatly increase the combustion speed and flame propagation. It is suggested that it has a strong potentiation effect on the explosion. Xue-Chao, H (2010) made an experimental study on the propagation process of propane-air premixed flames in a 90° bend and discovered that 90° bend distorted the flame and intensified the turbulence in the flow field.

Thus it can be seen bend has a significant impact on the premixed combustible gas explosion. However, previous studies mostly focus on a single working medium such as hydrogen and gas There has been little research on gasoline-air mixture, especially the explosive characteristics of gasoline-air mixtures in confined spaces with curved pipe structures. This experiment acquires data about pressure and flame produced during explosion with pressure sensors and high-speed cameras to further explore the explosion process.

2. Experiment devices and solution

The schematic diagram of experiment system is shown in Fig. 1. It consists of main experiment bench, dynamic data acquisition system, high-speed camera, gas distribution system, hydrocarbon concentration tester, ignition system, and synchronization control device, etc. The experiment bench adopts a transparent plexiglass tube. Pipe ahead of bend is 100mm×100mm×1200mm in size, and pipe behind the bend is 100mm×100mm×300mm in size; the wall thickness of the pipe is 20mm. A blind plate seals up the pipe at leftmost end; there is a rubber gasket used to tighten the blind plate and the pipe; the blind plate is equipped with an ignition head at the centre. A polyethylene film is used to block off the outlet of the pipe. A pressure sensor is installed in the front and rear part of the turn structure, respectively, in order to record the pressure

Please cite this article as: Li M., Du Y., Li G., Wang S., Liu C., Wei S., 2018, Gasoline-air mixture explosion in a semi-confined space with a 90° bend, Chemical Engineering Transactions, 67, 199-204 DOI: 10.3303/CET1867034

history inside the confined space during the explosion. Here is a ZXP660 high-frequency transient pressure sensor. High-speed camera records the experiment process. The acquisition frequency is set as 500 frames per second. Gasoline vapor generated by the gas distribution system should be measured for its volumetric concentration with a GXH-1050 hydrocarbon tester to achieve the initial volumetric fraction of oil and gas as required in the experiment.

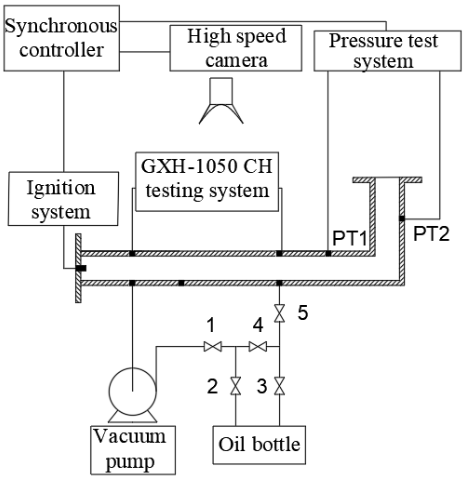


Figure 1: Schematic diagram of the explosion pipes

Gasoline vapor is produced by the gas distribution system in the following ways: under the action of the vacuum pump, air circulates in the closed pipe and the oil bottle to produce the initial gasoline-air mixture. At this time, the valves 1, 2, 3, and 5 are opened, and the valve 4 is closed (the valve numbers are shown in Fig. 1). After the gasoline-air mixture circulates in the closed system for a period (time duration depends on the initial gasoline-air mixture concentration required by the experiment), valves 2 and 3 are closed, valve 4 is opened, and the mixture in the system is cycled for about 3 minutes to evenly mix the gases. Here the GXH-1050 hydrocarbon tester is used to measure the volume concentration of oil vapor to make it reach the initial gasoline-air mixture concentration required for the experiment.

3. Results and discussion

3.1 Explosive overpressure characteristics

The curves of internal explosion overpressure in a confined space with a 90° bend are shown in Fig. 2, where PT1 and PT2 are the curves of overpressure time-sequence ahead of and behind bends. It is observed that the explosion overpressure curve has multi-peak characteristics. According to its characteristics, the explosion process is divided into four phases:

Constant volume explosion phase: At this stage, the film at the pipe pressure relief port is not broken, and the confined space is equivalent to a closed constant volume container. When the ignition head ignites the oil-air mixture in the confined space, pressure in it gradually builds up. After the film fracture pressure is reached, the film ruptures to form a ruptured film overpressure peak P1, about 5 kPa, within 25 ms.

Effusion overpressure phase: When the film ruptures, the pressure in the confined space is instantaneously released to the minimum; driven by the explosion pressure wave, a lot of gasoline-air mixtures within the confined space are discharged to the external space. When the mass flow rate reaches its maximum, an effusion overpressure peak value P2, 11.26 kPa, forms within 38 ms.

Disturbance explosion phase: When the explosion pressure wave propagates to the bend structure, it is reflected on wall surface, and intensified when overlapping with pressure wave. The local pressure thereby rises rapidly so that a disturbance overpressure peak P3, 19.8 kPa, forms within 44ms.

Damped oscillation phase: After the explosion, the internal temperature drops, and the pressure decays sharply. Because of the pressure drop in the pipe, a partial vacuum zone will form. Part of the unburned gasoline-air mixture is sucked back to mix with incompletely-reacted gasoline-air mixtures in the pipe, which re-explodes, resulting in the pressure rise again; the air in the pipe after explosion is again extruded the pipe so that the pressure in the pipe falls. These two processes repeat and the pressure oscillation attenuates.

As compared to the PT1 overpressure time-sequence curve, the PT2 overpressure time-sequence curve also shows four stages. The difference from it is that, in the effusion overpressure phase measured in PT2, the pressure presents a sustaining downward trend, and finally reaches negative overpressure peak. This may be due to the fact that PT2 is located near the pressure relief port. During outward effusion of the gasoline-air mixture, a negative pressure vacuum zone partially forms at PT2, resulting in a negative overpressure peak.

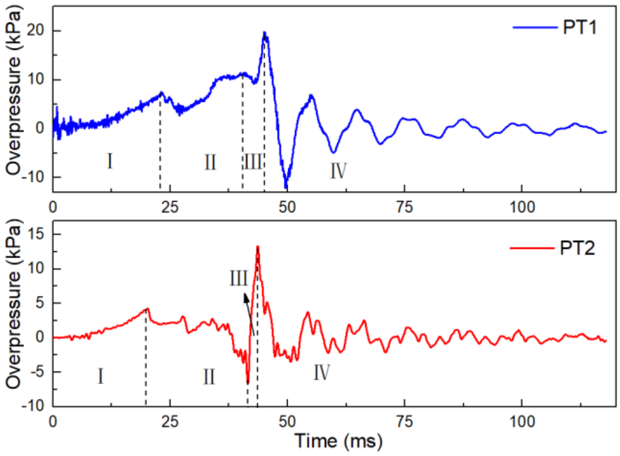


Figure 2: Explosive overpressure-time curve comparison

3.2 Flame structure

Figure 3 is an experimental image of gasoline-vapor explosion in confined space with a 90° bend with an initial concentration of 1.7%. It is obvious that the flame presents a transformation of sphere-finger-brush-like morphology. The flame propaganda process in the space with 90° bends can be divided into 6 phases:

Spherical laminar flame: When the gasoline-air mixture in the pipe is ignited, the flame initially presents a dim red spot in a tiny burning range. Its constraints from the pipe wall are negligible. The flame seems to be a sphere and propagates all around at a uniform velocity. It can be regarded that the flame at this time is free expansible. An obvious zoned phenomenon within the flame can also be seen. Surrounded by a bluish flame, partial zone in the interior is bright orange since gasoline-air mixture will undergo a string of complex chemical reactions during the combustion process. The flame will fully burn in oxygen enrichment condition to turn into pale blue colour, if it combusts incompletely in its internal part, reactants will form carbon particles which grow bright orange when combusting.

Laminar stretched flame: Constrained by the pipe wall surface, when the stretching velocity in axial direction is greater than that in radial direction, the flame is stretched along the axial opening direction, and the curvature of the flame front surface gradually decreases as the flame moves. Currently, the flame velocity gradually increases, and the flame front remains a smooth hemisphere.

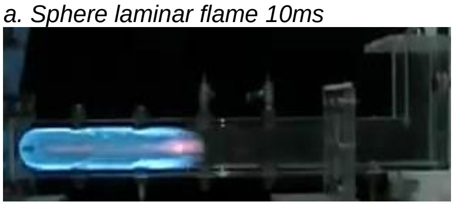
Accelerated deformation phase: As the pressure in the pipe builds up, the film at the opening of the pipe ruptures. And a bulk gasoline-air mixture is discharged to the external space. Flame moves at significantly faster velocity. It is obvious that the flame front gradually gets unsmooth from smooth state during the advancement when the low-density flame combustion products diffuse to high-density unburnt gasoline-air mixture, the contact interface between low- and high-density gases will gradually lose its stability subject to the density gradient, and the turbulence disturbance in the flow field will get stronger, so that the flame front turns to be unsmooth. In many literatures, this phenomenon is called Rayleigh-Taylor instability.

External Explosion: When the flame bypasses the bend and effuses via short pipe behind the bend to the external space (Figure 3.g). A part of flame effused to the outside space after perturbation in bend forms an irregular cloud-like flame.

Backflow combustion: When the flame effuses to the external space, due to the gas inertia, a negative pressure region is formed in the local of the confined space, which helps the influx of external air. During further combustion of the uncompleted gas inside the confined space, due to the lower oxygen content, the flame appears orange-red.

a. *Sphere laminar flame 10ms*

b. *Stretched laminar flame (18ms)*



c. *Accelerated deformation flame (34ms)*

d. *Accelerated deformation flame (40ms)*

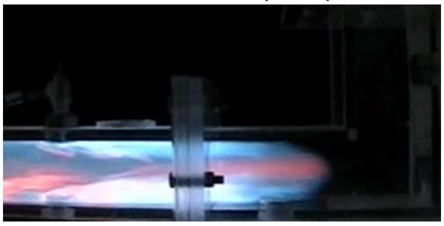
e. *Perturbation tensile deformation (44ms)*

f. *External explosion combustion (46ms)*

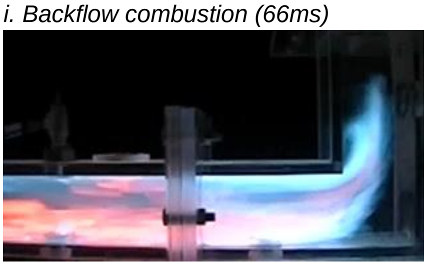
g. *External explosion combustion (50ms)*

h. *Backflow combustion (54ms)*

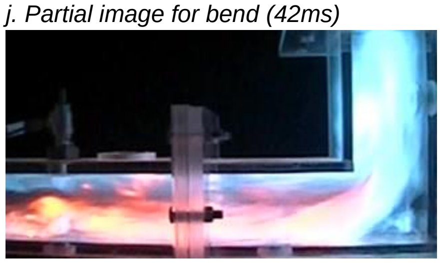
i. *Backflow combustion (66ms)*



j. *Partial image for bend (42ms)*



k. *Partial image for bend (44ms)*



l. *Partial image for bend (46ms)*

Figure 3: Flame propaganda image

3.3 Flame front position and flame propagation velocity

Figure 4 are curves of the flame front in a confined space with a 90° bend structure over time under three different gasoline-air mixture concentrations. They have a consistent law. In the initial stage of gasoline air explosion, the flame front has a less increase. In the accelerated effusion phase, as the chemical reaction aggravates, the flow field turbulence in the confined space increases, the flame front position changes more evidently; in the perturbation acceleration phase, when the flame passes through the bend, as the turbulence in the flow field in the confined space gets violent, the flame front position tends to change more obviously; in the energy attenuation phase, as heat dissipates and the reaction gas content decreases, The flame propaganda velocity swoops after reaching the peak, which is consistent with the internal form change of flame in confined space.

Figure 5 gives the curves of the velocity of internal flame in a confined space with a 90° bend under three different initial concentration as a function of time. In the initial phase of oil gas explosion, affected by the temperature of the flow field and the reaction advancement, the flame front moves slowly and propagates at a low velocity; in the flame acceleration effusion phase, as the chemical reaction aggravates, the temperature and pressure in the confined space continue to rise, and the flame propagation accelerates gradually; in disturbance acceleration phase, the flame spreads abruptly after going through the bend, and the maximum value is obtained at 44ms (Y_{CH}=1.7%); in energy decay phase, as the heat dissipates (enhanced heat losses at vessel's wall) and the reactant gas content reduces, the flame velocity drops rapidly after reaching the peak.

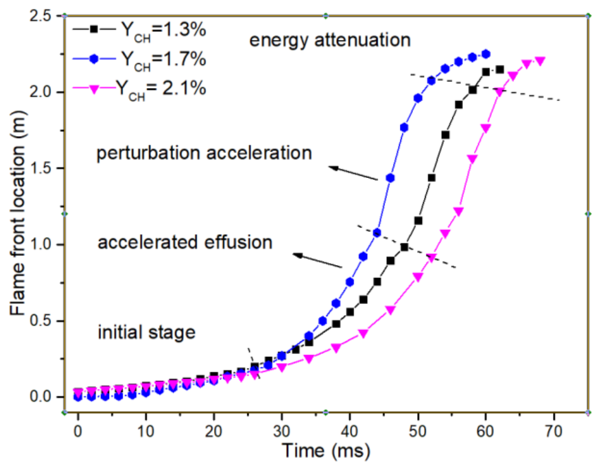


Figure 4: flame front locations along the pipe versus time

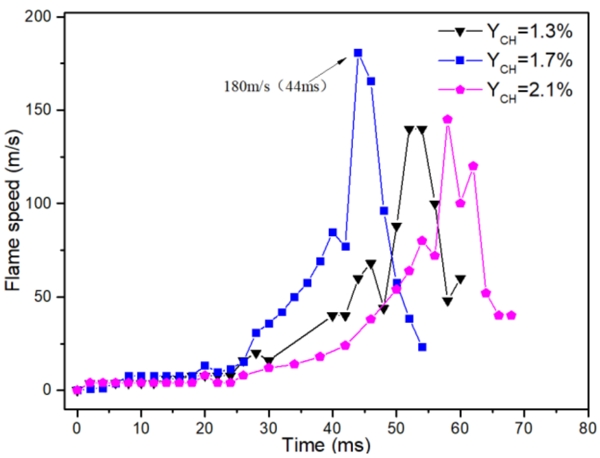


Figure 5: flame speeds along the pipe versus time

4. Conclusions

The internal pressure relief explosion in a confined space with a 90° bend structure can be divided into four phases: constant volume explosion, effusion overpressure, disturbance explosion and oscillation attenuation. The pressure measurement points ahead of and behind bend structure show different characteristics in the effusion overpressure phase. The pressure measurement point before the bend structure presents a positive effusion overpressure, and the pressure measurement point behind the bend structure does a negative overpressure.

The flame propagation in the space with a 90° bend can be divided into 6 phases: spherical laminar flame, tensile laminar flame, accelerated deformation flame, perturbation tensile deformation, external explosion, and

backflow combustion. When the flame propagates to the bend, the front surface deviates from the central axis of the pipe to pipe inner wall and bypasses the bend along pipe inner wall to spread outward.
The change of flame propagation and flame front position within a confined space can be divided into 4 phases: the initial explosion, the acceleration and effusion, the accelerated disturbance and the energy attenuation. The two have a consistent trend with the change in the flame morphology. When the flame passes through the bend, the flame propagation reaches its maximum.

Acknowledgments

Financial support for this work, provided by the National Natural Science Foundation of China (No. 51276195).

References

Bauwens C.R., Chaffee J., Dorofeev S., 2010, Effect of ignition location, vent size, and obstacles on vented explosion overpressures in propane-air mixtures, Combustion Science & Technology, 182(11-12), 1915-1932, DOI: 10.1080/00102202.2010.497415
Bauwens C.R., Chao J., Dorofeev S.B., 2012, Effect of hydrogen concentration on vented explosion overpressures from lean hydrogen–air deflagrations, International Journal of Hydrogen Energy, 37(22), 17599-17605, DOI: 10.1016/j.ijhydene.2012.04.053
Fakandu B.M., Andrews G.E., Phylaktou H.N., 2015, Vent burst pressure effects on vented gas explosion reduced pressure, Journal of Loss Prevention in the Process Industries, 36, 429-438, DOI: 10.1016/j.jlp.2015.02.005
He X.C., Sun J.H., Ding Y.B., Yi Y., Yuan G.J., 2010, Influence of 90° bend on propane-air premixed flame propagation, Journal of Combustion Science & Technology, 16(3), 241-245.
Li G., Du Y., Qi S., Li Y., Wang S., Wang B., 2016, Explosions of gasoline-air mixtures in a closed pipe containing a t-shaped branch structure, Journal of Loss Prevention in the Process Industries, 43, 529-536, DOI: 10.1016/j.jlp.2016.07.022
Molkov V., Makarov D., Schneider H., 2006, Les modelling of an unconfined large-scale hydrogen–air deflagration, Journal of Physics D Applied Physics, 39(39), 4366, DOI: 10.1088/0022-3727/39/20/012
Phylaktou H., Foley M., Andrews G.E., 1993, Explosion enhancement through a 90° curved bend, Journal of Loss Prevention in the Process Industries, 6(1), 21-29, DOI: 10.1016/0950-4230(93)80016-F
Qi S., Du Y., Wang S., Zhou Y., Li G., 2016, The effect of vent size and concentration in vented gasoline-air explosions, Journal of Loss Prevention in the Process Industries, 44, 88-94, DOI: 10.1016/j.jlp.2016.08.005
Sarli V.D., Benedetto A.D., Russo G., Jarvis S., Long E.J., Hargrave G.K., 2009, Large eddy simulation and piv measurements of unsteady premixed flames accelerated by obstacles, Flow Turbulence & Combustion, 83(2), 227-250, DOI: 10.1007/s10494-008-9198-3
Sato K., Sakai Y., Chiga M., 1996, Flame propagation along 90° bend in an open duct, Symposium on Combustion, 26(1), 931-937, DOI: 10.1016/S0082-0784(96)80304-3
Wang C., 2006, Schlieren visualization and numerical simulation on gaseous detonation propagation through a bend tube, Chinese Journal of Theoretical & Applied Mechanics, 38(1), 9-15.
Xiao H., Duan Q., Jiang L., He X., Sun J., 2015, Effect of bend on premixed flame dynamics in a closed duct, International Journal of Heat & Mass Transfer, 88, 297-305, DOI: 10.1016/j.ijheatmasstransfer.2015.04.078
Zhou B., Sobiesiak A., Quan P., 2006, Flame behaviour and flame-induced flow in a closed rectangular duct with a 90° bend, International Journal of Thermal Sciences, 45(5), 457-474, DOI: 10.1016/j.ijthermalsci.2005.07.001