Journal of Loss Prevention in the Process Industries 23 (2010) 253–259

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Explosions in closed pipes containing baffles and 90 degree bends

Robert Blanchard*, Detlef Arndt, Rainer Grätz, Marco Poli, Swen Scheider

BAM Federal Institute for Materials Research and Testing, Chemical Safety Engineering, Explosion Protection and Risk Assessment, Unter den Eichen 87, 12205 Berlin, Germany

A R T I C L E I N F O

Article history:
Received 11 May 2009
Received in revised form
3 September 2009
Accepted 3 September 2009

Keywords:
Explosion enhancement
Deflagration to detonation transition
Bend
Baffle

A B S T R A C T

There is a general lack of information on the effects of full-bore obstacles on combustion in the literature, these obstacles are prevalent in many applications and knowledge of their effects on phenomena including burning rate, flame acceleration and DDT is important for the correct placing of explosion safety devices such as flame arresters and venting devices. In this work methane, propane, ethylene and hydrogen–air explosions were investigated in an 18 m long DN150 closed pipe with a 90 degree bend and various baffle obstacles placed at a short distance from the ignition source. After carrying out multiple experiments with the same configuration it was found that a relatively large variance existed in the measured flame speeds and overpressures, this was attributed to a stochastic element in how flames evolved and also how they caused and interacted with turbulence to produce flame acceleration. This led to several experiments being carried out for one configuration in order to obtain a meaningful average. It was shown that a 90 degree bend in a long tube had the ability to enhance flame speeds and overpressures, and shorten the run-up distance to DDT to a varying degree for a number of gases. In terms of the qualitative effects on these parameters they were comparable to baffle type obstacles with a blockage ratios of between 10 and 20%.

1. Introduction

Explosions in the process industry are still a significant problem leading to injuries, death, destruction of equipment and downtime. As a consequence there is a need in many chemical processes for protection against propagation of unwanted combustion phenomena such as deflagrations and detonations (including decomposition flames) in process equipment, piping and vent manifold systems (vapour collection systems) (Grossel, 2002). Environmental and safety concerns relating to volatile organic solvents (VOCs) have also, in recent years, lead to a vast increase in the amount of piping and number of systems handling flammable fuel air mixtures for collection, containment and transport. Control over these mixtures is also required until flammable gases can be destroyed or safely discharged (Newsholm, 2004). In many of the above situations, in order to aid ATEX compliance, correctly placed and specified flame arresters are needed, dependent on the conditions they are likely to encounter. However, there is still some uncertainty over where best to locate these devices and concerns have been raised with safety standards for flame arrestors in regards to the lack of knowledge of where deflagration to denotation will/can occur in a pipe and what factors can contribute to this effect (Oakley & Thomas, 2004). These concerns persist still to this day and as part of a safety concept related to flame arrestor positioning it is important to be able to predict the mode of burning at various points in a pipe.

Explosions in pipes and ducts, flame acceleration and the transition from deflagration to detonation are well researched subjects (Ciccarelli & Dorofeev, 2008). However, research in this area tends to concentrate on the effects of baffle type obstacles or items in the path of the flow (Ibrahim & Masri, 2001; Masri, Ibrahim, Nehzat, & Green, 2000). Tube bends, for example, are full-bore obstacles used extensively in industrial applications, however little is known about their effects on flame acceleration, overpressure enhancement and their contribution to DDT.

1.1. Research aim

The aim of the research presented in this paper is to communicate data from explosion experiments in an industrial-scale closed pipe containing a 90 degree bend in order to better understand and quantify the affects these types of obstacle can have on flame acceleration and DDT. Experimental data is also compared to that found using baffle type obstacles in the same position as the 90 degree bend.

1.2. Background

Fluid and particle flow through pipe bends is a well understood subject due to its associated practical problems in the process

* Corresponding author. Tel.: +49 30 8104 4258; fax: +49 30 8104 1217.
E-mail address: robblanchard@hotmail.com (R. Blanchard).

0950-4230/$ – see front matter
doi:10.1016/j.jlp.2009.09.004

industry (Berger, Talbot, & Yao, 1983; Burgess, 1971; Green, 1999), however little research has been carried out on explosions through pipe bends, a complicated problem involving the interaction between fluid dynamics, heat transfer and (turbulent) combustion. In the first work carried out on this theme Phylaktou, Foley, and Andrews (1993) showed that with a short tube a 90 degree bend can enhance to both the flame speed and the overpressure for methane–air explosions compared to similar experiments carried out in straight pipes. The flame speed in these experiments was enhanced by a factor of approximately five and was equated to the effects of a baffle with a blockage ratio of 20% at the same position.

Sato, Sakai, and Chiga (1996) investigated the effects of ignition position on the shape of the flame front and the flame speed for methane–air explosions using an open ended small square channel containing a 90 degree bend. However, only a limited number of experiments were carried out and no comparison was given to an experimental set-up without the bend.

A 24% enhancement of the flame speed after a 90 degree bend placed half-way down a tube was observed in propane–air experiments by Chatrathi (1992), the pipe diameter used for these experiments was 152.4 mm and the pipe was open at the end furthest from the ignition source.

Observations of the flame front when travelling though a rectangular 90 degree bend were made by Zhou, Sobiesiak and Quan (2006), who showed that after initially propagating as a flat flame the flame front takes on the tulip configuration (Clanet & Searby, 1996; Gonzalez, Borghi, & Saouab, 1992). As the flame reached the bend the upper tongue (the one propagating towards the outside of the bend) of the tulip slowed down, relatively. Whereas the lower tongue the one propagating towards the inside of the bend began propagating more quickly around the inside of the bend, an effect named “flame shedding” by the authors. 3-D particle modelling of the flow around the bend showed that large vortexes were created just downstream of the inside wall of the bend while flow followed a more streamlined pattern around the outside of the bend. This was in good agreement with latter constant temperature anemometry (CTA) observations made by Lohrer, Hahn, Arndt, and Grätz (2008) who showed that a bend induced a significant increase in turbulence over the first 30% of the inner diameter of the pipe immediately after the bend. Whereas, only a relatively small amount of turbulence was induced around the outer side. Unfortunately in the study of Zhou et al. the bend was relatively close to the end of the tube giving little opportunity to observe the effect of the bend on downstream flow patterns.

Explosions (propane–air) have also been carried out in coiled pipes and pipes with multiple U-shaped bends (Frolov, 2008), while these configurations were able to produce fast DDTs, they are generally of more interest for pulse detonation engines (Roy, Frolov, Borisov, & Netzer, 2004), where fast DDT is a requirement, rather than for industrial-scale pipework carrying potentially flammable gas.

2. Experimental

2.1. Apparatus

A horizontal DN150 steel pipe, shown in Fig. 1, was used for the following tests ($d = 159$ mm). This pipe was made up of a number of segments ranging from 2 to 5 m in length, bolted together with a gasket seal in-between the connections and blind flanges at both ends. Evacuation prior to introduction of the test gas confirmed no significant leaks were present in the pipe. Early work employing constant temperature anemometry techniques (Lohrer, Drame, Schalau, & Grätz, 2008) had also shown that these connections introduced no significant turbulence inducing element to flow along the pipe. The total length of the pipe was approximately 18 m (L), giving an L/d ratio of 112.

Several tests utilised a 90 degree bend segment, this bend had a radius of 0.285 m and added a further 0.447 m to the length of the pipe (based to the centreline length of the segment). Initially this 90 degree segment was placed at a distance of 2 m from the ignition source. Due to the constraints of the dimensions of the room where tests were carried out this was the maximum allowable distance before the pipe bend. Several tests also utilised baffles, these were made from 3 mm thick sheet metal and were placed in-between connections in the pipe. Baffles used in these tests had sharp 90 degree corners and were made in 10% blockage ratio increments. The blockage ratio is defined as the surface area of the obstacle in the pipe over the cross sectional area of the pipe.

2.2. Sensors and data collection

The pipe contained sensor penetrations every 0.5 m in the axial direction which were used to position photodiodes and pressure transducers. Penetrations not used were filled with plugs which sat flush with the inside of the tube.

The position, and hence the speed, of the flame front was determined using BPY 62 Silicon NPN phototransistors (OSRAM) placed at metre intervals along the entire length of the pipe.

The pressure at various points along the length of the pipe was recorded using piezoelectric pressure transducers (PCB M113A22, 1,5 $\pm$ 0.005 mV/kPa) with the signal being processed by a PCB 481 Sensor Signal Conditioner. Pressures reported are the absolute maximum side-on overpressures recorded during experiments and the maximum side-on overpressures after a smoothing function had been applied to original pressure-time signals.

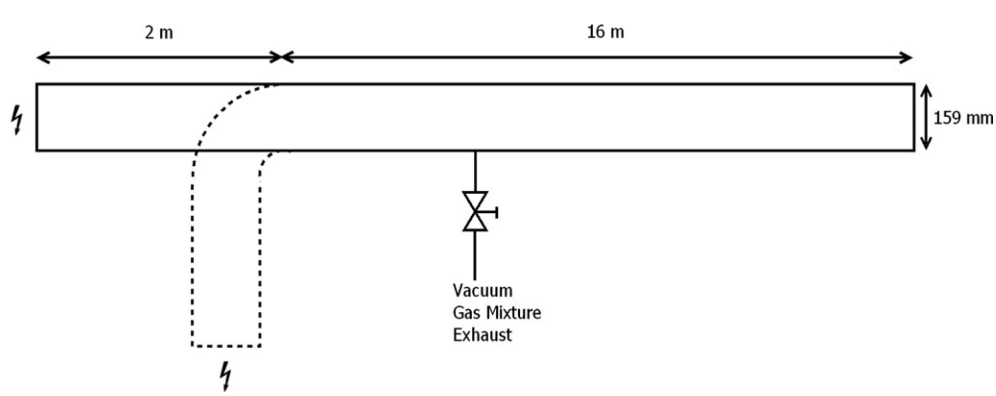

Fig. 1. Schematic of the pipe used for explosion experiments.