The Change in Explosion Overpressures Due to Obstructions

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Introduction

Early studies of explosions have mainly focused on large scale experiments [1] which do not lend themselves easily to complex diagnostics so the available experimental information has been rather limited to measured pressure-time histories. More recently, laboratory scale experiments have extended such measurements to monitor flame shape and flame speed. Studies of flame interaction with obstructions have focused on flows around baffle plates positioned on the wall of the vessel [2, 3]. The work in British Gas focused on a cylindrical tube where obstruction rings were placed at various axial locations on the wall of the cylinder [2, 4]. Flame visualisation studies have shown that unreacted mixture is trapped behind the obstruction rings and this reacts violently, after the main flame front leaves the vessel leading to high overpressures [2, 4]. Lindstedt and coworkers [5, 6] have investigated similar geometries (but different dimensions) and have extended the measurements to include velocity fields as well as averaged species concentrations.

The studies described here represent only a very limited set of scenarios of actual explosions situations where generally, the flame spreads past the ignition points interacting with obstruction of various sizes and cross section such as cylinders, squares, walls and sharp edges. The propagating flame front is likely to interact differently with these obstacles. The resulting overpressures and the amount of unreacted mixtures trapped behind various obstacles is also likely to be different. Current understanding of the nature of such interactions is extremely limited.

A collaborative effort between the universities of Sydney and Loughborough has been established with the aim of resolving the nature of the interaction between premixed flame fronts and turbulence structure. The initial focus is on explosions and on the interaction of the propagating flame front with various obstructions. The change in the turbulence structure, including turbulence level and length scales, is imposed by the size and geometry of the obstruction. This paper is the first report in a series. It is aimed at establishing the experimental configuration and reporting the effects of geometry and blockage ratio on explosion overpressures.

Experimental

The explosion vessel used here consists of a box, 545mm in height, with a square cross section of 195 by 195mm giving a total volume of 20litres of explosive mixture. The walls are 6mm thick perspex retained by a steel frame. The bottom plate is also made of steel. Liquified Petroleum Gas (LPG) (88% C_3H_8, 10% C_3H_6 and 2% C_4H_{10} by vol.) is used here. The fuel-air mixture enters the box through the bottom plate and may be vented through a valve positioned at the top bracket holding the perspex walls. A standard spark plug igniter is placed at the center of the bottom plate which is referred to as the "ignition" end of the explosion unit. The top end, which is referred to as the "vent" end is fully open and is covered with thin plastic film (household plastic wrap) during tests. The film is sealed on a layer of black tar lined around the retaining brackets on the vent end. Various obstructions may be mounted within the explosion unit and these are centred at 150mm from the "ignition" end.

The pressure is monitored using two piezoresistive pressure transducers with a range of 0-1bar (Keller series PR21SR), an accuracy of 0.5% (Total Error Band) and a response time of about 0.1ms. One transducer is placed flush with the bottom plate and is referred to as P_1 and the other is mounted flush with the retaining bracket on the "vent" end and this is referred to as P_2. A photodiode sensor is positioned outside the explosion unit pointing at the spark plug. The photodiode signal is used to determine the onset of the ignition. Signals from the pressure transducers and the photodiode are logged on a 12bit A/D converter sampling at 2kHz. When the contact switch is closed, the ignitor supplies a spark every 20ms. A relay timer opens the circuit after 50ms allowing for a maximum of three sparks to occur. The photodiode registers the spark at which ignition occurs.

Tests are conducted initially without obstructions in the explosion unit. Then, a range of obstruction geometries are introduced with blockage ratios ranging from about 10% to about 78%. The blockage ratio is an area percentage defined here as the largest cross sectional area blocked by positioning the obstruction in the test rig divided by the cross sectional area of the test rig which is $(195\times195)\text{mm}^2$. Table 1 shows specific dimensions for the various obstruction used in the tests:

Table 1: Various obstruction geometries investigated with the explosion unit.

Obstruction Type	Code	Dimensions (mm)	blockage ratio ratio (%)	Comment
Cylinder	C1	Diameter=19.0mm	9.7%	
Cylinder	C2	Diameter=63.5mm	32.6%	
Cylinder	C3	Diameter=106.7mm	54.7%	
Cylinder	C4	Diameter=139.6mm	71.5%	
Square	S1	Side=17.0mm	8.7%	
Square	S2	Side=50.8mm	26.0%	
Square	S3	Side=79.3mm	40.7%	
Square	S4	Side=108.0mm	55.4%	
Diamond	D1	Diagonals=24.0mm	12.3%	
Diamond	D2	Diagonals=71.8mm	36.8%	
Diamond	D3	Diagonals=112.1mm	57.5%	
Diamond	D4	Diagonals=152.7mm	78.3%	
Triangle	T1	Equal sides=24.5mm	12.6%	pointing down
Triangle	T2	Equal sides=62.0mm	31.8%	pointing down
Triangle	T3	Equal sides=103.0mm	52.8%	pointing down
Wall/Plate	W2	Width=40.0mm	20.5%	thickness=6mm
Wall/Plate	W3	Width=107.0mm	54.9%	thickness=6mm
Wall/Plate	W4	Width=146.5mm	75.1%	thickness=6mm

Results and Discussion

Figure 1 shows the effects of increasing the blockage ratio on the pressures obtained for the walls/plates obstruction geometry. Pressure-time traces for P_1 and P_2 are shown. It is clear that as the obstruction ratio increases, the overpressure increases while the venting pressure remains almost uniform. This is true for both P_1 and P_2 although the peak pressures measured at the exit end, P_2 are slightly lower than those measured at the ignition end, P_1. As the blockage ratio increases, the time needed to reach the peak overpressure decreases. This implies that the flame is now accelerating faster due to to the stronger turbulence induced by the larger obstruction.

Figure 2 shows the effects of blockage geometry on the overpressure, P_o and the venting pressure, P_v. Results are shown for various obstruction types used here: cylinders, triangles, squares, diamonds, and walls/plates. The results plotted here are averages obtained from 5 runs. The results are repeatable to within $\pm$ 10%. It is clear from this plot that the geometry of the obstruction does indeed have a direct influence on the explosion overpressure. The highest overpressure is obtained with the wall/plate type obstruction and the lowest is obtained with cylinder type obstructions. Overpressures obtained from square, diamond and triangle type obstructions are intermediate. It is interesting to note here that the venting pressures as well as the time taken to reach P_v are similar regardless of the geometry and the obstruction type. This is consistent with the expectation that the pressure required to break the sealing film (here only one film is used) should be the same regardless of the blockage ratio of type of obstruction. The time delay to reach the peak overpressure (not shown here) decreases with increasing blockage ratio and is shortest for the case of wall/plate type obstruction. This indicates that the flame acceleration rate is dependent on both the obstruction type as well as blockage ratio.

Before reaching the obstacle, the flame is expected to travel at the laminar flame speed since the flowfield ahead of the flame remains undisturbed. When it hits the obstacle, the flame starts to interact with a modified flowfield where the turbulence levels and length scales are different depending on the size and the geometry of the obstruction. This causes the flame to move to a different regime of premixed turbulent combustion on Borghi's diagram [7]. When the blockage ratio increases, the gas velocity in the gap around the obstacle increases along with the turbulence levels. This speeds up the flame and hence the reaction rates leading to a higher overpressure.

The dependence of overpressure on geometry is significant. This implies that the nature of the flow around the obstacle and hence the intensity of the recirculation zone which forms and the amount of unreacted gas which is trapped downstream of the obstacle play a significant role in determining the overpressure. The plate or "wall" type obstructions, gives the highest overpressure implying that here, the volume of fresh mixture trapped behind the plate is largest. With a cylinder type obstruction, the amount of trapped mixture is expected to be low resulting in lower overpressures. The explanations discussed here remain speculations and need to be confirmed.

Conclusions

This paper establishes a new experimental set-up for studying the interaction between premixed flame fronts and turbulence. A specific focus is on explosion phenomena. Turbulence levels and length scales are changed by introducing obstructions in the path of the propagating flame. As the blockage ratio increases, the maximum overpressure increases while the venting pressure remains unchanged. The increase in maximum overpressure depends on the geometry of the obstruction as well as its size. The cylinder-type obstruction yields the lowest overpressures while plates and wall-type obstruction results in the highest overpressures.

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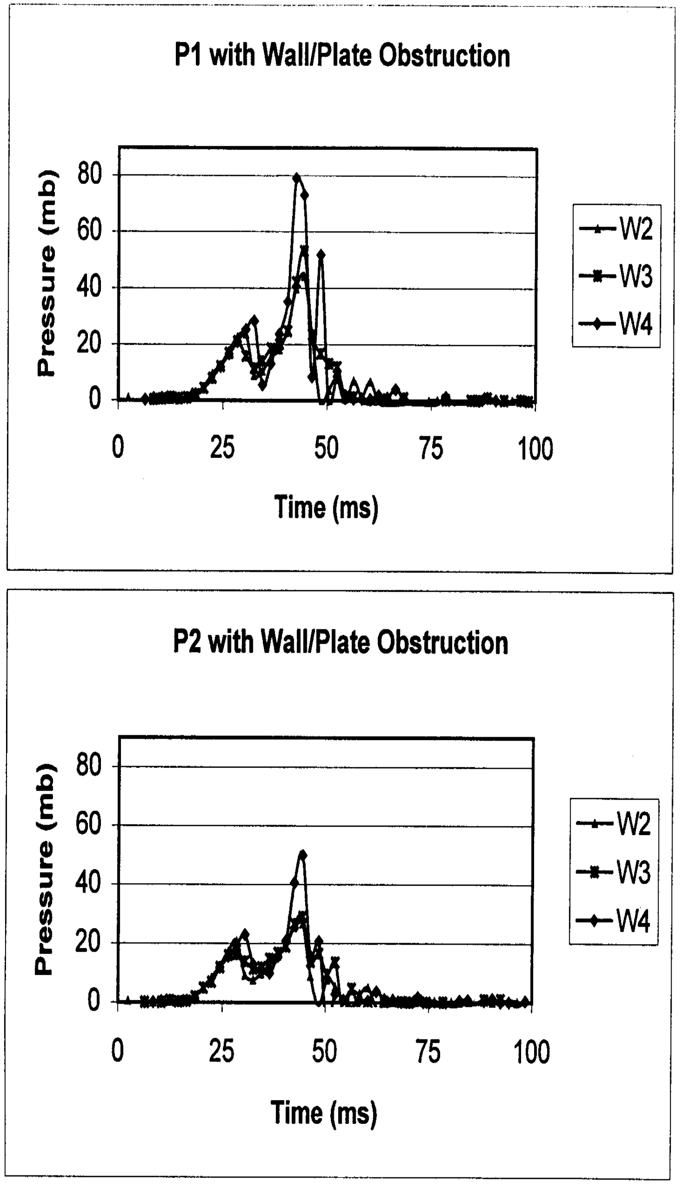

Fig 1. Pressure-time traces showing the effects of increasing blockage ratio

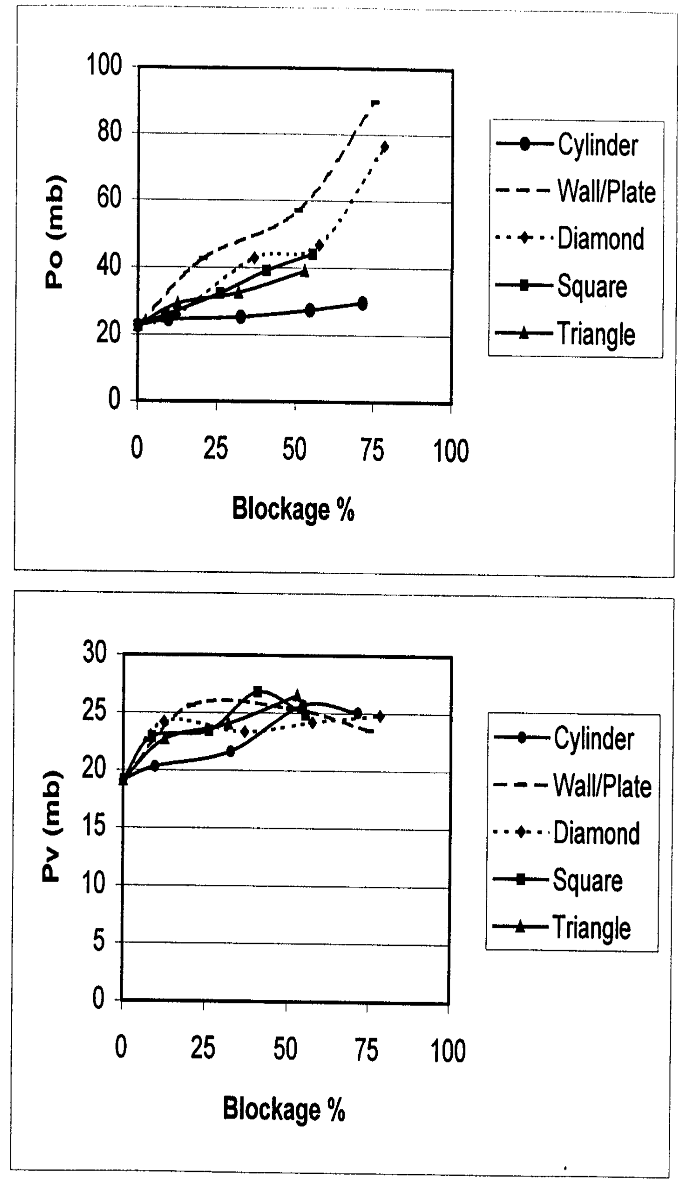

Fig 2. Overpressure Po and venting pressure Pv versus blockage ratio for a range of obstruction geometries.