Evidence from explosions in vessels divided into two compartments which are connected by a small opening, show that ignition in one can propagate into the other producing peak pressures and rates of pressure rise several times greater than in single vessel explosions, an effect referred to as pressure piling. Calculation of these pressures and rates of pressure rise has up to now not been possible. This paper will present a review of the pressure piling hazard including experimental data that can be used to formulate a semi-empirical model for hazard prediction. The relative importance of parameters such as the volume and shape of the chambers, the point of ignition, the size of the connecting tube and the type of gas mixture will be discussed and limitations of available data stated.

Key words
explosions, pressure piling, vessels, explosion pressure, hazard

1. INTRODUCTION

Stoichiometric mixtures of most hydrocarbons in air (initially at atmospheric temperature and pressure) produce explosion pressures of about 8 bar in single vessel. If the vessel is in the form of two chambers connected to each other by a small diameter tube these same mixtures have been shown to produce peak pressures in excess of 35 bar. The explosion of gases in multicompartmented vessels is usually referred to as "pressure piling." Pressure piling was recognised as a special explosion hazard by Beyling when he noticed that enclosures that were divided into separate compartments and connected by small tubes, tended to suffer very violent and destructive explosions.

In the chemical industry interconnecting vessels and pipes handling flammable materials are commonplace and the hazard posed by pressure piling is therefore of considerable relevance.

The first piece of work undertaken specifically to investigate pressure piling was by Grice and Wheeler, who were initially working with spheres of up to 8 litres capacity, connected by short lengths of steel tubing 3.2 cm diameter, and a mixture of 9.5% methane in air. The effect of the size of the passage connecting the compartments upon the extent of pressure piling was studied by Brown using a pair of cylinders whose volume ratio was 13.5. The diameter of the connecting tube was varied from 0.64 cm to 2.54 cm, and its length from 6.35 cm to 38.10 cm. The results of this study showed that change in the length of the connecting tube is much less marked than the effect of change in diameter. Indeed, over the range of lengths used the peak pressure remained virtually constant at about 34.5 bar.

A thorough study of the subject was also undertaken by Gleim and Marcy. They worked with a box constructed from steel plate which could be sub-divided into different sections of
different volume ratios by partition plates having openings of various sizes. Apart from changing the volume ratios and the size of the hole in the partition plates, they investigated the effect of varying the position of the spark.

The most recent and comprehensive study investigated all the parameters important to pressure piling on the same system in order to assess their relative importance and their interrelationship. All the experiments were carried out in a pair of cylindrical chambers connected to each other by a small tube (see figure 1). The larger vessel, referred to as the primary chamber, could be made up by joining any combination of three cylinders whose internal diameter was 30.48 cm and whose lengths were 22.86 cm, 29.85 cm and 45.09 cm. Seven different lengths could be achieved in this way. The small, secondary chamber, was a cylinder whose internal diameter was 15.24 cm, and effective length 38.1 cm. The volume of this vessel could be varied by adjusting the position of a gas-tight piston fitted inside it.

The two chambers were connected to each other by a cylindrical tube whose internal diameter was 7.62 cm and into which pipes of various wall thickness could be inserted, and in this way the internal diameter of the connection was altered. The length of the connection was fixed at 26.0 cm. The gas mixtures used in the course of the experiments were 9.5% methane in air, and 4.05% propane in air, both corresponding to approximately stoichiometric concentrations.

The extensive data from this last study will be used to explain the variables important in pressure piling and to generate an empirical basis for the prediction of maximum explosion pressure.

2. **TYPICAL EXPLOSION PRESSURE DATA**

The typical form of a pressure-time trace following ignition of a gas mixture is shown in figure 2 where the rise in pressure in both compartments is shown. The maximum pressure in the primary (larger) compartment is $P_m$, close to the value in a single vessel explosion; the peak pressure $P_k$ occurs in the secondary (smaller) vessel. In the explosion build-up, ignition in the secondary vessel occurs when the pressure in that vessel is $P$, and the corresponding primary pressure is $P_z$.

Some typical data for the peak pressure $P_k$, as a function of the connecting tube diameter ($d_c$) are shown in figure 3. This covers primary chamber volumes 21.8 and 54.6 litres and a volume ratio of 14.0. As a rule, the peak pressure is reduced with increase in $d_c$. This is consistent with the data from Brown. For a fixed volume ratio and connecting tube ($d_c$), an increase the primary chamber volume increases the peak pressure. For example, peak pressure with a primary chamber volume 54.6 litres is typically over twice that with a volume 21.8 litre, both at a volume ratio of 14.0.

Further peak pressure data, this time for a fixed connecting tube diameter, are shown in figure 4, as a function of primary chamber volume. This confirms that although volume ratio between the compartments is important, the scale effect is dominant.

The effect of volume ratio between the connected vessels is more clearly illustrated in figure 5. This shows that in fact $P_k$ peaks at some value of volume ratio and then further increases in the ratio lead to a reduction in pressure.
The data in figures 3 to 5 relates to gas ignition at the centre of the primary chamber; figure 6 shows a comparison between the peak pressure due to central ignition and due to ignition at the extreme (furthest away from the connecting tube). By moving the ignition source in this way, the peak pressure is typically increased by a factor of 1.80.

3. EVALUATION OF MAIN VARIABLES

3.1 Basic Principles

The pressure-time relationship for explosions in single vessels follow the well documented 'S' shape and methods for accurate analytical description are available. The maximum explosion pressures \( P_f \) in such explosions, which varies with the type and concentration of the flammable mixture and the initial conditions of temperature and pressure, can be calculated from:

\[
P_f = P_0 \left( \frac{T_b}{T_0} \right) \left( \frac{M_f}{M_o} \right)
\]

(1)

where \( P_0 \) is the initial pressure, \( T_0 \) the initial temperature, \( T_b \) the mean burnt gas temperature and \( M_o \) and \( M_f \) are the moles of reactants and products respectively. Approximate values for fuel-air mixtures can be obtained from:

\[
P_f' = P_0 \left( \frac{T_f}{T_0} \right)
\]

(2)

where \( T_f \) is the flame temperature of the fuel-air mixture.

Let us now consider a pair of vessels connected to each other by a pipe as shown in figure 1, with both vessels containing the same flammable mixture at a pressure of \( P_o \). If the mixture is ignited in the primary chamber at some point near the centre, the ensuing flame will expand outward from the ignition point causing a simultaneous rise in pressure. This will immediately produce a pressure difference between the primary and secondary chamber causing unburnt gas to be pushed out into the latter chamber. This process will continue until the flame propagates into the secondary chamber itself and ignites the gas within it.

However, whereas the system was originally at a pressure \( P_o \), the pressure in the secondary chamber at the point of ignition will be \( P_f' > P_o \). Hence from equation (2), the maximum possible pressure in the secondary chamber will be

\[
P_f' = \eta P_f
\]

where \( \eta \) is a constant for the particular gas mixture and approximately equal to \( (T_f/T_0) \). (Strictly, the value of \( \eta \) for the initial mixture (at \( P_o \)) will be different to that for the
compressed gas at $P_1$, but the difference is relatively minor). The actual peak pressure experienced by the secondary chamber will be $P_k$, less than $P_k'$ due to the fact that some gas will be vented back into the primary chamber. Hence in general,

$$P_k = P_k' - \Delta P = \eta P_1 - \Delta P$$  \hspace{1cm} (3)$$

where $\Delta P$ is the reduction in pressure caused by the back-venting.

Even from this simple description of the explosion process, a number of the features observed in experiments can be explained. Consider for example an increase in the length of the primary chamber, the position of the ignition source being in the centre of the chamber. The initial influence of this will be to delay the time at which ignition in the secondary chamber will occur (since the flame will now travel a greater distance). Thus the quantity of gas that will be pushed out from the primary chamber and as a consequence the pre-ignition pressure $P_1$ in the secondary chamber will be higher than before, causing in turn an increase in the peak explosion pressure.

### 3.2 Flame Movement in Primary Vessel

When ignition occurs in the primary (large) vessel, the flame grows outward from that point as pressure increases. When the pressure has risen to $P_z$ (and the pressure in the secondary vessel is $P_2$), ignition in the secondary vessel occurs.

In the experiments by Grice and Wheeler in spherical chambers, some photographs showing flame movement were taken. For central ignition in the larger sphere, the flame travelling towards the smaller, the photographs showed that in the early stages the flame propagated symmetrically in all directions just as it would in the absence of compartmentation. After a few centimetres travel, it displayed a tendency to move more quickly towards the opening into the smaller chamber than in other directions; eventually it very quickly accelerated into the smaller chamber (half the size of the larger one), in which the gas was in a state of turbulence, before the flame in the larger chamber had reached the walls.

It seems that the unburnt gas between the flame front and the connecting tube assumes a velocity similar to that in the connecting tube (which is much higher than in the primary chamber generally) at some point ahead of the entry to the tube and when the flame reaches this point, it is seen to accelerate into the tube and across to the secondary chamber. In fact it could be said that the effective entrance to the connecting tube is some distance ahead of the real entrance. This distance, $Z$ say, determines the point at which flame transfer to (and subsequently ignition in) the secondary chamber will result.

The relationship between flame position and pressure is well established for explosions in closed vessel. For example, in a spherical vessel:
\[ I_b = I \left( \frac{(P/P_o)^x - 1}{(P/P_o)^x - \alpha} \right) \]  

(4)

where \( r \) is the vessel radius and \( r_b \) the flame radius at pressure \( P \). \( (P_o, \alpha) \) is the initial pressure, ratio of the burnt to the unburnt gas density and \( x = 1/\gamma \), where \( \gamma \) is the ratio of specific heats for the unburnt gas).

Thus, if \( P_z \) is known experimentally, then from equation (4) the flame position \( r_b \) can be calculated. The distance \( Z \) from the connecting tube at which flame transfer occurs is therefore:

\[ Z = I - I_b \ (P_z) \]  

(5)

A number of systems were studied in this way and lead to the following empirical relationship:

\[ Z = d_c^{2.3} \]  

(6)

(both \( Z \) and \( d_c \) being in centimetres). This suggests that \( Z \) is strongly influenced by gas flow rate through the connecting tube, itself proportional to \( d_c^2 \). Further evidence is available which supports the view that \( Z \) is a function only of flow rate through the connecting tube. As the flow rate increases, \( Z \) is increased. Using equation (6) and relationships such as equation (4) it is possible to calculate the pressure \( P_z \) at which flame flashes across into the secondary vessel, for any diameter of the connecting pipe. These equations, simplified with typical physical properties for stoichiometric hydrocarbon-air mixtures are:

For spherical vessels (radius \( r \)):

\[ \frac{P_z}{P_o} = \frac{-0.265 \ (1 - Z/r)^3 - 0.735}{0.602 \ (1 - Z/r)^3 - 0.735} \]  

(7)

For short cylinders (radius \( r_c \))

\[ \frac{P_z}{P_o} = \frac{(0.353/r_c^2 L) \ (L/2 - Z)^3 - 0.735}{(0.802/r_c^2 L) \ (L/2 - Z)^3 - 0.735} \]  

(8)

For long cylinders

These equations relate to central ignition in the primary vessel.
3.3 Pre-ignition Pressure in Secondary Vessel

It is possible to calculate, analytically, the pressure in the secondary vessel \( P_z \) corresponding to that in the primary vessel \( P_o \), as the explosion develops. However, this requires considerable computation and so an alternative empirical approach is suggested based on experimental data. Analysis of experimental pressure-time records indicates that the fractional pressure rise in the two vessels is relatively constant for a given set of conditions. That is:

\[
\frac{P_1 - P_o}{P_z - P_o} = \text{Constant} = \sigma_z
\]

This pressure ratio correlates quite well with the parameter:

\[
\lambda = \frac{d_c^2}{S_v V_o} r
\]

where \( V_o \) is the primary chamber volume, \( S_v \) the burning velocity and \( r \) the radius of the primary vessel if it is a sphere; otherwise replace \( r \) by \( r_s \) given by

\[
r_s = \left[ (3/4) \right] \left( \frac{r_c^2 L}{V_o} \right)^{1/3}
\]

The reciprocal of \( \lambda \) represents the rate at which the explosion develops (\( \lambda \) has units \( \text{s/m}^3 \)); low values of \( \lambda \) (i.e. high velocity) lead to large differences in pressure between the two vessels while at high values (low velocity) pressures are very similar.

The empirical relation between \( \sigma_z \), the pressure ratio, and \( \lambda \) is plotted in figure 7.

Note that at \( \lambda \approx 0.2 \text{ s/m} \), \( \sigma_z \) approaches a limit of approximately 0.96 and above this value, pressures in the two vessels are almost equal. The relationship between \( Z \) and \( d_c \) (i.e. equation 6) is valid only up to this point.

Thus, the compression in the secondary vessel, \( P_1 \), may be calculated from

\[
P_1 = P_o + (P_z - P_o) \sigma_z(\lambda)
\]
where \( \sigma_2 (\lambda) \) may be obtained from figure 7 for the relevant equipment geometry.

3.4 Back-venting from Secondary Vessel

Referring back to equation (3) for calculation of \( P_k \), the next step is to evaluate \( \Delta P \), the back-venting from the secondary chamber. When the flame transfers from the primary to the secondary chamber, the gas mixture that it encounters in the secondary chamber is at a pressure, \( P_1 \), higher than when ignition occurred in the primary chamber. Ignition in the secondary chamber causes the pressure within that vessel to rise very rapidly (due to the fact that the gas is in a state of turbulence). As a result, this pressure soon exceeds the level in the primary chamber, causing burnt gas to be vented back into the primary chamber. There is, however, lack of detailed information regarding the combustion process in the secondary chamber. There is uncertainty for example regarding the nature of the turbulent combustion and hence the rate of pressure rise, the transport properties of the gas vented out of the secondary chamber, the gas flow mechanism through the connecting tube and the degree of choking that takes place inside it. In the absence of this information, an empirical approach may be used. Based again on experimental data\(^6\), the back-venting may be calculated from:

\[
\Delta P = \left( \frac{2 \cdot 31}{S_u} \frac{d_c^2}{V_s} \right) P_1
\]

where \( V_s \) is the volume of the secondary vessel. Combining this with equation (3) leads to the following expression for the peak explosion pressure:

\[
P_k = P_1 \left( \eta - \frac{2 \cdot 31}{S_u} \frac{d_c^2}{V_s} \right)
\]  

(11)

3.5 Effect of Variations in the Point of Ignition: Qualitative Aspects

The discussion above and indeed the applicability of equation (11) applies only to explosions resulting from gas ignition in the centre of the primary vessel. It is necessary to evaluate the influence of the point of ignition because this can affect the severity of the explosion.

Consider a pair of connected cylinders, the primary one being of length \( L \) and radius \( r_c \), where \( r_c \ll L \). Suppose the distance from the point of ignition to the primary chamber end furthest from the connecting tube is \( y \), which can be varied from \( L \) to zero. When the point of ignition is such that \( y \) is nearly equal to \( L \), the pressure in the primary (and in the secondary) chamber will rise by only a small amount when flame transfer occurs (i.e. \( P_c \) will be small). Essentially, under these conditions, the flame will expand spherically and when it gets to a distance \( Z \) from the connecting tube, it will flash across.

As \( y \) is decreased, the distance that the flame has to travel, and hence also the degree of burning that takes place prior to flame transfer, will increase and consequently so will \( P_c \).
This is illustrated in figures 8a and 8b where the shaded areas represent the volume of gas burnt.

Eventually, as \( y \) is decreased to below \( L/2 \), a critical point of ignition, \( y_c \), will be reached when all the gas between the point \( z \) and the extreme end of the primary chamber will be totally burnt at the precise moment of flame transfer. This is shown in figure 8c. If \( y \) is decreased still further, the amount of gas burnt prior to flame transfer will be unchanged (see figure 8d) and hence \( P_z \) will also be unchanged. Clearly then, if the point of ignition is anywhere between \( y = \text{zero} \) and \( y = y_c \), the value of \( P_z \) should remain constant.

The pre-ignition pressure in the secondary chamber, \( P_1 \), corresponding with values of \( P_z \) is related by the parameter \( \sigma_z \) which is itself a function of \( \lambda \). In general \( \lambda \) (and \( \sigma \)) are functions of the gas mixture and the experimental system only, except that when the flame propagation rate changes (as a result of ignition at one end of a vessel as opposed to the centre, for example) the effective burning velocity is altered. This will alter both \( \lambda \) and \( \sigma \). Thus \( P_1 \) will increase as the point of ignition is moved away from the connecting tube (during the initial stages as a result of increase in \( P_z \), with \( \sigma \) constant, and later for values of \( y = y_c \), when \( P_z \) is constant, due to increase in the value of \( \sigma \)).

Hence, unlike \( P_z \), \( P_1 \) would not be expected to become constant for \( y \) less than \( y_c \). Furthermore, as \( P_k \) is proportional to \( P_1 \) (assuming equation (11) to be valid) the former should also increase continuously as the ignition point is moved away from the connecting tube.

Experimental verification of the above trends is clearly essential to establishing the credibility of the model. Experimental data with a stoichiometric methane-air mixture using a primary chamber of volume 32.9 litres is shown in figure 9. The diameter of the connecting tube is 1.6 cm, volume ratio 14.0 and the point of ignition was moved along the axis of the primary chamber. Clearly the results relating to \( P_z \), \( P_1 \) and \( P_k \) are all in agreement with the qualitative predictions discussed above.

### 3.6 Peak Explosion Pressure Due to Ignition at the Extreme End of the Primary Chamber

From a practical viewpoint, it is of interest to know the maximum possible hazard, irrespective of where ignition takes place. In practice this necessitates determining the maximum explosion pressure when the source of ignition is at the primary chamber end furthest from the connecting tube. The analysis for doing such a calculation changes in two ways compared with central ignition: firstly it changes because the explosion develops more slowly, and secondly because the amount of gas burnt in the primary chamber prior to flame transfer increases.

The decrease in the rate of pressure rise in the primary chamber (prior to flame transfer) is reflected in \( \sigma_z \), which increases slightly. For cylinders of the shape discussed in the last section, (and used in this study) \( \sigma \) can be determined in the same manner as for explosions due to central ignition (i.e. from figure 7) provided \( S_u \) in \( \lambda \) is replaced by the 'effective' burning velocity \( S_{u,\text{eff}} \), where:
to reflect the fact that ignition is at one end.\(^7\)

The increase in the amount of gas burnt in the primary chamber (prior to flame transfer), which is the second main effect of moving the point of ignition from the centre of the extreme end of the primary chamber, results in an increase in \(P_z\). The pressure \(P_z\) is dependent upon the development of the flame front and its position prior to flame transfer and therefore in order to calculate \(P_z\), the movement of the flame front must be quantified. It is possible to develop simple expressions for end-ignition, similar to the above treatment for central ignition.\(^5\) Alternately, the effect can be incorporated by simply comparing data ignition at the two positions. The data for a range of systems is shown in Figure 6 and this indicates that:

\[
\frac{P_k \text{ (end ignition)}}{P_k \text{ (central ignition)}} = 1.80
\]

Therefore it is possible, for any system, to calculate \(P_k\) initially for central-ignition and then modify this value according to the above ratio.

4. APPLICATION OF THE MODEL

1. Basic Procedure

The information required in order to use the empirical model is the following:

(a) dimensions of the primary chamber
(b) diameter of the connecting tube
(c) volume of the secondary chamber
(d) \(S_u\) and \(\eta\), for the unburnt gas at the pre-explosion conditions.

Before proceeding with the calculation it is necessary to decide the likely point of ignition, the centre or the extreme end of the primary chamber being the two points considered in detail in the model. If the ignition point is unknown, then ignition at the extreme end should be taken, this being the most pessimistic.

For central ignition the calculation procedure is the following:

1. Calculate \(\lambda = d^2 z / S_u V_a\).
   - For a cylindrical vessel, replace \(r\) by \(r_s\), the radius of a sphere, equivalent in volume to the primary chamber.
2. Using Figure 7, evaluate \(\sigma\).
3. From equation (6) calculate \(Z\).
4. Using the equation appropriate for the primary chamber geometry, evaluate \(P_z\). The simplified equations (which incorporate physical properties of stoichiometric
hydrocarbon-air mixtures) for $P_z$ are the following:

- spherical chambers, equation (7).
- short length cylinders, equation (8).
- long cylinders, equation (9).

5. Evaluate $P_1$ from the expression

$$\sigma = \frac{P_1 - P_2}{P_x - P_0}$$

6. Substitute $P_1$ into equation (11) to give $P_z$.

The above procedure cannot be used for $\lambda > 0.2$; see later for further discussion.

If ignition is assumed to be at the end of the primary chamber furthest from the connecting tube, two alternatives are available. The first is to use the above procedures for central ignition and then multiply the value of $P_z$ by 1.80. The second is to apply suitable modifications to the above steps and thus calculate $P_z$ 'rigorously'.

4.2 Comparison with Experimental Results

The explosion pressure predicted by the above procedure can now be tested against experimental data.

Two systems are presented for comparison: 71.4 litre and 54.6 litre chamber, both with a connecting pipe diameter of 1.9 cm. The flammable gas is methane. The values of $P_z$ from equation (11) as a function of volume ratio are shown in figures 10 and 11 together with the experimental results. Good agreement is obtained.

4.3 Explanation for 'Peaking' of Explosion Pressure

It was noted in the experimental data (e.g. figure 5) that the explosion pressure reaches a maximum as volume ratio between the vessels is increased and further increases in the ratio can lead to a reduction. The explanation for this is related to balance between compression of the gas in the secondary chamber (which leads to an increase in the explosion pressure) and the back-venting (which leads to a reduction in pressure). In the example considered above (see figure 11) the explosion pressure is seen to plateau (also predicted by the model).

If the point at which this maximum occurs corresponds closely with the pressures in the connected vessels being very similar to each other during explosion build-up. This takes place when $\lambda \geq 0.2$. (This is also the point at which the empirical model for explosion pressure prediction breaks down). This means that the worst configuration can be predicted and is a function of $\lambda$ and not any individual variable (such as volume ratio).
The diameter of the pipe connecting the two chambers is a particularly important variable. As the diameter is increased, the pressures in the two vessels become more similar (i.e. the partition is less effective) and so the peak pressure is reduced. The smallest size permissible which would still avoid pressure piling may be estimated by reference \( \lambda \); as \( \lambda \) gets much above 0.2 the peak pressure will fall rapidly.

5. CONCLUSIONS

The equations presented should enable the explosion hazard presented by a pair of interconnected vessels to be assessed from a knowledge of the system geometry and the nature of the flammable gas. Although experimental verification will be necessary, it is expected that the results can be extrapolated to systems somewhat larger than studied at present, possibly up to a volume of a few hundred litres. Within this range, accuracy may be of the order to 10%.

Possible areas of application include electrical equipment casings in flammable atmospheres, and vessels and reactors for flammable gas handling systems such as in hydrocarbon oxidation plants. If the magnitude of the hazard is identified during the design stage, the either the process equipment can be designed to contain the explosion or the phenomenon can be ‘designed out’ by selecting suitable equipment geometries.

It has been suggested that if the connecting tube as used in this study is replaced by a short orifice type connection, the system behaviour could be substantially altered due to the difference in turbulence that this would cause compared with tube. The fact that varying the length of the connecting tube from about 6 cm to 38 cm had no effect upon the explosion behaviour and that the degree of turbulence in the secondary chamber is so large even with a tube connection that it behaves almost like a stirred reactor, suggests that changing to an orifice type connection should have little or no effect. However, this also needs to be confirmed experimentally.

Another feature that would particularly benefit from further analysis is the mechanism of flame transfer from the primary to the secondary chamber. The complexity of this process is probably not adequately reflected by the model described.

SYMBOLS USED

- \( d \) diameter of connecting tube
- \( L \) length of cylinder (primary chamber)
- \( M_r \) moles of burnt gas (products)
- \( M_u \) moles of unburnt gas (reactants)
- \( P \) absolute pressure
- \( P_t \) pressure (absolute) in secondary chamber just prior to ignition in it
- \( P_p \) peak pressure (absolute) in a single vessel explosion
- \( P_s \) peak pressure (absolute) in the secondary chamber
- \( P_0 \) initial pressure (absolute)
- \( P_{t1} \) initial pressure in primary chamber
- \( P_u \) maximum pressure in primary chamber
- \( P_Z \) pressure in primary chamber just before ignition in secondary vessel
REFERENCES

FIGURE 1: TYPICAL SETUP FOR PRESSURE PILING EXPERIMENTS

FIGURE 2: A TYPICAL RECORD OF AN EXPLOSION IN COMPARTMENTED VESSELS SHOWING THE VARIABLES MEASURED
FIG 3: EXPLOSION PRESSURE Vs CONNECTING TUBE DIA.
(TEST GAS: STOICHIOMETRIC METHANE-AIR)

Primary Vessel 54.6 Litres, Vol. Ratio = 14

Primary Vessel 21.6 Litres, Vol. Ratio = 14

FIG 4: EXPL. PRESSURE Vs VOLUME OF PRIMARY VESSEL
(GAS: STOICHIOMETRIC METHANE-AIR)

Vol Ratio = 14, Tube dia = 1.9 cm

Vol Ratio = 8, Tube dia = 1.9 cm
FIG 5: EXPLOSION PRESSURE Vs VOLUME RATIO
(PRIMARY VESSEL VOLUME = 54.6 Litres)

FIG 6: EXPLOSION PRESSURE AT RANGE OF CONDITIONS
EFFECT OF IGNITION POINT IN PRIMARY VESSEL
FIGURE 8: EFFECT OF THE POSITION OF THE SOURCE OF IGNITION ON THE DEGREE OF COMBUSTION PRIOR TO FLAME TRANSFER
FIG 9: EFFECT OF CHANGE IN POINT OF IGNITION

FIG 10: COMPARISON OF PREDICTED & CALCULATED DATA
(Primary Chamber Volume = 71.4 Litres)
FIG 11: PREDICTION OF PEAK EXPLOSION PRESSURE
(Primary Chamber Volume = 54.6 Litres)

- O: Calculated
- ●: Experimental

PEAK PRESSURE [bar a]

VOLUME RATIO

14.00 16.00 18.00 20.00 22.00
5.00 10.00 15.00 20.00 25.00 30.00 35.00