A METHOD FOR ASSESSING THE CONSEQUENCES OF SMALL LEAKS IN ENCLOSURES

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Recently there has been interest in the possible consequences of a small leak of natural gas from high-pressure plant located in a confined volume. This paper describes a method for assessing the explosion hazards produced by such leaks. The method may be used for natural gas fired plant in turbine halls, for example. Of particular interest in this context is a method for assessing the consequences of the largest leak that is not detected by a gas detection system of a specified sensitivity.

The scenario that is analysed is a high-pressure release of natural gas into an enclosure. The natural gas mixes with the surrounding air and the gas concentration distribution in the enclosure increases towards a steady state determined by the leak mass flow rate, location and orientation, the volume and shape of the enclosure and the ventilation characteristics of the enclosure. If the enclosure has a gas detection system then it is possible that the leak could be detected and mitigating actions taken before the steady state conditions are reached. The flammable volume that is produced by such a small leak may never then reach the hypothetical steady state value that would be created if the leak had not been detected. In this work, the consequences of igniting the flammable volume that is produced by the leak, whether it is detected or not, are evaluated. The method that is used to assess the consequences includes mathematical models for the leak flow rate, the gas dispersion or accumulation and the pressure generation, should a flammable volume be ignited.

The method has been applied to a number of gas dispersion experiments carried out in enclosed volumes and has been found to give reasonable agreement with the data for the flammable volumes that are produced by the leaks. As an illustration of its application, the methodology is applied to two enclosures with different ventilation systems. In both cases, the predicted consequences of a small leak are evaluated and discussed.

KEYWORDS: Gas releases, Gas explosions, Small releases, consequence assessment

INTRODUCTION

This paper describes a method for assessing the explosion hazards produced by small leaks in natural gas handling plant situated within an enclosure, such as a gas turbine hall. Historical data demonstrates that small leakages from fittings or connections are more likely to occur than larger releases associated with the complete failure of a vessel or pipe-work. Hence, there is a need to assess the consequences of small releases, to ensure that the hazards that they pose are understood and are being controlled. Of particular interest is the possibility of the formation of a flammable mixture of gas and air in the immediate neighbourhood of a small release. Such an accumulation might be difficult to detect and so persist for a long time, posing a possible explosion hazard.

This paper provides an explanation of the methods that can be used to assess the explosion hazards produced by a natural gas release in an enclosure. Particular attention is paid to ensure that the methods can be used for the smaller, more credible releases. From a practical viewpoint, the individual methods have been linked in such a way that they can provide an estimate of the size of the largest release that just fails to trigger an alarm from a gas detector of a given sensitivity placed in the outlet from the enclosure or can be used to investigate the effects of different mitigation actions, such as isolation and blowdown of the gas supply pipe-work on gas detection.

A description of the separate models that are used to predict the leak flow rate, gas accumulation and overpressure generation, should any flammable cloud ignite, is given in the following Section and the way in which these individual models are combined to analyse a release inside an enclosure is explained. A comparison of the resulting method with experimental data is then provided, along with two examples of the application of the model. Finally, the paper ends with a discussion of the results of this work.

INDIVIDUAL MODELS

The separate models that are used to assess the consequences of small releases are discussed individually below.

LEAK FLOW RATE

The first step in assessing the consequences of a natural gas leak in an enclosure is the specification of the leak flow rate. The operating pressure of the gas handling equipment under consideration is known in most cases. The area through which the leakage occurs is more difficult to define. It is sensitive to the mode of failure, the type of equipment and the operating environment. Further, failure frequency databases rarely include detailed information on leak size to allow conclusions to be drawn

Nevertheless, guidance documents for hazardous area classification (HAC) often include information on what is viewed as a maximum 'credible' leak – that is, one that is likely to be experienced in the lifetime of a plant. The hazardous area classification recommendations for natural gas installations, IGE SR25[1], specifies a maximum credible leak area of 0.25 mm^2, for non-vibrating equipment with dry natural gas and 2.5 mm^2 for equipment operating in adverse environments (i.e. not clean or vibrating). The 1996 version of Institute of Petroleum Code of Practice for HAC, IP15[2], provides guidance for facilities used for the storage, transportation and processing of flammable liquids, and also includes guidance for equipment processing flammable gases. It specifies the extent of a 'hazard radius' around different types of equipment. The hazard radius is defined as the largest horizontal extent of the hazardous area generated by a leak when situated in an open area. The hazard radius defines the distance to a 'safe' gas concentration. Using correlations given by Birch et al[3], for natural gas concentration decay on the axis of a sonic natural gas free jet, the leak diameter or area that is associated with the hazard radius can be inferred once a 'safe' concentration and operating pressure are defined. Table 1 shows the values that have been deduced for the equipment listed in IP15. . These results are obtained assuming an unimpeded leak directed horizontally close to the ground and by taking a safe concentration of one half of the lower flammable limit for natural gas (2.5%) and an operating pressure of 100 bar.

Equipment	Hazard Radius (m)	Leak Diameter (mm)
Compressor	5*	2.6
Diaphragm Compressor	3	1.6
Flange	1.5**/3	0.78/1.6
Valve	1.5**/3	0.78/1.6
Instrument vent		
Diameter 6 mm	3	1.6
“ 12 mm	7.5	3.9
“ 25 mm	15	7.8

* - Compressors fuelled by natural gas

** - Flanges or valves broken infrequently (2 years or more), and there are no other factors, such as pressure or thermal shocks or excessive pipe loading.

Table 1 – Leak sizes inferred from the hazard radii specified in IP15.

The leak diameters inferred in this way cover a wider range than those defined in IGE SR25 for natural gas equipment ($d_{leak,}$=0.6mm for non-vibrating equipment with dry natural gas or $d_{leak,}$=1.8mm for adverse environments), but they are of a similar order. Recently, work has been carried out for the Institute of Petroleum to provide a risk based approach to HAC[4]. The resulting values recommended for hole size and their corresponding frequency of occurrence are summarised in Table 2. These values were recommended based on data from a number of sources[5-7].

Equipment	Category	Hole size	Frequency per year
Centrifugal pump	Seal failure single seal pump	Manufacturers data or: 0.1x shaft diameter 0.23 x shaft diameter	2.4E-2
“	Seal failure double seal pump	Manufacturers data or: 0.1x shaft diameter	1.5E-3
“	Minor	0.01 A*	1.5E-3
“	Major	0.1 A*	3.E-4
“	Rupture	A*	3.E-5
Centrifugal compressor	Small	7 mm	1.65E-2
“	Medium	22 mm	8.4E-4
“	Large	70 mm	1.03E-4
Flange	High Frequency	0.6 mm	1.E-2
“	Medium Frequency	2 mm	1.E-3
“	Low Frequency	6 mm	1.E-4
Valve	High Frequency	0.1 mm	1.E-2
“	Medium Frequency	2 mm	1.E-3
“	Low Frequency	0.1 D**	1.E-4

* A - Cross-sectional area of shaft

** D -Diameter of valve

Table 2 – Hole size and frequency data taken from an IP report[4] on HAC

The hole sizes in Table 2 include those that are up to two orders of magnitude larger than the leak diameters recommended in IGE SR25, or inferred from the hazard radii in IP15,[2]. However, if leaks with a frequency of greater than once in a hundred years are considered to be equivalent to those 'likely to be experienced in the lifetime of a plant', then some consensus in the range of leak sizes for HAC purposes is obtained – that is, releases in the range from about 0.1mm to 10 mm, with an average of about 1mm. It is noted that if the objective is a more complete assessment of the safety of some natural gas handling plant, then considering all modes of failure, including the wider range of leak sizes indicated in Table 2, may be more appropriate.

Once the leak area and stagnation pressure are known the gas mass flow rate can be calculated using an outflow model. Standard methods are available from engineering text books. For natural gas, models have been developed that use 'real gas' thermodynamics and solve conservation equations for mass and energy to calculate the mass flow rate either in a steady state or transient mode.

GAS ACCUMULATION IN THE ENCLOSURE

Once the leak size, location and orientation are specified, the gas accumulation in the enclosure can be estimated using a simple zonal approach, such as that given in Cleaver et al[8] for example. This model predicts whether the gas-air mixture is well mixed throughout the enclosure or, because the natural gas is lighter than air, forms a stratified layer from the enclosure ceiling. The model predicts the bulk gas concentration and the depth of the gas–air layer that the release creates, as a function of time. The term 'bulk' concentration is taken to refer to the concentration that would be measured within the layer, outside of the direct path of the natural gas jet issuing into the enclosure. The model has been extended more recently to incorporate the effects of natural or a forced ventilation system within the enclosure. For a naturally ventilated enclosure, the method balances the pressure in the enclosure with that on the four external walls, taking into account the external wind speed and direction, to calculate the elevation of the effective 'zero' or neutral pressure plane within the enclosure. Lighter than air mixture is assumed to flow out of all openings above the zero pressure level, to be replaced by an equal volume inflow of heavier air beneath it. A forced ventilation system is incorporated within the model by adjusting the level of the zero pressure plane so the total inflow and outflow are balanced. The predictions of this aspect of the model have been compared with experimental data for high pressure gas releases into otherwise empty enclosures of volume up to 216m^3. Satisfactory agreement has been found for the 'bulk' concentration within the regions in which mixture accumulation took place for a variety of ventilation flows.

In cases in which the model predicts that the concentration everywhere in the bulk atmosphere exceeds the lower flammable limit for natural gas of 5%, the flammable volume is taken to be that of the enclosure. When the bulk concentration satisfies the inequalities,

$$2.5\% < \langle C \rangle < 5\%,$$

the contribution to the flammable volume from the bulk atmosphere is taken to be,

$$\mathrm{V}_{\mathrm{flam,AGRO}} = \frac{\langle C \rangle - 2.5}{2.5} V_{encl}$$

This is used as a pragmatic estimate to take account of the nonhomogeneity in the distribution of gas in the bulk atmosphere. Available experimental evidence on the behaviour of high-pressure gas releases in enclosures, obtained over a range of enclosure sizes and for a variety of size and direction of releases, suggests the above provides a cautious estimate of the contribution to the flammable volume from the bulk atmosphere (that is, tends to over-predict the volume).

LOCAL INFLAMMATORY INVENTORY

The gas concentration distribution immediately downstream of the gas leak can be calculated using a variety of mathematical models, ranging from empirical concentrations to advanced computational fluid dynamic codes. An empirical model has been used in this study, using correlations similar to those in Birch et al[3]. The model covers two jet configurations, a free jet and a jet impacting normally onto a flat surface. The model has been adapted for this study to calculate the local flammable volume taking account of the composition of the bulk atmosphere predicted by the gas accumulation model. That is, the concentration of gas arising directly from the jet is supplemented by the concentration of gas in the entrained mixture from the 'bulk' atmosphere in the enclosure to give a time dependent concentration in the vicinity of the release.

EXPLOSION OVERPRESSURE

Explosions can be produced by the ignition of a region of pre-mixed flammable gas inside an enclosure. To make an assessment of the 'worst case' consequences, the volume enclosed by the specified concentration level, predicted by the flammable inventory model, and the flammable volume in the bulk atmosphere inside the enclosure, predicted by the gas accumulation model, are added together. For the purposes of the 'worst case' assessment, the concentration in the flammable volume is assumed to be uniform and stoichiometric, and the overpressure following ignition is predicted using a confined volume explosion model,[9,10]. This model was developed and validated for those enclosures in which the congestion is typically in the form of a smaller number of large obstacles, as found in an onshore compressor cab, rather than a more homogeneous and extensive distribution of obstacles of all sizes, as may occur in offshore modules, for example. A different explosion model would have to be used in the latter case to take account of the rapid flame acceleration produced as a result of encountering repeated obstacles.

IMPLEMENTATION OF THE METHODOLOGY

The individual models described above are linked together, as shown in Figure 1. A flow chart showing how the models would be applied in practice is shown in Figure 2. The information necessary to use this method includes a specification of the leak (its location, orientation and size); the enclosure (its dimensions, vent area and location, estimate of congestion such as volume blockage and representative obstacle diameter); the ventilation system (the type, rate, opening area and location); the gas detection system (detection response and threshold values and location) and explosion relief panels or other potential perimeter openings (their size and weight, failure pressure and location).

By implementing the models in the way shown in Figure 2, an estimate of a representative 'worst case' value for the amount of flammable accumulation and the overpressure generated by any subsequent explosion can be obtained for a gas leak. The method can also be used to estimate the time at which a gas leak would be detected for a gas sensor located in the outlet of the ventilation system and to investigate the results of mitigating actions, such as isolation and blowdown of the gas supply. Further, by changing the threshold values used within the methodology to define the flammable volume, the method can be configured to provide a representative 'best estimate' values.

EVALUATION OF THE SMALL LEAK METHODOLOGY

The separate models that form the method have all been validated independently. However, an assessment of the performance of the composite method has not been given previously. In this section, the flammable volumes predicted by the method are compared with the measurements of Santon et al.,[11] and a programme of gas build-up experiments carried out in a representation of an offshore module[12].

Considering firstly the experiments of Santon et al, the experimental rig was a rectangular enclosure with dimensions 15m long by 2.5m wide by 2.5m high. The gas leak was introduced through a horizontal pipe orientated to be parallel with the major axis of the enclosure. The geometry of the enclosure is shown schematically in Figure 3. Downstream of the leak a number of different obstacles, such as a flat plate, were located across the middle of the enclosure to investigate how such obstructions modified the gas accumulation characteristics. Ventilation air was introduced at one end of the enclosure and the outlet for the ventilation air was located at the other end. In the experiments, the volume defined by the 2.5% contour was estimated for a range of gas leak mass flow rates, air ventilation rates and obstacle types downstream of the leak using a matrix of probes to detect the gas concentration. Table 3 shows a comparison of the methodology with the measurements of Santon et al.

Q_{air} (m^3/ sec)	m_{leak} (kg/ sec)	A_{vent} (m^2)	Obstacle type	V_{flam} (m^3)*	
				Measured	**Predicted**
800	0.023	0.63	None	0.02	0.04
400	0.046	0.63	Small tray	0.25	0.6
400	0.046	0.63	Large tray	0.75	0.6

* - Volume defined by the 2.5% contour

Table 3 – Comparison of measured and predicted 'flammable' volume for the experiments of Santon et al.

A similar comparison of the flammable volume with a much larger database of experiments studying gas dispersion in an offshore module has been carried out. Experimental details and information on the measurements that were made can be found in Savvides et al[12]. The rig has a solid, impermeable roof and floor and Figure 4 illustrates the different arrangements of perimeter confinement that were used in the test programme. The releases that were studies in this test programme were much larger than those normally considered for HAC. Typical release rates were in the range of 5 kg/s to 10 kg/s, driven by an upstream pressure of typically 30 bar. However, the test rig that was used, being 28m long by 12m wide by 8m high, has a similar size to some of those of concern here and so the comparison is of interest, representing a test of the flammable volume estimates for larger releases.

The rig configurations A and C have two of the perimeter boundaries open to the atmosphere and are outside the limits of applicability of the gas accumulation model referred to in Section 2. Nevertheless, there were a number of experiments carried out in these configurations in which the release was directed towards an open boundary and significant accumulation did not occur. Comparison with experiments of this type carried out in lower wind speeds indicates that the dilution rates are consistent with the predictions of a model of the type discussed above.

The accumulation model would be expected to be more applicable for rig configuration B, in which the two short end walls were partially obstructed as well. The quality of the agreement in this case is dependent on the orientation of the gas release and the extent to which it interacts with the ventilation flow. The agreement was found to be reasonable for gas leaks co-flowing or normal to the direction of the ventilation flow prior to the release being initiated. However, when the gas leak was directed into the pre-existing ventilation air, the flammable volume is under-predicted for some of the experiments. This appears to be associated with the interaction of the natural ventilation flow in the rig with the large, release driven motions. However it is thought that the conservative assumptions in the method as a whole, such as assuming that the flammable volume is taken to be the volume enclosed by the 2.5% gas concentration contour and that the flammable volume is taken to be stoichiometric, mean that any overpressure would tend to be overpredicted, provided an appropriate explosion model were used.

APPLICATION OF SMALL LEAK METHODOLOGY

In this section, the method is applied to consider small releases in two different enclosures. The first case to be considered is inside a larger enclosure having a high ventilation rate and a gas detection system able to detect gas concentrations greater than 0.5% (10% of the LFL). The second is for a smaller enclosure, fitted with a less sensitive gas detection equipment, assumed to respond at a natural gas concentration of 1.25%.

LARGER ENCLOSURE

The dimensions of the enclosure are 14m long by 9.4m wide by 7m high. The ventilation rate under normal operation is taken to be 25 m/sec^3, equivalent to 98 air changes an hour. The enclosure is assumed to have a number of gas detection sensors located near the ceiling, set to detect gas concentrations in excess of 0.5%. The ventilation inlets and outlets are distributed around the perimeter of the enclosure, as defined in Table 4.

Outlets	**Vent Location**			**Wall**
	Elevation of bottom	**Elevation of top**	**Width**	
1	0	1	1	West
2	4	5	1	West
3	5.2	5.9	0.7	North
4	5.2	5.9	0.7	North
5	5.2	5.9	0.7	West
6	5.2	5.9	0.7	West
7	4.8	5.6	0.5	South
8	4.8	5.6	0.5	South
Inlet				
1	3.8	5	3	East

Table 4 – Details of the ventilation inlet and outlets in the enclosure

The explosion model represents the level of congestion in the enclosure by a volume blockage parameter and a blockage length. In the following calculations it is assumed that the internal volume blockage is 20% and the blockage length scale is 0.5m, typical values for those of compression facilities associated with gas transmission. Three scenarios have been considered, as follows. A leak of natural gas either during normal operation or when the ventilation system fails and a leak that is sufficiently small to be undetectable by the gas detection system when the ventilation system is operating.

The leak source assumed for scenario 1 and 2 has a diameter of 1.7mm and a drive pressure of 85 bar. For scenario 3, the leak volume flow rate is dependent on the ventilation rate and the threshold of the gas detection system and using the gas detection threshold of 0.5%, it follows that the leak flow rate is approximately 0.12m^3/sec. The results of using the methodology for the three scenarios are summarised in Table 5

d_{leak} (mm)	Q_{air} (m^3/sec)	t_{det} (min)	t_{steady} (min)	$<C>_{max}$ (%)	V_{flam}^{*} (m^3)	O.P. (mbar)
1.7	25	-	3	0.16	0.14	less than 1
1.7	0	1.8	-	1.1**	0.70	less than 1
3.0	25	-	5	0.5	0.85	less than 1

* - Volume defined by the 2.5% contour
** - Volume defined after a further 2.5 minutes

Table 5 – Summary of results obtained for the small leak assessment

The calculations suggest that the representative small leak would be undetected when the ventilation supply is operating normally, as the gas detection threshold is not attained before steady state conditions are reached. Steady state conditions are calculated to occur after 3 minutes. The steady state bulk gas concentration is predicted to be 0.16%, with a corresponding flammable volume of 0.14 m^3, equivalent to 0.015% of the volume of the enclosure. The overpressure predicted is less than 1mbar, taking the volume defined by the 2.5% concentration contour to be at a stoichiometric concentration in the explosion calculation.

In the second scenario it is assumed the ventilation system fails or is not in operation at the time of the gas leakage. The gas accumulation model predicts that the gas detection threshold is reached after about 105 seconds. In practice, some mitigating action would be taken on gas detection (e.g. the gas leak would automatically be isolated or the air ventilation rate increased). However, the gas leak would continue for some time after it is detected. This is because the system will remain pressurised for some time, even if it is isolated and blown down. However, once the leak is isolated, the natural gas mass flow rate will tend to decay, albeit slowly initially, tending to reduce the flammable inventory in the jet and the bulk atmosphere. For the purposes of illustration, an estimate of the largest flammable volume produced by the leak is obtained by calculating the inventory that would have been produced had the leak continued at a constant rate for a further 2.5 minutes after it had been detected. At this time the predicted bulk gas concentration is 1.1%. The volume enclosed by the 2.5% contour is predicted to be 0.7 m^3. This gives some insight into the sensitivity of the flammable inventory to changes in the gas concentration in the bulk atmosphere at relatively low levels of gas concentrations. However, the predicted overpressure for scenario 2 is still less than 1 mbar.

In the third scenario, the gas leak is prescribed such that the gas concentration in the bulk atmosphere of the enclosure, assuming perfect mixing, is below the detection threshold. Under these circumstances, it is only the region immediately downstream of the gas leak that is contributing to the flammable volume. This scenario gives the largest flammable volume of 0.85m^3. However the predicted overpressure is still less than 1 mbar. The small overpressures predicted by the explosion model suggest that it is more plausible for the ignition of the flammable volume to have the characteristics of a flash-fire, followed by a jet fire, rather than an explosion followed by a fire.

The largest acceptable flammable volume in all three cases meet the criterion recommended in Santon et al[11] that less than 0.1% of the enclosure volume is filled by a given release.

SMALLER ENCLOSURE

The dimensions of the second enclosure are smaller and are taken to be 12.8m long by 5.6m wide and only 4.4m high. The rate of supply of ventilation air is assumed to be 6 m^3/sec, equivalent to 68 air changes an hour. Ventilation air is introduced through two vents with a combined flow area of 0.6 m^2. The ventilation air is assumed to leave the enclosure through a centrally located stack with a cross-sectional area of 0.9 m^2. A gas sensor with a detection threshold of 1.25% is assumed to be located in the stack. The release specification for the first two scenarios is taken to be the same as example 1, with a pressure of 85 bar and a leak diameter of 1.7mm.

The results of the gas accumulation and explosion calculations are summarised in Table 6.

d_{leak} (mm)	Q_{air} (m^3/sec)	t_{det} (min)	t_{steady} (min)	$<C>_{max}$ (%)	V_{flam}* (m^3)	O.P. (mbar)
1.7	6	-	5	0.74	0.34	less than 1
1.7	0	1.6	-	2.9	50	90
2.3	6	-	6	1.2	1.6	3.3

* - Volume defined by the 2.5% contour

Table 6 – Summary of results in the older compressor cab small leak assessment

As in the first example, in scenario 2 (in which the ventilation system is assumed to fail or not to be operating when the release takes place), the release is assumed to continue for 2.5 minutes after the gas concentration remote from the gas leak is detected in the outlet. The largest flammable volume and overpressure occurs in scenario 2. For this scenario the bulk gas concentration 2.5 minutes after gas is detected is 2.9%, the flammable volume is 50m^3 and an overpressure of 90 mbar is predicted. Depending on the details of the construction of the enclosure, such a pressure may cause some structural damage. In this particular case, the safety criteria recommended in Santon et al[11] is violated, as the flammable volume is over 150 times larger than 0.1% of the enclosure volume. The largest 'non-detectable' leak in the third scenario is predicted to produce approximately steady conditions after approximately 6 minutes. The maximum flammable volume is calculated to be 1.6 m^3 and the corresponding maximum overpressure is 3 mbar. In this case the threshold criterion for the size of the flammable volume is just exceeded, although the overpressures that are calculated, assuming a stoichiometric mixture, are small.

DISCUSSION

A method for assessing the explosion hazard relating to small leaks in enclosures is described in this report. The method has been applied to a number of gas dispersion experiments and found to give reasonable agreement or overestimate the flammable volume except for cases in which a large release is directed against the ventilation stream. However the conservative assumptions in the methodology, such as the flammable volume is taken to be the volume enclosed by the 2.5% gas concentration contour and the flammable volume is taken to be stoichiometric, mean that the overpressure would tend to be overestimated in all cases by the methodology. Application of the method to a number of test cases demonstrates that its predictions are consistent with data in Santon et al[11]. However, because of the simplifying assumptions that have been made, the model may not be applicable in more complex cases, especially those in which large recirculating flows are produced by the release. There may be a need for a more sophisticated analysis of these cases.

As an illustration of the application of the method, it has been applied to two different types of enclosure. In both cases the consequences of a small leak are shown to be within typical design specifications for an enclosure provided the ventilation system is operational. In the second case, with a higher gas detection threshold and a smaller enclosure volume, the overpressure that is calculated in one case approached the design value for a typical compressor cab. The model could be used to investigate the effectiveness of possible mitigating actions for such a scenario, for example isolating the gas supply and/or reducing the inventory through blowdown, or to test the sensitivity of the consequences to changes in operating conditions, such as changing the ventilation flow. The capability to examine these factors would also be useful at the design stage for projects. The models may be used at this stage to compare alternative options and to identify a smaller number of cases for more detailed analysis, using experimental or more detailed modelling techniques

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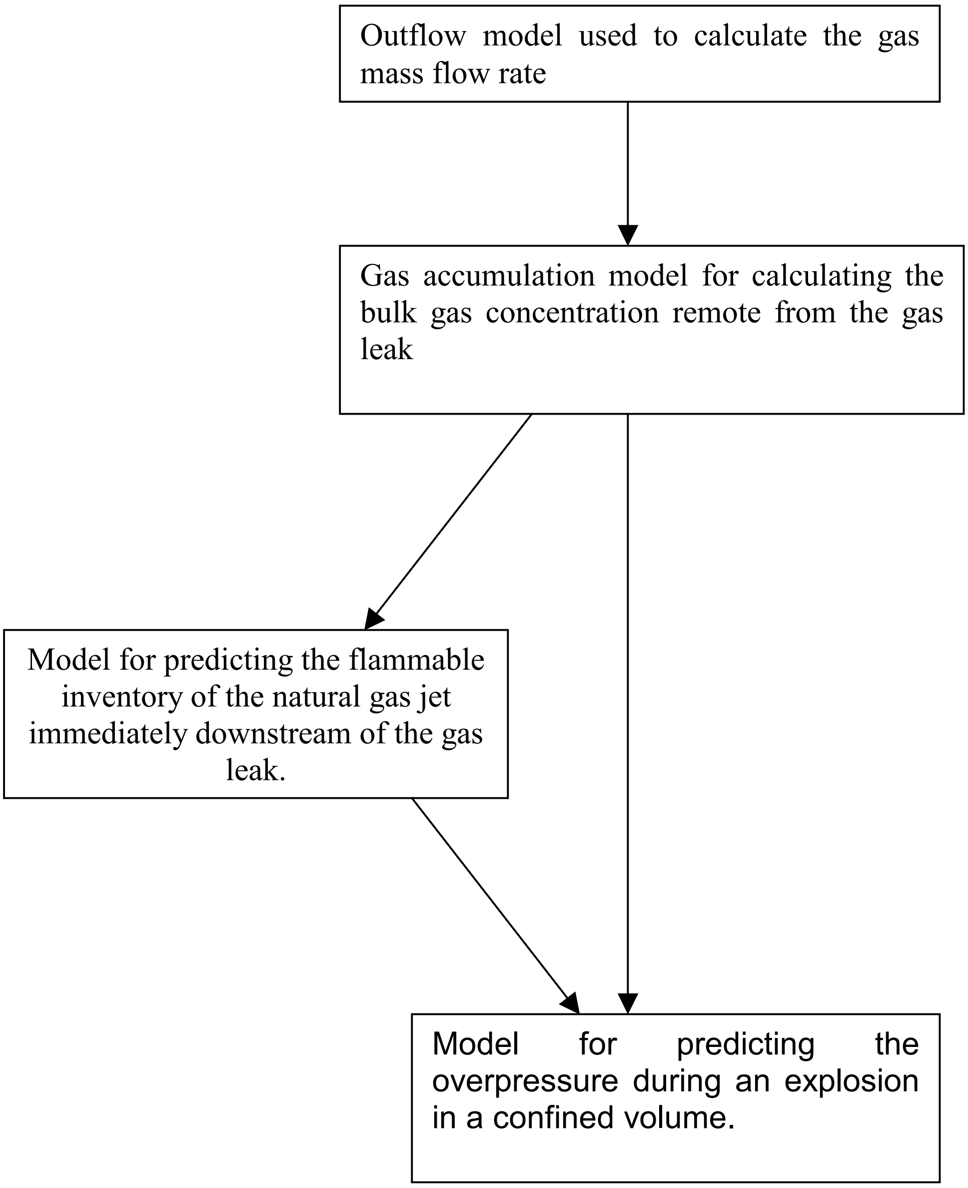

Figure 1 – Schematic diagram showing the linkage between models

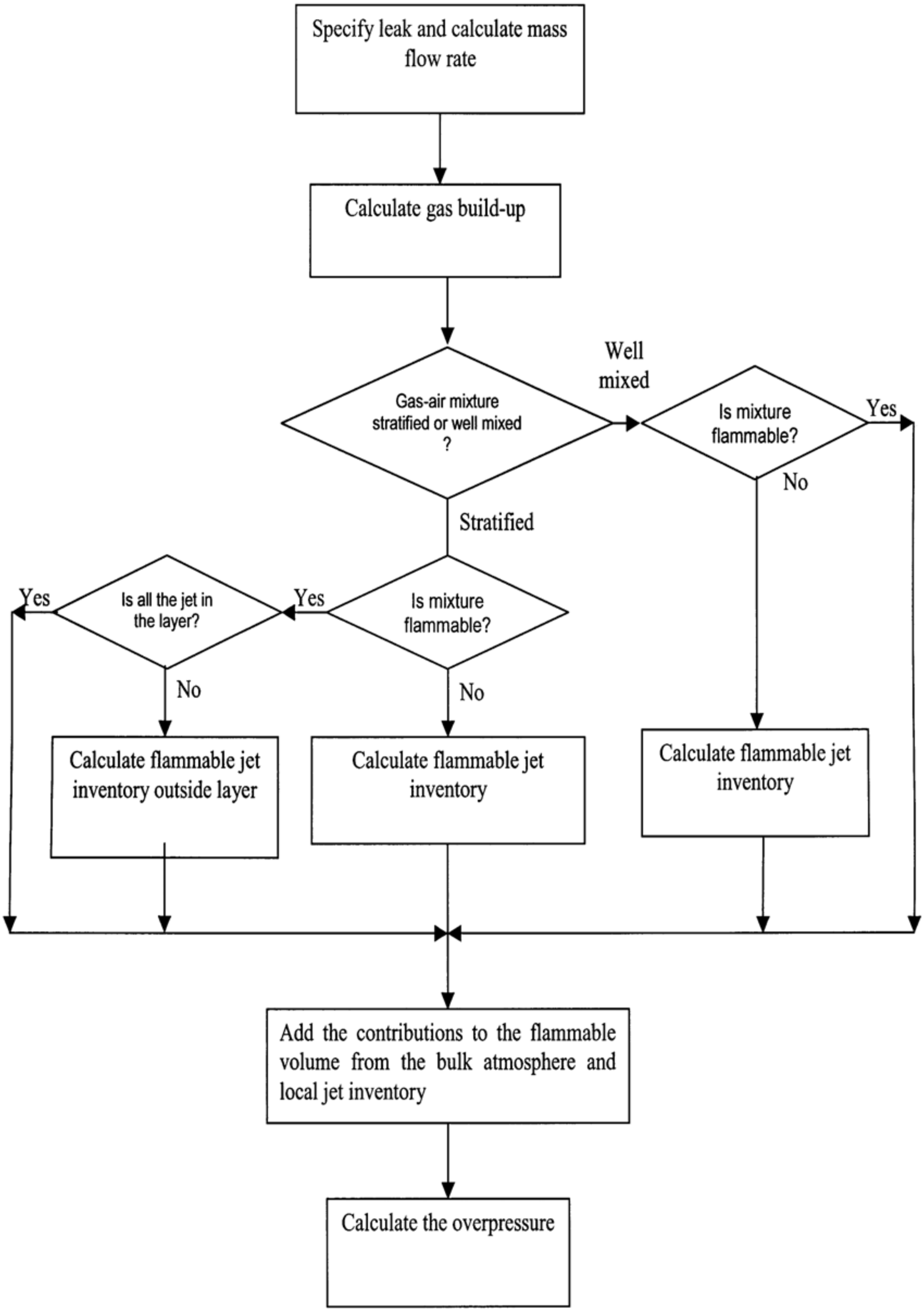

Figure 2 – Flow chart of how the models are applied to assess a small leak

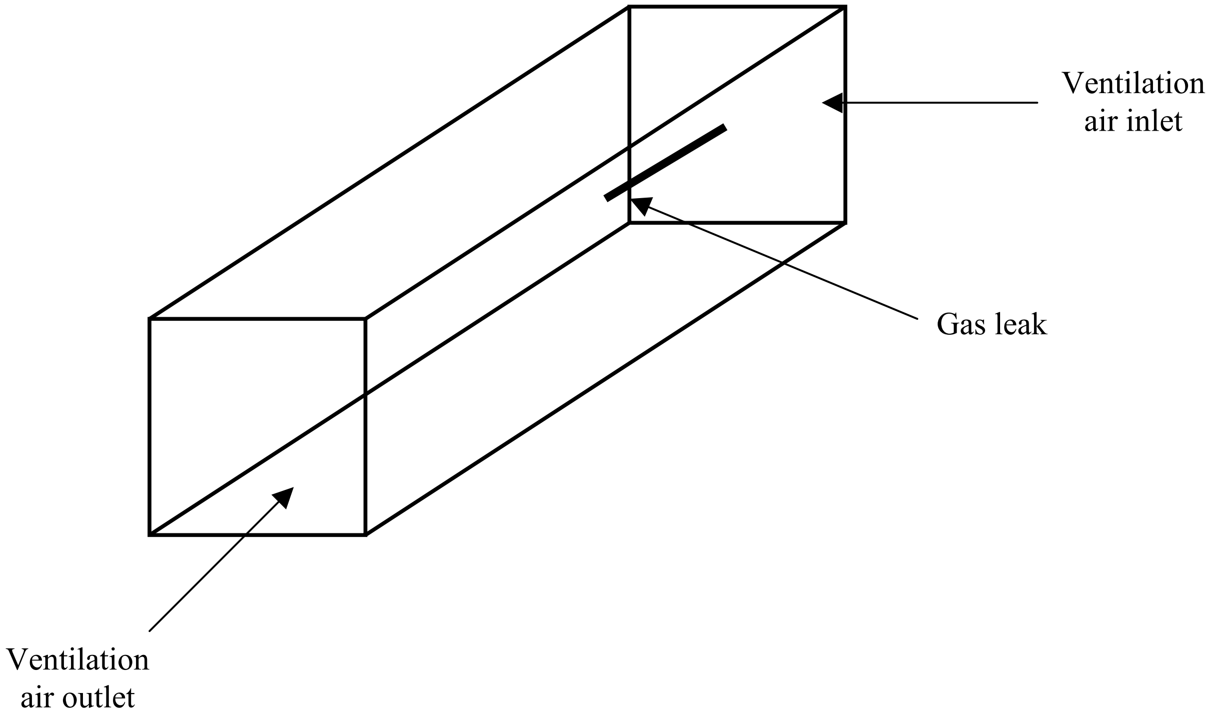

Figure 3 – A schematic diagram showing the experimental rig used by Santon et al[11].,.,

Figure 2a. Confinement C1 - Test Series A

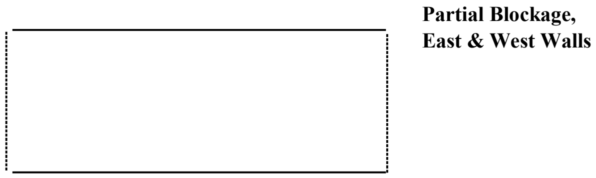

Figure 2b. Confinement C2 - Test Series B

Figure 2c. Confinement C3 - Test Series C

FIGURE 2. Perimeter Confinement Arrangements

Figure 4 – Arrangements of perimeter confinement used in the dispersion experiments to investigate dispersion in an offshore module[12]