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The dispersion of gases in offshore platforms

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SYNOPSIS

Offshore related work has always demanded the highest standards of safety in design and operation. Recent tragic events have emphasised the need for constant awareness and development of safety techniques. Gas leakage is an inherent risk in certain areas of a platform. These areas require intrinsically safe equipment together with detection and fire control systems. However, for overall safety, ventilation is the major preventative influence. Ventilation design should therefore optimise proven techniques for dilution and removal of gases and the elimination of stagnant areas of potentially high gas concentrations. The paper will describe the ventilation requirements for hazardous areas in particular and for open as well as closed modules, and will discuss the advantages and disadvantages of these two types from the point of view of ventilation in direct relation to safety.

The wind influences the effect of a ventilation system, whether it is of the natural or mechanical type. A wind tunnel test will be presented which demonstrates areas of over and under pressure around the structure. Simple prediction techniques have been established to enable the wind effect to be quantified.

Effective ventilation systems for closed modules can be designed taking into account the wind influence. Recommended procedures based on the wind tunnel tests are presented for positioning of main air intake and discharge openings, system design, selection of fan characteristics and damper control systems. The main task of the ventilation system is to dilute gases and prevent formation of dangerous concentrations of gas–air mixtures. Tests have proved that the best and most efficient method of achieving these criteria is to employ an air jet nozzle system. This practical assessment is confirmed by the results from laboratory tests carried out in Sweden and the UK.

The industry has widely adopted the use of open modules for ventilation. Open modules utilise wind forces and air movement by convection of 'wild heat' generated within the module for ventilation. ['Wild heat' is a term used in the HVAC (heating, ventilation and air conditioning) industry describing casual heat gains from miscellaneous sources, eg electrical appliances, equipment and lighting.] Ventilation performance of such systems is less than dependable when wind speeds are low or in the wrong direction, and also when heat sources are not constant or are not placed in an effective position. In these circumstances the weaknesses of natural ventilation can be overcome by a ventilation system of proven design utilising air jet nozzles to ensure a positive rate of air change independent of wind condition and heat generation.

A laboratory test carried out at the Building Services Research and Information Association (BSRIA) laboratories at Bracknell in 1986/87 compared the various methods of ventilation for open modules. The results, presented in detail, show the advantages of the air jet nozzle system.

In conclusion, the operational safety of an offshore platform can be improved or enhanced by the use of a high induction air jet nozzle ventilation system, and a good knowledge and interpretation of the effect of wind forces on the platform. As the air jet nozzle system requires little space, has low weight, and is easy to install, it is particularly useful for refurbishing or upgrading existing offshore structures and for application in new projects.

Mr Bengt Lindberg began his career in the field of marine ventilation and air conditioning as a draughtsman at Eriksberg Shipyard in Gothenburg. In 1952 he was employed by Flakt (Marine Division) as a Contracts Engineer. Promoted through a number of positions to President of Flakt Marine, he is now an adviser to the Group Management of Flakt Indoor Climate AB. Mr Lindberg is Chairman of the subcommittee TC8/SC21 of ISO under the title 'Air conditioning and ventilation requirements on board ships'.

Mr Kenneth McFadyen trained as a draughtsman in the HVAC industry at Winsor Engineering Co, Glasgow. After some years as a Contracts Engineer he left to work with Carlyle Engineering on various land-based air conditioning and refrigeration projects. He joined Flakt as Senior Engineer responsible for major passenger liner projects and is now Divisional Director of the Flakt UK Marine and Offshore Division located in Glasgow.

Mr Robert Fulton initially trained as a draughtsman in the HVAC industry at Winsor Engineering Co, Glasgow. He gained additional experience with Thermotank Ltd, Carrier Eng, before joining Flakt as a senior engineer. He was promoted through several Divisions gaining experience in a variety of air techniques for industrial uses and human comfort for land, marine and offshore structures. He was Managing Director of Flakt Ltd for some time, the President of HEVAC Association, and is now operating as an Environmental Consultant.

INTRODUCTION

The tragic accident on the British offshore platform 'Piper Alpha' has shown the need for the highest standards of safety for offshore operations. At the time of writing this paper the cause and development of this accident had not been released. It is therefore not possible to assess the contributory factors or whether the ventilation system played an important role in the events leading to the explosion or the development of the disaster and the consequences thereafter.

One thing is however quite clear – it has once again underlined the importance of safety in the design of systems on offshore platforms.

Explosion is an ever present risk as it is not possible to reduce gas leakages to zero. Everything must therefore be done to improve information for safe design and as far as possible prevent accidents in the future. Offshore work has always demanded the highest standards of safety in design and operation. The rules and regulations are very rigorous, especially for the production areas.[1,2] These require intrinsically safe equipment together with gas and fire detection systems and fire control systems. However for overall safety, ventilation is a major preventative influence. Ventilation design should therefore optimise proven techniques for dilution and removal of gases and the elimination of stagnant areas of potentially high gas concentration.

The wind influences the effect of the ventilation system whether the system is of the natural type, which is the normal practice for open modules, or of the mechanical type, which is used for closed modules.

A wind tunnel test was carried out in 1976 at British Aircraft Corporation, Filton Division (Bristol), and was presented at the Offshore Technology Conference in 1977 in Houston.[3] It demonstrated areas of over and under pressure around the structure. Based on the results of this test, simple prediction techniques have been established to quantify the effect of the wind. Using these techniques, it is possible to design a mechanical ventilation system which will operate as specified, independent of wind conditions.

Having assured a sufficient rate of ventilation at all predicted wind conditions is not enough. It is not adequate merely to supply sufficient ventilation to reduce average concentrations to below a hazardous level. It is also essential to prevent local areas of dangerous concentrations of gas–air mixtures by achieving good mixture between ventilation supply and the room air.

One solution to this is an air jet nozzle system.[4] This system proved to be the most efficient during a laboratory model test carried out in Sweden in 1978, which compared both a fully ducted and a simple, abbreviated ducted system with mechanical supply and exhaust, with a jet nozzle-assisted system with mechanical supply and exhaust.

These two tests and a further wind tunnel test to study the internal pressure differences caused by the wind were originally made for closed modules having a mechanical ventilation system.

The increased use of open modules with natural ventilation raised the need for an investigation of how to ensure the required fresh air ventilation rate as well as a good mixture and the prevention of stagnant pockets for naturally ventilated, open modules. The two latter duties are achieved by the air jet system and the physical characteristics of this system indicated that it would also be able to assist the natural forces to ensure an adequate ventilation rate when the natural forces are insufficient.

A model test was carried out at the BSRIA[5] Laboratories at Bracknell in 1986/87 to verify these theories.

The present paper will describe this test and make a summary of previous tests in order to give an overall picture of the technology with regard to the dispersion of gases in offshore platforms.[6]

THE EXPLOSION HAZARD

As long as hydrocarbon liquids and gases are handled on n offshore platforms, there is an inherent risk of leaks occurring in the process and other related areas. The only possibility of limiting gas leakage to 0% is to forbid any handling of hydrocarbon oil and/or gas of any kind on the platform. This of course is not practicable.

Gas leakage

Having established the fact that gas leaks are always present, the next and very important question is, how large is the leakage rate?

Although the aim should be to make the production systems gas-tight, there is a potential risk of gas leakage at joints, valve spindles, shaft seals, etc. It is of course impossible to give accurate figures for such leaks.

The authors are not aware of an established method of predicting the gas leakage rate from items of operating process equipment. A standard method of predicting leakage rates should be developed by a suitably informed group to provide essential information for the designers of the ventilation systems. The predicted gas leakage should be referred to the size of the module and the type of activity the module is intended for.

The explosion risk

It is a well known fact that there are three essentials required for an explosion:

Gas (hydrocarbon) + oxygen (air) + ignition source

A certain proportion of gas and air is required to form an explosive mixture. A mixture that is too lean or too rich will not ignite.[7] The concentration below which the mixture is too lean (with respect to the proportion of hydrocarbon) is called the lower explosion level (LEL), while a mixture that is too rich has a concentration above the upper explosion level (UEL). As the ignition cannot be fully eliminated, the only possibility is to avoid a gas–air mixture within the explosion range, ie between LEL and UEL.

To maintain the gas concentration above the UEL is of course impractical as it will be almost impossible to prevent fresh air entering the module and so cause an explosive mixture.

The gas concentration must therefore be controlled to give a level below the LEL. In order to have sufficient safety margins there are some different safety levels, eg alarm at 0.2 LEL and production shut down at 0.6 LEL. The ventilation system should hence be designed to prevent the gas concentration in the space rising above 0.2 LEL.

Another factor to be taken into consideration is that the gases may be either lighter or heavier than air which means that they may rise up under the ceiling or sink down to floor level. Here they can form areas of high gas concentration between beams, machinery, etc.

It is thus necessary to ensure that the ventilation system is capable of preventing stagnant pockets where the gas concentration is allowed to reach critical levels.

VENTILATION REQUIREMENTS

From a safety point of view the following are requirements of the ventilation system.

1. To supply sufficient fresh air to prevent the average leakage gas–air concentration rising above 0.2 LEL.
2. To prevent stagnant zones with potentially high gas concentrations.
3. To maintain a pressure differential.

Fresh air supply

It is possible with the normal equation for a gas mixture in a room:

$$k = \frac{x}{q} \cdot \left(1 - e^{-\frac{q \cdot t}{v}} \right)$$

to calculate the air flow required to maintain the concentration below a certain level, eg 0.2 LEL.

At steady state the equation can be written as:

$$k = \frac{x}{q} \text{ or } q = \frac{x}{k}$$

where k is the concentration, x is the gas production (leakage) and q is the required air flow.

As mentioned above in the 'Gas leakage' section it is impossible to give an accurate figure for gas leakage. The calculation must therefore be based on the predicted rate. The ventilation will thus cope with the normal situation at an assumed maximum leakage rate but will not be able to handle an occasional large leak. For such an incident there must be other safety measures that will shut down the operation, sound alarms, etc at very short notice.

The equation further assumes a complete mixture between the ventilation supply air and the room air. It is therefore important that the air supply is introduced in such a way that the air in the room is agitated, so that any gas leaks are mixed with as large a proportion as possible of the ventilation air, rather than being carried through the room as a cloud of high concentration, which is often the case with a conventional ventilation system (as described later).

Prevention of stagnant zones

Heavy gases will sink to floor level and in the case of a raised, false floor they will penetrate below the grating and create pockets between equipment and in large skids when such are used to support heavy machinery.

The light gases will rise and form pockets with high concentration between deep roof beams, etc.

These pockets provide potential risks for explosions. The ventilation system must ensure that such pockets are not formed. This requires a very widely distributed ventilation system with air supply into every compartment of the floor or roof construction. As will be seen later, this can also be achieved with a system with air jet nozzles positioned and directed so that the air jets force the gases out of the compartments and disperse the gases throughout the module.

Pressurisation

A large platform which has production/process areas, stores, tanks, control rooms and possibly also accommodation spaces is normally divided into areas classified as hazardous and safe as appropriate. The hazardous areas are those in which there is a greater risk of oil or gas leakage than in those areas that are classified as safe where there is a limited risk of leakage.

There are more stringent demands on systems and equipment to be installed in the hazardous areas.

In order to prevent any gas leaks from penetrating the safe areas, they are maintained at a higher air pressure, eg 120–150 Pa pressure difference. Normally the safe areas are kept at 60 Pa over pressure and the hazardous at 60 Pa under pressure, but it is also possible to keep all areas at positive pressure with the safe areas at a higher pressure.

Ventilation system for process modules

Open modules

The main reason for adopting open modules is that they can be ventilated by natural forces – either the external wind or the force from convection, caused by wild heat generated within the module. In both cases the module is provided with weather louvres covering large parts of the outer walls, at least on two sides, or the outer walls have slots in the lower and upper parts. The difference in external pressure normally caused between the two faces of the module will cause air movement through the internal space, while convection will cause the air to rise up under the ceiling and pass out through the openings in the upper part of the walls. Outside air will also pass through the openings in the lower part to replace the exhausted air.

Closed modules

As the closed modules cannot rely on the natural forces for ventilation, a mechanical system is needed. Many different systems have been used on offshore platforms over the years. The systems may have a mechanical supply or exhaust ventilation, or both supply and exhaust fans.

The fans have been of the axial flow type or radial flow (centrifugal) type, preferably with backward-curved blades or so-called mixed flow fans.

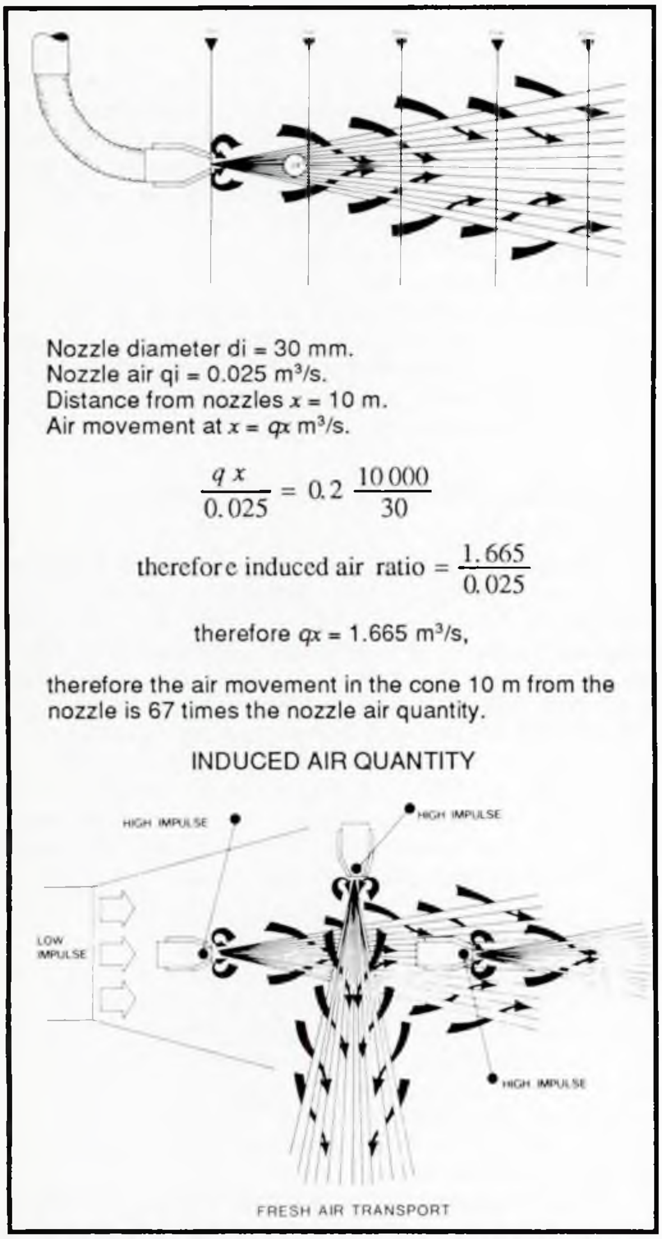
The duct system can be very short or well distributed. Control dampers at supply and/or exhaust openings are either self-operated or actuator-operated and controlled from a master controller with sensors in the modules and an external reference sensor.

A special separate air jet nozzle system is also available. This is a high velocity-inducing and circulating ventilation system which obtains its unique feature by using small quantities of room air blown at high velocity from nozzles, producing turbulent movement and induction of the surrounding air. The nozzles utilise the mass conservation of energy, converting the small flow of air from each nozzle at a high velocity, to a very large flow of air at a low velocity. The principle is shown in Fig 1. This system has been used to distribute the air in large premises, without utilising large space-consuming duct systems, and to mix the air in the space to prevent stagnant pockets.

Advantages and disadvantages of open versus closed modules from a ventilation point of view

Advantages of open modules

1. They can have natural ventilation
2. They cost less for installation and operation
3. Their energy consumption is less



Nozzle diameter di = 30 mm.
Nozzle air qi = 0.025 m³/s.
Distance from nozzles x = 10 m.
Air movement at x = qx m³/s.

$$\frac{q x}{0.025} = 0.2 \, \frac{10\,000}{30}$$

$$\text{therefore induced air ratio} = \frac{1.665}{0.025}$$

therefore $qx = 1.665$ m³/s,

therefore the air movement in the cone 10 m from the nozzle is 67 times the nozzle air quantity.

INDUCED AIR QUANTITY

Fig 1: Induced air quantity and fresh air transport

Disadvantages of open modules

1. They depend on wind pressure (velocity and direction)
2. They depend on heat generation
3. High winds and rain or snow drifts create uncomfortable working conditions and an aggressive atmosphere for equipment and personnel
4. There is bad air distribution
5. There is a risk of forming stagnant zones
6. It is impossible to create an under pressure

EFFECT OF WIND

Wind conditions

To understand why natural ventilation cannot give safe ventilation at all times and how the wind influences mechanical ventilation it is necessary to consider the wind and how it affects the air pressure around a structure.

Predicted wind conditions for different areas are available from meteorological institutes etc in the form of Tables and so-called wind roses which give for each month the time duration for different wind speeds and directions.[8] Fig 2 is a wind rose for the month of July for a typical North Sea position and shows that the wind will be less than 2 m/s for 18% of the time, that is 134 hours during that month. For the whole year the statistical average wind speed is below 2 m/s for 832 h. When consideration is taken of the wind direction, it can be shown that 20–30% of the time, wind-induced ventilation will not be effective.

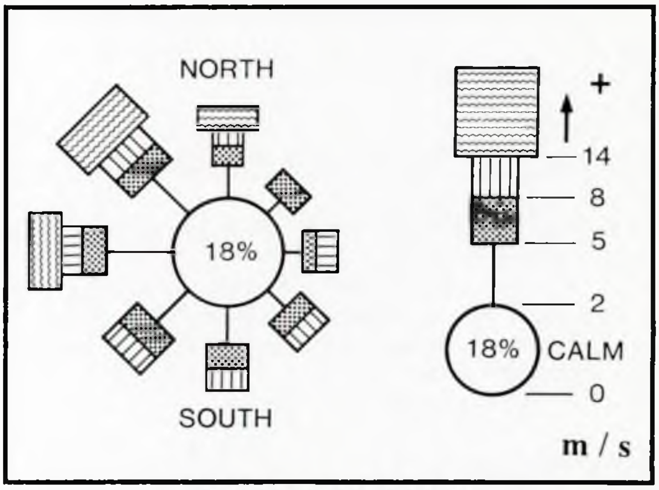


Fig 2: Wind rose for July

On the other hand it should be noted that for the same position the wind speed will exceed 15 m/s for nearly 20% of the year. The ventilation system must operate reliably at these higher wind speeds up to the limit when operations will be shut down, which is often set at 60 miles/h (27 m/s) which occurs approximately 1% of the time in the North Sea.

Wind effect on the ventilation system

The dynamic pressure of the wind will create a force on a flat surface normal to the wind direction. Theoretically this force is equal to 1 dynamic pressure. In a similar way there will be a negative pressure on the opposite side. Areas of varying pressure will be built up around the platform, depending on the shape of the structure.

The pressure differences will act on the air inlet and outlet openings and thus influence the operation of the ventilation system. In the extreme case, and if the ventilation system is not designed with due consideration to the wind effect, the ventilation rate could be zero and the pressurisation could be completely off-set. In order to study this, wind tunnel tests are the obvious solution.

Wind tunnel test

A wind tunnel test was carried out in 1976 at the British Aircraft Corporation, Filton Division.[9] A model of scale 1:100 of a typical North Sea platform was mounted in the wind tunnel on a turntable which could be rotated to produce any wind direction (Fig 3). The influence of the rough sea was simulated and other precautions were taken to perform the test as realistically as possible. The static pressure was measured at some 88 points around the platform, some of them at simulated air inlet or outlet grilles or inside ducted inlets or outlets projecting above or below the structure. During the tests the model was turned through increments of 15 deg for a complete rotation. For each wind direction the pressure was measured at the pressure points and transmitted to a computer for processing.

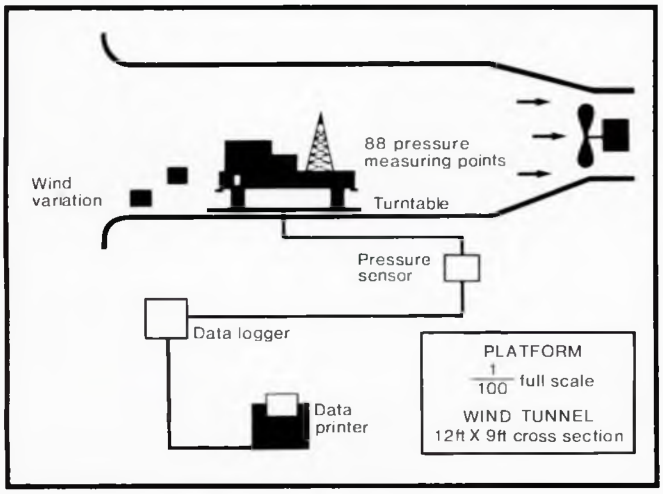


Fig 3: Wind tunnel

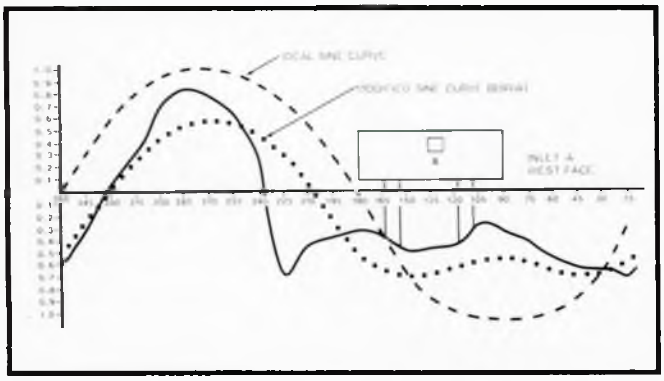


Fig 4: Pressure coefficients – side wall inlet

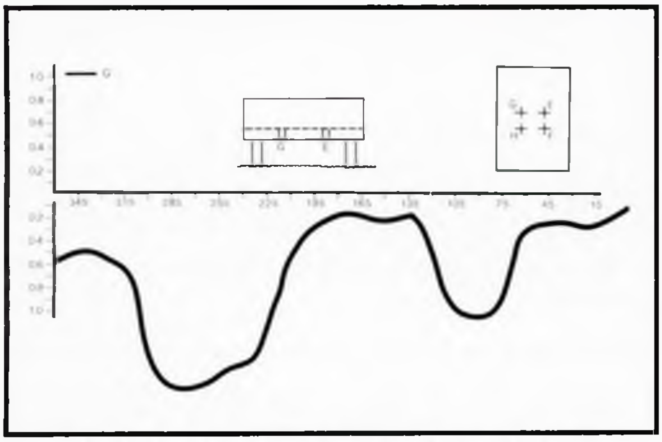


Fig 5: Tapping 'G' on underside duct outlets

Results of the wind tunnel test

The printed data showed that when the inlets or outlets are on the side of the structure, the pressure is directly proportional to the cosine of the wind dynamic pressure, with an over pressure of approximately 1.0 dynamic pressure when the wind direction is 90 deg to the surface, and a corresponding negative pressure when the wind is in the opposite direction (as shown in Fig 4, which represents an opening on the facade of the platform).

As can be seen the curve is very close to the ideal sine curve in the area of positive pressure but deviates on the leeward side. This corresponds very well with observations made by eg BSRIA for buildings on land. During the laboratory test carried out by BSRIA which are presented in this paper they used pressure coefficients from the 'Air Infiltration Calculation Techniques – An Application Guide',[10] which are converted into, what we can call, a modified sine curve. For comparison this has been drawn in on Fig 4 together with the ideal sine curve.

Apart from the sides of the structure the other positions that can be used for ventilation openings are the top of the platform or the underside of the platform deck. The test showed that, although there are pressure variations depending on the form and position of the openings in relation to legs etc, the pressure is always negative, especially on the underside, as shown in Fig 5.

Interpretation of the results

Using the results of the wind tunnel test, it is possible to calculate theoretically the effect of the wind on the ventilation system air flow and the static pressure inside each module for different wind directions, depending on the position of openings, the fan characteristics, and the system layout.

This has been presented in the form of a Table for four different ventilation opening configurations and nine different systems, three with axial flow fans and six with centrifugal fans (Table I).

This clearly indicates the performance of the different systems. As an example the module with openings on north and east sides and wind direction south-east, line 15, a simple system with self-operated dampers and an axial flow fan for exhaust only, column E, will have an air flow of 140% and a positive pressure of 0.9" water gauge (WG) (220 Pa) when it should be negative 0.3" WG (80 Pa). With a north-westerly wind, line 16, the air flow will be zero.

On the other hand a more sophisticated system with both supply and exhaust fans of the centrifugal type and with motorised dampers, column L, will be able to maintain the pressure at all wind directions and the air flow will only vary by ±15 %.

The conclusion of this test is that a suitable system, where the pressure will be maintained constant under all wind conditions, is one with both supply and exhaust fans as well as actuator-operated dampers centrally controlled in relation to a common atmospheric sensor, as illustrated in Fig 6.

In cases where exhaust openings could be arranged on the underside of the platform deck a somewhat simpler system can be used, as shown in Fig 7. This will have only a supply fan and this fan can have a lower pressure as there will never be a positive external pressure acting on the discharge, which the fan must overcome. An automatically controlled damper system would be needed.

The fans should preferably be of the centrifugal (radial flow) type with backward-curved blades which give a steep characteristic. However, even with the good characteristics this type of fan has, they can be selected at the wrong point of their performance curves, which would mean the fan giving zero air flow with certain wind directions. The following rules should therefore be followed when selecting the fans (Fig 8).

1. The design pressure should, as a minimum, be between 1- and 2-times the design wind speed dynamic pressure.
2. At the top of the curve, for the fan speed selected, the total pressure should be at least the sum of the designed pressure plus the dynamic wind pressure.

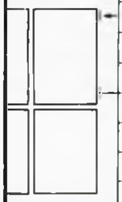
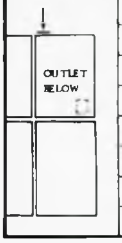
A	B	C		D		E		F		G		H		I		K		L		
				SELF OPERATED DAMPERS								MOTOR OPERATED DAMPERS								
MODULE SHAPE	FAN	AXIAL		AXIAL		AXIAL		CENTRIFUGAL		CENTRIFUGAL		CENTRIFUGAL		CENTRIFUGAL		CENTRIFUGAL		CENTRIFUGAL		
	PRESSURE INS. WG	2"		2"		2"		3.5"		3.5"		3.5"		3.5"		3.5"		3.5"		
	SYSTEM	+0.3		+0.3		-0.3		+0.3		-0.3		+0.3		-0.3		+0.3		-0.3		
	WIND SPEED	75 MPH		60 MPH		60 MPH		60 MPH		60 MPH		60 MPH		60 MPH		60 MPH		60 MPH		
	WIND DIRECTION	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	MOD. PRESS.	Q %	
	→	-2.4	100	-1.4	100	-2.0	100	-1.6	100	-2.0	100	+0.3	85	-2.0	100	+0.3	85	-0.3	85	1
	←	+3.0	100	+2.0	100	+1.4	100	-2.0	100	+1.4	100	+2.0	100	-0.3	85	+0.3	85	-0.3	85	2
	↓	-0.1	-20	+0.3	65	-2.0	65	+0.3	85	-2.0	85	+0.3	85	-2.0	85	+0.3	85	-0.3	85	3
	↑	+0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	4
	↗	-1.6	100	-0.9	100	-1.5	100	-0.9	100	-1.5	100	+0.3	88	-1.5	100	+0.3	88	-0.3	88	5
	↙	+2.2	100	+1.5	100	+0.9	100	+1.5	100	+0.9	100	+1.5	100	-0.3	88	+0.3	88	-0.3	88	6
	↖	+2.2	100	+1.5	100	+0.9	100	+1.5	100	+0.9	100	+1.5	100	-0.3	88	+0.3	88	-0.3	88	7
	↘	-2.2	100	-0.9	100	-1.5	100	-0.9	100	-1.5	100	+0.3	88	-1.5	100	+0.3	88	-0.3	88	8
	→	-0.1	-20	+0.3	65	-2.0	65	+0.3	85	-2.0	85	+0.3	85	-2.0	85	+0.3	85	-0.3	85	9
	←	+0.6	145	+0.3	125	+1.4	125	+0.3	110	+1.4	110	+0.3	115	-0.3	100	+0.3	100	-0.3	100	10
	↓	+2.6	-20	+2.0	65	-0.3	65	+2.0	85	-0.3	85	+2.0	85	-0.3	85	+0.3	85	-0.3	85	11
	↑	-2.1	145	-1.4	125	-0.3	125	-1.4	110	-0.3	110	+0.3	100	-0.3	115	+0.3	100	-0.3	100	12
	↗	-1.6	100	-0.9	100	-1.5	100	-0.9	100	-1.5	100	+0.3	88	-1.5	100	+0.3	88	-0.3	88	13
	↙	+2.2	100	+1.5	100	+0.9	100	+1.5	100	+0.9	100	+1.5	100	-0.3	88	+0.3	88	-0.3	88	14
	↖	-1.2	160	-0.9	135	+0.9	140	-0.9	115	+0.9	120	+0.3	110	-0.3	110	+0.3	110	-0.3	110	15
	↘	+1.8	-60	+1.4	0	-1.4	0	+1.5	75	-0.9	75	+1.5	75	-1.5	88	+0.3	88	-0.3	88	16
	→	+0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	17
	←	+0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	+0.3	100	-0.3	100	18
	↓	-1.8	170	-1.4	150	+1.4	150	-1.4	125	+1.4	125	+0.3	115	-0.3	115	+0.3	115	-0.3	115	19
	↑	+2.6	-80	+0.8	0	-0.8	0	+2.0	55	-2.0	55	+2.0	85	-2.0	55	+0.3	85	-0.3	85	20
	↗	+1.8	-60	+1.4	0	-1.4	0	+1.5	75	-1.5	75	+1.5	75	-1.5	75	+0.3	88	-0.3	88	21
	↙	-1.2	160	-0.9	145	+0.9	145	-0.9	120	+0.9	120	+0.3	110	-0.3	110	+0.3	110	-0.3	110	22
	↖	+1.8	-60	+1.4	0	-1.4	0	+1.5	75	-1.5	75	+1.5	75	-1.5	75	+0.3	88	-0.3	88	23
	↘	-1.2	160	-0.9	145	+0.9	145	-0.9	120	+0.9	120	+0.3	110	-0.3	110	+0.3	110	-0.3	110	24
 OUTLET BELOW	→	-1.0	115	-0.6	115	-0.3	115	-0.6	105	-0.3	105	+0.3	100	-0.3	100	+0.3	100	-0.3	100	25
	←	-2.1	140	-1.4	125	-0.3	125	-1.4	110	-0.3	110	+0.3	100	-0.3	100	+0.3	100	-0.3	100	26
	↓	-0.6	160	-0.6	140	+1.4	140	-0.6	120	+1.4	120	+0.3	115	-0.3	110	+0.3	110	-0.3	110	27
	↑	-1.2	70	-0.6	85	-2.0	85	-0.6	85	-2.0	75	+0.3	85	-2.0	90	+0.3	85	-0.3	85	28
	↗	-1.2	90	-0.6	110	-1.5	90	-0.6	95	-1.5	80	+0.3	88	-1.5	95	+0.3	88	-0.3	88	29
	↙	-1.8	170	-1.4	145	+0.9	145	-1.4	120	+0.9	120	+0.3	110	-0.3	115	+0.3	110	-0.3	110	30
	↖	-2.3	115	-1.4	110	-1.5	110	-1.4	105	-1.5	105	+0.3	88	-1.5	105	+0.3	88	-0.3	88	31
	↘	-0.8	145	-0.6	130	+0.9	130	-0.6	115	+0.9	115	+0.3	110	-0.3	105	+0.3	110	-0.3	110	32

Table I: System comparison

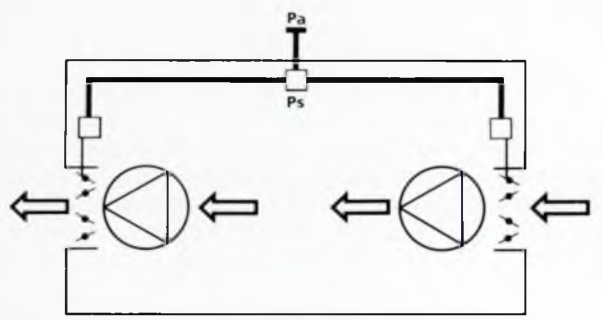


Fig 6: Centrifugal fans for supply and exhaust inlet + outlet openings as required

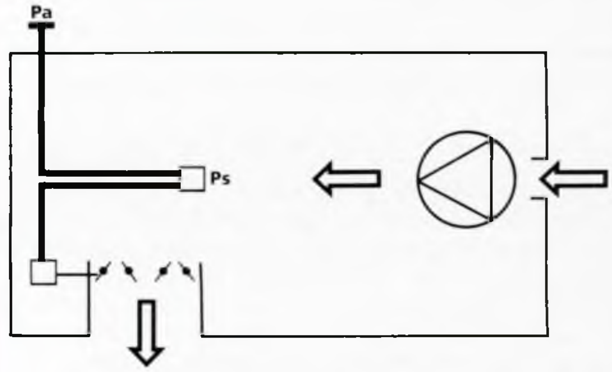


Fig 7: Centrifugal fan and outlet below deck

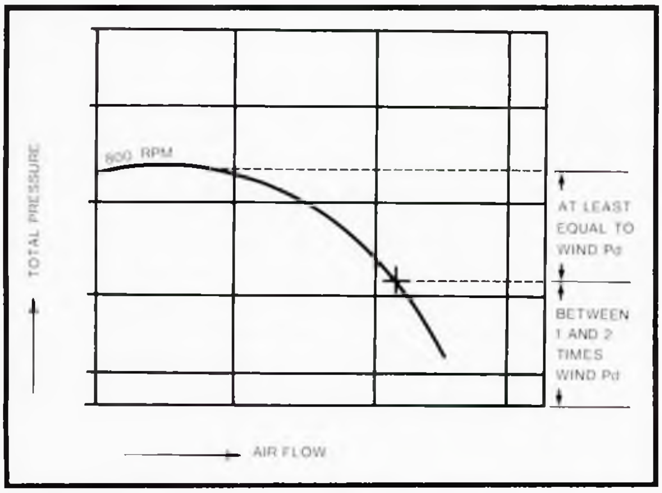


Fig 8: Total air pressure versus air flow fan selection characteristics

Wind tunnel test for the Norwegian Petroleum Directorate (NPD)

A second wind tunnel test was carried out in 1981 at the request of NPD,[11] as the previous test did not provide all the necessary information, especially regarding possible changes in the safe and hazardous area ventilation pressures which the wind may induce. Again the British Aerospace Laboratory, Wind Tunnel Department, Filton, was chosen for the test. The test arrangement was similar to that used in 1976, but the model had four modules with arrangements to study the pressure within the modules and inlets and outlets on different aspects. Furthermore some areas had partly open sides, also with pressure sensors within the module, in order to study open modules with natural ventilation. In addition, typical walkways were mounted around the perimeter of the accommodation as well as stairways. Corridors between modules were arranged and provided with measuring points. Finally various types of inlet and outlet hood or cowl-type protection devices were tested.

The test confirmed the results from 1976 that the wind force creates over and under pressures around the platform almost corresponding to a sine wave in relation to the wind direction.

While tests have not been made to establish the depth of the pressure wave, the measurements made at simulated ventilation-type cowls, which at full scale extend to over 2 m in height, clearly indicate that the pressure area is well outside the platform envelope.

The deviation from the ideal or theoretical sine wave, particularly on the negative or leeward side, has not been further analysed. It is assumed that local protrusions may affect individual readings. However, in the context of safety this could be disregarded because the ideal sine wave curve, which should be used for calculations, will always be on the safe side.

As in the previous test all measurements taken across the top of the platform showed negative pressures. The same was the case with the tappings on the underside of the deck support. Differences were caused by the steel structures and by the legs. Tappings close to the edge produced a negative pressure equal to the wind dynamic pressure whereas at points in the centre or close to the leeward side the negative pressure was considerably reduced.

The measurements made in various positions in and close to the 'corridors' showed that these have no effect on equalising pressure differences.

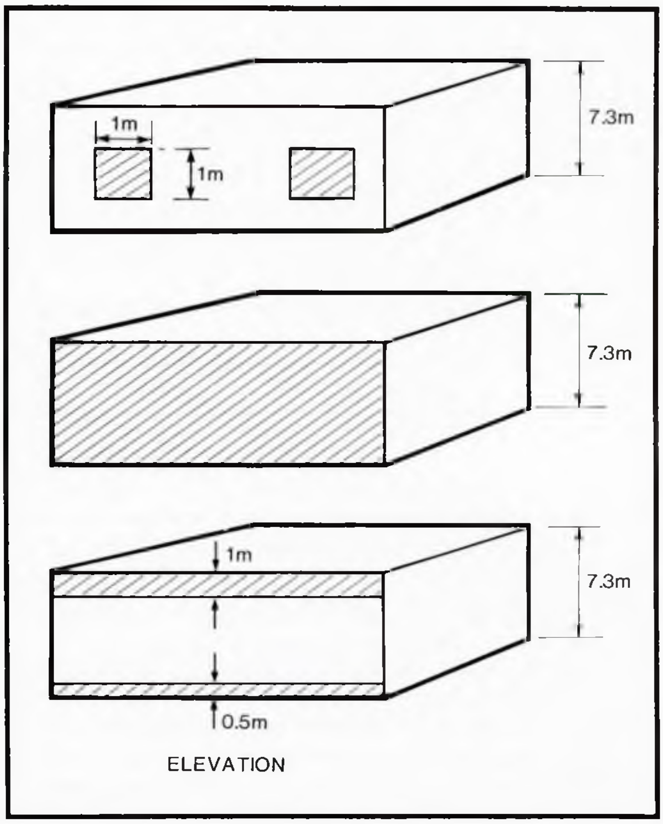


Fig 9: Typical type of vent opening

The tests made with different protection devices for ventilation openings showed that neither a hood over a side wall inlet or outlet, nor an upward discharge cowl, had any significant effect, but does of course stop rain and snow entering provided that air velocity through the device is below 3 m/s.

The stairs which were modeled as solid floor treads once again had little effect on the pressure readings.

Fig 9 illustrates how a module was used to test pressures within an open module, depending on the degree of outside wall opening. Three different arrangements were tested: one with supply and exhaust openings equivalent to 1 m^2; one with an open wall; and one with a 1 m slot along the top of the module and an 0.5 m slot at the bottom. The pressure curves were visually identical for all tests.

A test was also made with two modules linked to each other. The measurements clearly showed the static pressure change within each module and hence a pressure difference between the modules which could be as large as 60 Pa, ie 6 mm WG. It was decided to verify the theoretical calculations made from the tests in 1976. For that reason the four modules, with arrangements to test internal pressures, were used (see Fig 10). Module A had an inlet on one side and an exhaust directly opposite.

Module B had the inlet and outlet on the same side. Module C had the inlet on one side and the outlet on the bulkhead, 90 deg to the inlet. Module D had the inlet or exhaust on the side and the other opening on the deck, directly connected to the atmosphere below the platform.

Generally, when the exhaust opening is subject to an over pressure, the pressure in the centre of the modules tends

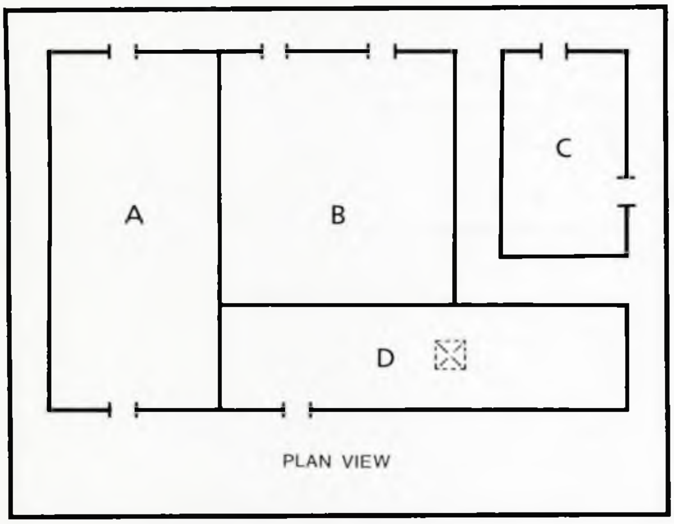


Fig 10: Typical vent locations in modules

towards the supply side opening as the supply side normally has a higher resistance than the exhaust system.

Module A showed that both positive and negative influences on the internal pressure are created and depend on the wind direction. Module B showed no influence as both openings were subjected to the same external pressure, and the internal pressure followed exactly the external pressure created on the wall of the module. These and the tests with Modules C and D followed very closely the previous theoretical predictions, derived from the tests carried out in 1976.

STAGNANT POCKETS

Conventional ventilation systems with extensive duct systems are able to give adequate ventilation but the air will not be sufficiently well distributed to prevent stagnant areas.

The air flow from each supply opening, representing a fraction of the total air flow, will move in a more or less uniform way across to the exhaust opening on the opposite side of the module and not give sufficient turbulence particularly between equipment and in the beam spaces. A gas leak into this air stream will cause a high gas concentration in this part of the total air flow.

A much better result would be achieved if the total supply air flow mixed with the room air in a turbulent environment. This can be created by the supplementary jet nozzle system referred to earlier. The primary ventilation system can then consist of a very simple, short duct system with only a few large openings in both the supply and exhaust systems. The total air flow will thus be mixed with the room air and any possible gas leaks. The jet nozzles will be so positioned that the air jet induction causes supply air to flow and be transported as required creating a turbulent flow and so dispersing the gas from any leaks. Additional nozzles will be placed in strategic positions to cause ventilation air to flow into positions where stagnant areas can be anticipated.

Model test

A laboratory test was made in Jonkoping, Sweden, in 1979[3] in order to compare different ventilation systems and determine which is the most reliable system.

The test was made with a model on a scale of 1:5 using a general purpose process module with two decks; a lower deck and a mezzanine deck. Tanks, pumps, heat exchangers, pipes, cable trays, etc were all made to scale. Internal heat load was represented by electrical elements within heat exchangers and tanks and circulation of warm air in the piping system (Fig 11).

Three different systems were tested: one corresponding to a conventional system with an extended duct system (supply air at one side and exhaust at the other), one system with only two supply and two exhaust openings (one on each level and on the same side of the module), and finally one system the same as the latter but with an air jet nozzle system added.

During the test trace, gas was released at ten different positions within the module simulating possible gas leaks using both a heavy and a light gas mixture of nitrous oxide (N_2O) and He. In total, 57 probes were arranged for the measurement of gas concentrations by an infrared analyser.

Test results

The results were presented in three sections – one longitudinal and two cross-sections, where the air velocity, temperature and relative gas concentrations were indicated. The dispersion of the gases was presented in several different ways, ie by percentile distribution of different concentration ranges, by standard deviation on graphs of frequency, by standard deviation at different air changes and by gas concentration at different air changes.

All these showed that the system with the air jet nozzles gave the best dilution of the air both at low air changes (3 and 6 air changes/h) and at high (12 air changes/h). Of the two other systems the ducted one gave better result at the higher air change rate, whereas the system with only a single supply and exhaust openings on each level gave better performance at the lower air changes. This is clearly demonstrated by the two frequency graphs shown in Fig 12 and the gas concentration diagram shown in Fig 13 in which the jet nozzle system follows closely to the ideal curve, ie at full mixture between the trace gas and the total air flow. Stagnant zones were clearly avoided with the jet nozzle system.

OPEN MODULES

Normally, open modules have natural ventilation which is wind- or heat-related.

The two wind tunnel tests have clearly shown that there are zones around the platform of varying pressure that will influence any natural ventilation system. Openings cannot be placed so that ventilation is assured in all wind conditions, and certainly not in calm conditions. The wind data referred to earlier indicate that for the North Sea, there is as much as 832 h/ year when the wind speed is below 2 m/s.

Under ideal wind conditions the natural ventilation system can give in excess of 6 air changes/h. As the driving force is very weak, the air cannot be ducted and the dilution of gases and prevention of stagnant zones will be insufficient and uncontrolled.

A jet nozzle system will therefore be advantageous, perhaps even more than for a mechanically ventilated, closed module.

The jet nozzles can also be used to assist the natural ventilation by placing nozzles so that they cause outside air to flow through part of the weather louvres or ventilation slots and assist the exhaust air through other parts of the louvre wall or slots.

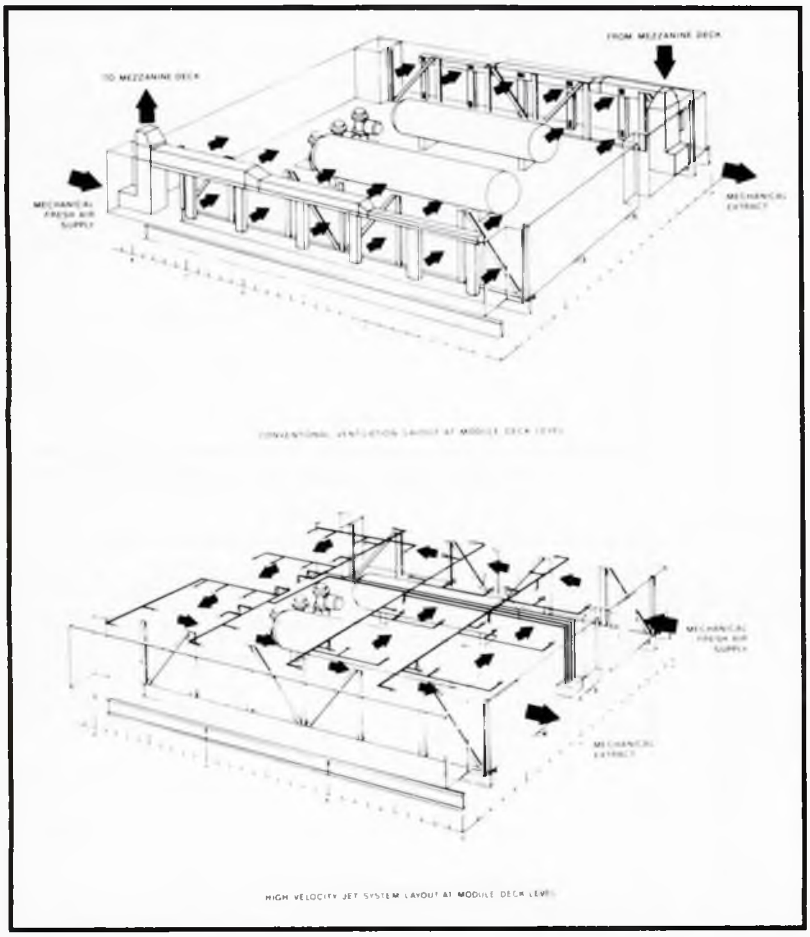
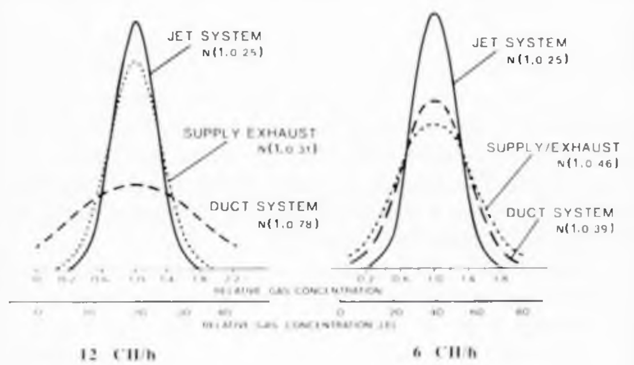


Fig 11: Conventional ventilation layout (above) and high velocity jet system layout (below) both at module deck level



$$\text{Graph of frequency} = F(X) = \frac{1}{\sigma\sqrt{2\pi}}\,E - \frac{(X-\mu)^2}{2\sigma^2}$$

where μ = expected value, σ = standard deviation

Fig 12: Graph of frequency

Laboratory test

In order to verify this theory and test the system a laboratory test was carried out in 1986/87 at the BSRIA Laboratories. A model of a production module, scale 1:5, was built of wood and board. The model, having the dimensions 7.34 x 6.0 x 2.0 m (Fig 14), had natural ventilation openings in the form of continuous slots at high and low level on three sides, as required by Det Norske Veritas. These were later replaced for further tests by simulated weather louvres on two sides. Heat generation from equipment was simulated by tungsten filament lamps inside appropriate tanks, heat exchangers, etc.

The test was performed with simulated wind from different angles with a speed of 2.25 m/s and zero. The wind force was created by fans through external plenum boxes on two opposite sides, as shown in Fig 15.

Tracer gas N_2O was released from eight points at a constant rate of 6.15 litres/min. Gas concentration was sampled at 15 points where leakage of gas may result in high concentrations. The gas analyser equipment consisted of a Leybold–Heranes Binos 1.2 infrared gas analyser, two multi-valve boxes and a personal computer to control the switching and store the readings.

The jet nozzle system consisted of a fan placed in the lower level of the module and pipework distributing the air to jet nozzles placed inside one half of the inlet openings. These caused outside air to flow into the module on one side, and other nozzles were placed to assist the air flow through the module, and finally force the used air out of the module on the other side, as shown in Fig 16. Additional nozzles were used to stir the air and prevent stagnant pockets.

Test results

A total of 17 individual sequences, covering six wind directions at 2.25 m/s and zero wind speed were run. As an example the results for a wind direction of 270 deg is shown in Fig 17. The improvement when the jet nozzle system is operating is clearly seen, as the two peaks are reduced by over 60% giving a more uniform gas concentration.

The diagram shown in Fig 18 shows the average of all the values measured during the tests in the form of standard deviation. Again the values are only half when the jet nozzle system is in operation.

These measurements confirmed the test made in Sweden.

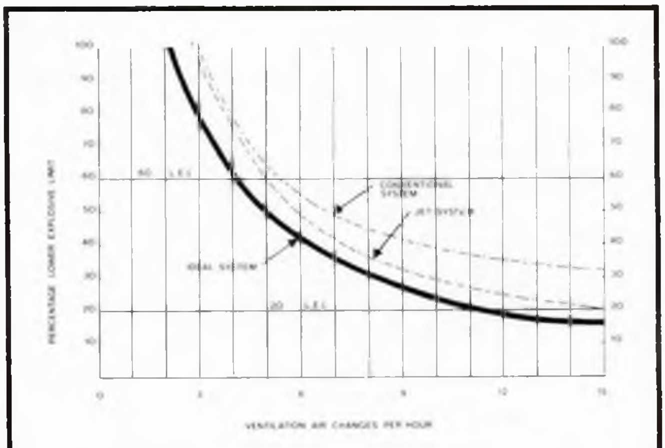


Fig 13: Comparative curves of ideal ventilation versus conventional system and high velocity jet system at a specified gas leakage rate

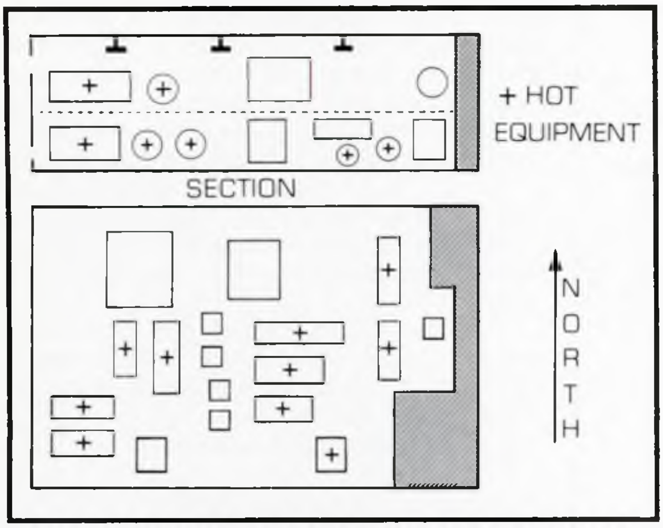


Fig 14: Layout of module and position of equipment

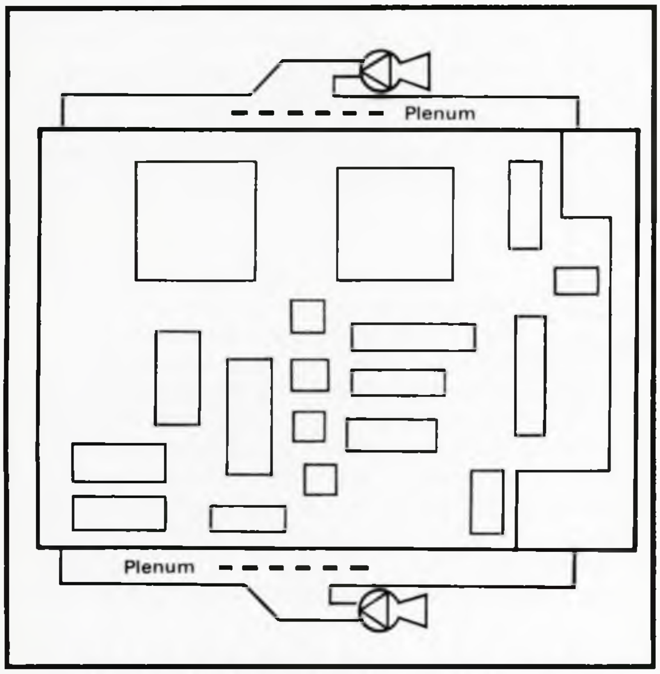


Fig 15: Wind simulating plenum chambers

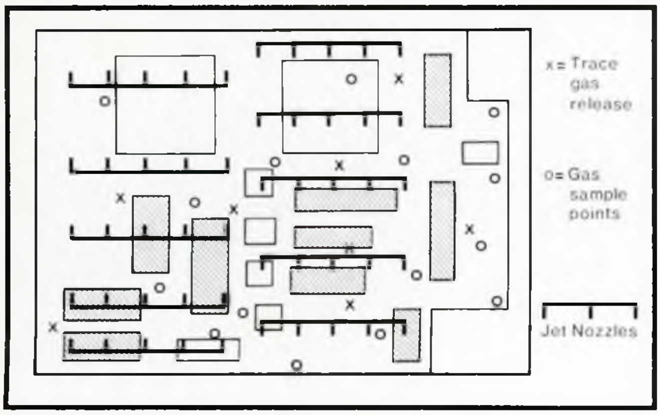


Fig 16: Intermediate deck, jet system ducting, test points

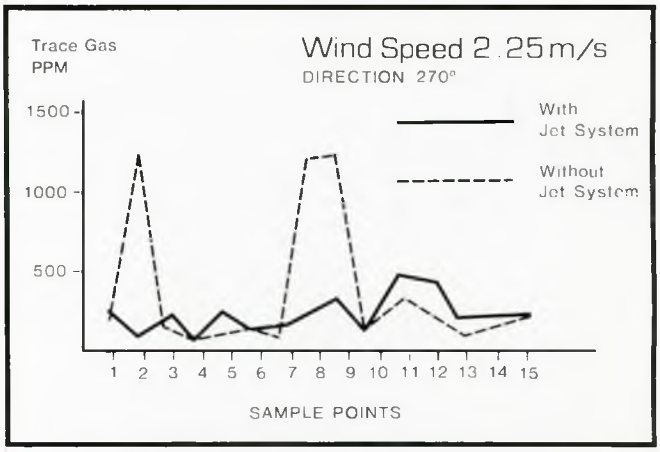


Fig 17: Trace gas peak readings with wind at 270 deg

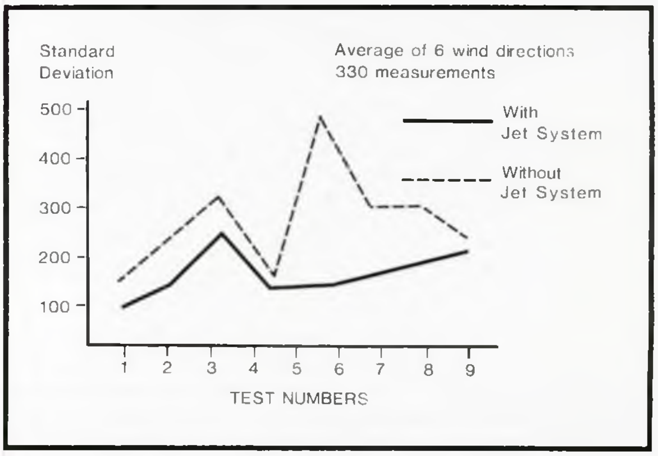


Fig 18: Mean standard deviation – all wind directions

The tests with heat-induced ventilation at zero wind showed that when the walls were provided with slots, the jet nozzle system was able to induce greater air flow through the slots, increasing the air change from 7.2 to 10.2, as shown in Fig 19.

When the jet nozzle system was operated, gas concentration levels showed the peak value change from 550 to 276 ppm. The overall sample standard deviation also decreased from 148 to 95 indicating greater mixing.

When the side wall openings were modified to louvre type, with heat-induced ventilation only, the improvements were less dramatic; an increase of air changes was only from 4.1 to 4.5. However, it should be noted that the positions and discharge directions of the jet nozzles had been designed specially for the high and low level slots and were not altered when the module was provided with weather louvres. An examination of the standard deviation shows that the jet nozzle system produced a more mixed environment with standard deviation values for 45 deg and 270 deg improving from 293 and 299 to 155 and 161 respectively.

Due to the method of wind simulation it was not possible to quantify the change in ventilation brought about by the jet nozzle system under wind conditions. The conclusion of BSRIA specialists is however that it is likely that where wind produces forces of a similar magnitude to those generated by heat release in the module, the jet nozzle system will have a significant effect in supplementing the air change rate. Under calm condi-

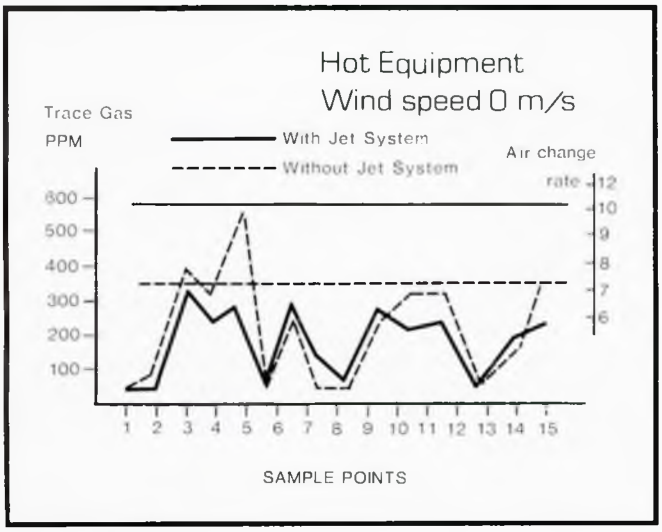


Fig 19: No wind, heated equipment – air change results

tions and without heat release, the jet nozzle system would still be capable of generating significant air change rates and limit the build-up of dangerous gas concentrations by the mixing caused in the space.

CONCLUSIONS

Ventilation has a major preventative influence on the safety of offshore platforms.

Wind forces must be taken into account when designing the ventilation plant.

The knowledge gained from results of wind tunnel tests should be used for the positioning of air intake and outlet openings and the general system design, concerning selection of fans, damper controls and maintaining the required air flow and pressure differences to ensure modules are safe.

A jet nozzle system will improve dilution and prevent stagnant zones as well as assist natural ventilation for open modules.

As the jet nozzle system takes little space and is easy to install, it is particularly important for refurbishing or upgrading existing offshore structures.[12]

As far as the authors' know, no on-site verification of the operation of ventilation systems in varying wind speeds and direction has been carried out, and this perhaps is the next step to be taken to further improve safety in offshore platforms.

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Discussion

B A Børresen (Techno Consult A/S) First of all let me thank you for a most interesting presentation covering quite an extensive range of work starting in the late 1970s. In Norway we are very lucky to be working on several of the new projects under the general heading 'Offshore'. There are significant improvements to be made regarding safety and the working environment. Not least is this within the exciting areas concerning shaft and topside process and drilling. It should be stressed that these improvements often also mean reduced installation and maintenance costs.

New thinking and theoretical knowledge combined with experience and an open mind are keys to improvement. The use of air jet nozzles for mixing is an approach to be used in different situations.

I will briefly mention four aspects that we feel are of importance in our design work.

1. Gas density – The simulations we have carried out for specific oil fields have indicated that the expanded gas at a leakage will give a gas mixture of lower density than air. Critical gas concentrations (in these cases spots), will often appear in connection with typical low temperature corners. On site measurements and follow up are necessary here.
2. Leakage size – One approach is to base the ventilation design on a design leakage rate. The Norwegian approach is to base this on a rate occurring 4–6 times per year. Based on leakage estimates from an earlier platform, one of our newest platforms is based on a leakage rate of 0.1 kg/s per module deck. Some statistical data are available, but more systematic field work combined with alarm statistics are necessary.
3. Ventilation concept – Ventilation is never adequate for large leakages. However, hydrocarbon concentrations normally hold to 0.2 LEL.
   The effect of a leakage rate exceeding the design rate can mean a delay in hot maintenance work.

Other interesting aspects include the following. Should we advocate full air mixing in a room? Normally we find few ignition sources up underneath the ceiling. Allowing gas to gather up under the ceiling can improve early detection and the effectiveness of gas exhaust.

How well does a certain ventilation rate work? For instance, introducing the displacement ventilation concept ('piston flow') is showing a high effectiveness in shaft ventilation, actually with reduced ventilation rates.

4. Natural ventilation – This not only means making openings, but also making them certain sizes and placing them in the best directions regarding 'shading' for wind, and allowing for wild heat in modules with excessive heat gain. Too much ventilation produces problems with the working environment and therefore safety. We found it important to include in our design statistical weather data covering all wind directions and speeds. Specialised computer analysis is therefore necessary where wind gust can also be taken into account. Be aware of explosion ventilation, ie pressure reduction panels.

I must stress the importance of doing not only desk work, but also laboratory tests, as shown here, and field measurements. Our experience gained from Gullfaks A and C is very positive and shows that tests can be run at low cost.

The paper presented covers many interesting aspects and figures.

B Lindberg *et al* (Flakt, and Future Consultant Services) The authors are pleased to note that research and development is being carried out into 'Offshore' ventilation. We would like to comment on some of Mr Børresen's statements.

1. At the time of the first 1:5 scale test at Jonkoping in 1979, drawings of an actual process module were used, and the module process designers provided the chemical specification of the likely hydrocarbon leakage. At atmospheric pressure and temperature a proportion of the hydrocarbon was defined as heavier than air. The proportions of light and heavy gases were used in the model tests.
2. We are glad that Mr Børresen supports the authors request for a defined leakage rate to enable the ventilation system to be calculated on a firm technical basis.
3. Allowing gas to gather in the deep beam spaces of the roof of a module could result in even a very small leakage of low density hydrocarbon gas eventually displacing air until a high concentration is reached. This could bring about frequent alarms and possible process stoppage.
   High impulse turbulent ventilation would in these circumstances keep the hydrocarbon/air ratio lower for an extended period, avoiding alarms and possible production losses. We support the view that more on site skilled and knowledgeable measurements should be made, and the results should be published to aid the ventilation system designers, eventually resulting in a standard specification of requirements.
4. The wind tunnel test witnessed by the authors showed that 'shading' of ventilation openings does not take place. Tests were made with variously shaped covers and hoods over the ventilation. They did not influence the pressure the wind created on the opening.
   Explosion relief (pressure reducing) panels are of course important.

H S Dhargalkar (Offshore Environmental Services) How were heat loads for the scale models calculated?

B Lindberg *et al* (Flakt, and Future Consultant Services) The surface temperature of the full size elements, which the process system indicated would be warm, were assumed to be 60 °C, allowing for the benefit of insulation. BSRIA carried out the necessary calculations to suit the model and Mr Seymour's comments explain this further.

M J Seymour (BSRIA) Three main subject areas were discussed as follows.

1. Use of computer modelling techniques to predict ventilation. The paper presented results of extensive experimental studies carried out over a period of several years investigating and assessing a jet nozzle system's performance for ventilation of open and closed modules. BSRIA now believes that the development of sophisticated Computational Fluid Dynamics Codes is such that they can provide valuable contributions to ventilation performance assessment.
2. The question of how heat loads for the scale models were calculated was raised by Mr Dhargalkar. Values were calculated using standard scaling laws applicable to models of limited scaling factors; for example, power output can be calculated using Archimedes Number.

3. The importance of physical and numerical modelling techniques being complementary was stressed. It is difficult to predict natural ventilation by using any one technique. Numerical models are limited by computer capacity, cost and solution time so that often only one module at a time can be modelled. Similarly, a scale model of 1:100 or 1:200 for wind tunnel tests can be used for pressure prediction but scaling laws for other features are tenuous. In general no individual technique provides the whole solution. However, a combination of several techniques can be used effectively.

B A Børresen (Techno Consult A/S) In answer to Mr Seymour, three-dimensional computer programs are already taken into account in ventilation design. We have used it in one of the platform designs in search of dead spots. The simulations were carried out to see if mechanical air mixing devices were necessary. In this specific case they were not. Advanced fluid flow programs are beginning to be a part of our design tools.

Also, we would like to stress that wind tunnel tests extrapolated to also cover internal ventilation design of modules should be watched out for. We have seen cases all too often, from different countries, where it was evident that the laboratory's knowledge of module laws should have been questioned.

M E Davies (BMT Fluid Mechanics Ltd)

1. Dr Knight (Department of Energy) questioned whether obstructions within modules were always beneficial in producing turbulence. Whereas turbulence mixing is important in diluting and dispersing gases, it should be remembered that obstructions extract energy from the flow (thereby changing its dilution potential) and also create regions in which little transport of the leaked gas may occur. A solution does not therefore lie in excessive blockage of modules.
2. A statement comparing wind tunnel and computational modelling was made which implied that only pressures could be reliably predicted in wind tunnel modelling of offshore platforms. It is not true as stated that velocity and concentration cannot be sensibly measured. Whereas care in modelling is always necessary in model tests, this applies equally to turbulence modelling in numerical codes. With the present state of the art both modelling tools should be regarded as complementary.

B Lindberg *et al* (Flakt, and Future Consultant Services) The principle of the jet system is to use many small jets, at relatively high pressures. This enables spaces behind obstructions to be treated.

S Singh (Independent Safety and Environmental Consultant) The authors are to be congratulated for preparing an interesting and highly topical paper. Unfortunately, whilst they mention some of the major features relevant to the assessment of topside safety (namely ventilation, gas leakage, dispersion, ignition and explosion), no attempt was made to link these factors and to examine the full consequences of gas leakage and dispersion on offshore platforms. The consequences of gas leakage on offshore platforms should be assessed on a probabilistic basis whereby the likely gas releases (source sizes, locations and release rates), the subsequent dispersion behaviour, and the likely ignition sources, are examined. Such information could then be used to decide on the needs and capabilities of any mechanically assisted ventilation system. The authors' comments on this general point would be appreciated.

It is acknowledged that it is impossible to design a platform with a ventilation system which makes it completely safe at all times. Is the jet nozzle system then being proposed as a method of ventilating platforms to satisfy regulatory criteria, or is the system meant to provide additional ventilation in the event of a leakage?

The paper describes the use of wind tunnel tests to examine pressures around and within platforms and so assist in the general positioning of inlets and outlets. Results were then used to calculate theoretically the effect of wind on ventilation. With complex structures such as offshore platforms, methods for calculating the external flow and particularly the internal flow, can be subject to large errors and uncertainties. This is true even for the large three-dimensional codes. Such wind tunnels can be used to assess the general ventilation of complete platforms, either qualitatively by the use of smoke, or quantitatively by the measurement of velocities and gas concentrations (which can be used to derive ventilation rates). Why then have the authors chosen to assess ventilation indirectly by combining wind tunnel tests with theoretical methods?

It should be pointed out that whilst the determination of ventilation rates (however derived) is an important step in assessing the quality and magnitude of air flow through a platform, the use of such information to assess the consequences of a gas leakage is far from straightforward. The initial release conditions, such as buoyancy and momentum, are highly relevant to the subsequent dispersion of the gas. Hence a knowledge of the (neutrally buoyant) air flow patterns alone is an insufficient basis on which to design a mechanical ventilation system. Would the authors please comment on this?

B Lindberg *et al* (Flakt, and Future Consultant Services) The authors have many years experience of ventilation systems, as applied to offshore and other spheres. They do not have the expertise to link together all of the factors as Mr Singh suggests, and it is possible that the best way for all of the factors to be correctly examined, and the interaction of each to be given its importance, is by the formation of a suitable technical body, with suitably qualified persons working together to produce guidance notes to be used by platform designers.

The jet nozzle does not provide additional ventilation. The rate of ventilation air within the space is not increased, except when zero wind conditions exist on an open naturally ventilated module. What the jet system does is ensure that the leakage hydrocarbons are effectively dispersed within the ventilation air flow (see Figs 12 and 13 of the paper).

Due to the limited size of the wind tunnels available to the authors, ie a 3.5 m^2 test section, only a 1:100 scale model could be tested, and within this size of module neither smoke nor gas concentration measurements could be used. The accuracy of the ventilation rates derived by calculation is not in this case important. The order of magnitude is mainly an indication that better control and selection of equipment is required.

Of great importance is the pressure within modules which the wind can generate and the wind tunnel tests give good external pressure results. But the small 1:100 scale model does not allow internal pressures to be measured with accuracy so the external pressures were combined with calculations to give a good indication of the likely range of pressures which will exist. This enables the system designer to select the range of equipment to maintain the required module pressures and air flows.

The series of tests carried out at Jonkoping in 1979 used trace gases, both heavy and light. Also, the equipment within the test module was heated to the degree that the scale size required. The data gained from these tests were used to arrive at empirical methods developed for the design of the jet system.

K S Preston (OIL Marine Ltd) Although not directly related to the content of the paper, OIL Marine are experiencing problems with gaseous mixtures at platforms and floating storage units, and would like to ask the authors' advice.

At one North Sea location when discharging at a platform the crew of a vessel complain of eye irritation from an unidentified gaseous source.

In West Africa at an offshore oil terminal we are experiencing high levels of toxic gases, in particular hydrogen sulphide, on occasions at distances of up to 800 feet from the terminal.

Our concern therefore is for conditions external to platforms and I would ask the authors if they can make any recommendations as to suitable courses of action available to us concerning ventilation, gas detection and safe working conditions when either moored to or remote from offshore units. In addition, what could be done on the platforms to minimise the risks externally, bearing in mind the periods of no wind quoted as 20–30% of the time in the paper?

B Lindberg *et al* (Flakt, and Future Consultant Services) The authors do not have knowledge of gas mixtures external to the platform envelope. Some wind tunnel tests did use released smoke to indicate the likely path that emissions would take close to the outside envelope of the platform, but measurements or records were not made outside this limited area.

D Brown (Matthew Hall Engineering) I would like to make some comments on the following sections of the paper.

'Pressurisation' section: Enclosed areas which are non-hazardous due to their location do not require pressurisation for purposes of certification.

'Results of the wind tunnel test' section: Pressure is sometimes positive around legs and other obstructions.

'Interpretation of the results' section: Use of a centrifugal fan with an outlet below deck is suitable for non-hazardous areas. If used for hazardous areas, the pressure in the hazardous area will become positive at low wind speeds due to duct resistance exceeding the negative pressure of the wind.

'Laboratory test results' section: The paper says that a jet nozzle system would be capable of generating significant air change rates in an open module under minimal wind conditions. Could the authors give a value to their wording of 'significant air change rates' and could they explain why it should take place?

B Lindberg *et al* (Flakt, and Future Consultant Services) Non-hazardous areas may not need pressurisation for certification although the authors think they would be better pressurised. Should a safe area develop a negative pressure, due to the effect of the wind, then hazardous gases could be drawn into the safe module, with possible hazardous effects.

It is possible that close to legs pressure on the underside of the platform may be positive, but the series of tests which the authors conducted did not show such results.

The air change rate which the jet nozzle system should generate would be between 3 and 6 times/h, depending on the siting of the nozzles and ventilation openings, and under still air conditions.

The ventilation is created by the high induction effect of the nozzles, and some of the nozzles are placed so that they induce air flow into the module, while other nozzles are placed to induce air flow out of the module.

G A Smith (BP Engineering) The authors are to be congratulated on presenting a paper containing such valuable information and advice for the use of HVAC design engineers.

Semi-open process modules: I endorse the authors' comment that air flow through semi-open process modules in an offshore installation is rarely uniform and requires special attention if areas of entrainment (stagnation) are to be avoided. My comments are based upon experience of offshore tests and observations from the wind tunnel.

The air jet system generally, as described by the authors, has provided effective mixing performance in a North Sea offshore installation known to me, and has been operative for approximately 6 years. In certain cases the air jet system may need additional mechanical extract ventilation to achieve 'adequate' ventilation by combined natural and mechanically assisted means, for an acceptable annual percentage frequency value, required by a certifying authority.

With regard to jet nozzles, it should be noted that in practice the free flow from these is frequently inhibited by pipes, cable racks and equipment. It follows that secondary air entrained by the primary jet stream is reduced and more nozzles are needed to compensate.

Wind tunnel tests: Wind tunnel testing of a 1:100 or 1:150 scale model of the topsides installation, in conjunction with video sequence recording of flow conditions around and through the modules, is certainly a recommended and valuable design facility for identifying areas of poor mixing and flow which will require mechanical ventilation assistance in some form or other.

It is acknowledged that computer programs are available for three-dimensional simulation of flow through modules. However, to achieve the same boundary definitions achieved in wind tunnel modelling, the computer work may well be more expensive initially.

Gas releases: The authors rightly mentioned a need within the offshore industry to agree a design basis for gas/hydrocarbon releases upon which ventilation systems will be deemed by the authorities to have been adequately designed in terms of risk. The authors also mentioned that there is a general acknowledgement of the fact that releases greater than the agreed basis cannot be contained below the stoichiometric mixture level by the ventilation system. Under the authors' heading in the paper 'Gas leakage', I would recommend that the text is amended to read:

'Having established that gas leaks are potentially present, the next ...'.

B Lindberg *et al* (Flakt, and Future Consultant Services) The authors note with interest that Mr Smith has good experience of a jet nozzle ventilation system. For the configuration of module to which Mr Smith refers, the authors agree that extract fan ventilation is required to supplement the natural ventilation.

We hope that Mr Smith and others will now create an initiative to arrive at an agreed basis for design regarding hydrocarbon releases. The industry should ensure that the correct basis of design is available as an aid to producing safe ventilation systems.

Mr Smith's modification to the text is noted.