AN IMPROVED AIR BREAK RECEIVER UNIT
A design suited to high-vacuum scavenging systems

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SUMMARY

The advantages of active anti-pollution systems are discussed, in particular those depending on a high vacuum and narrow-bore pipework. The design requirements of a receiver for such a system are set out and the detailed design of such a receiver described. The performance of the unit is assessed with special regard to efficiency and safety.

The danger to persons working in operating theatres and elsewhere from exposure to waste anaesthetic gases, although not proven beyond per-adventure, is generally seen as justifying the provision of scavenging equipment (Department of Health and Social Security, 1976; National Institute for Occupational Safety and Health, 1977; Heerdt, 1978; Tomlin, 1979; Lane et al., 1980; Vessey and Nunn, 1980).

Passive disposal systems, although cheap to install, are in effect only a very long pipe attached to the adjustable pressure limiting valve (APL valve) of the patient circuit (North West Thames Regional Health Authority, 1977; Mehta et al., 1977). Since the patient must provide the driving force for the waste gases, pipe runs have to be relatively short and pipe diameters large if excessive back pressure is not to be imposed on the patient breathing circuit. Wind effects in the vicinity of the point of discharge outside the building impose variable and unwanted pressure surges on the system (Parbrook and Monk, 1975; Asbury and Hancox, 1977). These considerations make the use of a passive anti-pollution system impossible except where the theatre has an outside wall or is on the top storey of the building (Parbrook and Monk, 1975). These significant build in size of the building may be achieved by mechanical means. Occasionally, these are located close to (2 m) the point of origin of the pollution, when the waste gases may be discharged at the intake grill or into the nearby ductwork (Parbrook and Monk, 1975). If the extract duct is not close to the origin of the waste gases, but operates at a sufficient negative pressure with respect to the theatre, a piped disposal system containing an air break unit to isolate the patient circuit from excessive negative or positive pressures can be installed (North West Thames Regional Health Authority, 1977). An adequate air flow rate must be maintained of not less than 30–40 litre min⁻¹ in the disposal system and it should be remembered that this is sensitive to pressure changes in the theatre resulting from the opening of doors and the like. All the systems so far discussed require relatively large-bore connections (at least 22 mm diameter) from the APL valve to the fixed parts of the system and these are not always convenient in use.

A generally applicable solution to the disposal of waste anaesthetic gases is to provide a fully active disposal system in which the pollutants are extracted dynamically through a suitable run of pipe and discharged outside the building (Parbrook and Monk, 1975). An air break unit is provided in the system to isolate the patient from the large negative pressures in the disposal pipework. The extraction unit may be either a fan or other device operating at low negative pressures when large diameter pipes are required, or a pump producing a large negative pressure (say 30 kPa) when small diameter pipes suffice. The flow rates required by either system depend on the performance required and the efficiency of the air break receiver unit used, and may be from about 35–40 litre min⁻¹ to as great as 160 litre min⁻¹ in some cases (Department of Health and Social Security, 1981).
The high vacuum type of disposal system offers a real advantage over all other systems in that the receiver can be coupled to the fixed part of the disposal system by narrow-bore tubing. Thus, if the combined air break receiver unit is mounted on the anaesthetic machine the fixed part of the disposal system can be connected to the receiver by a 13-mm diameter plastic hose fitted with a quick-release probe. Such a hose has handling characteristics similar to the other gas supply hoses on the anaesthetic machines — a matter of some convenience. If the receiver is placed on the anaesthetic machine, wide-bore corrugated tubing is only required to provide a transfer system between the expiratory valve of the patient circuit and the receiver vessel, a distance of about 1 m. Moreover, that part of the anti-pollution system connected directly to the patient is, along with the rest of the breathing circuit, under the anaesthetist's immediate supervision and so requires no separate pressure-limiting valves (Tavakoli and Habeeb, 1978). The receiver unit must incorporate all the safety features in a fail-safe form necessary to isolate the patient from excessive negative pressures derived from the disposal line and provide for the free escape of exhaled gases to the atmosphere if the scavenge line fails or is not connected so as to prevent back pressure developing in the patient circuit (Thompson, 1978). The machine-mounted receiver has a further advantage in that the whole unit with its transfer tubing can be removed, along with the rest of the breathing circuit, for sterilization should this be required.

If the advantages of the high vacuum disposal system are accepted, then a suitable receiver is required. In new installations the receiver and disposal system may be designed as an entity and the disposal flow made suitable for the requirements of the receiver, but since there are already systems of this type installed, the proposed receiver should be compatible with these, if possible. This requires the receiver to capture physiological inputs at scavenge rates as low as 35 litre min\(^{-1}\) whilst being quite safe for use with scavenge rates of up to 200 litre min\(^{-1}\) without including a flow restrictor in the disposal line. The capture performance at the designed scavenge rate must meet the requirement of the Department of Health and Social Security both for "physiological" inputs and inputs containing a continuous flow element (Department of Health and Social Security, 1981). The receiver, as already mentioned, must incorporate all the safety features necessary to isolate the patient from excessive pressures. The receiver must be easily fitted to a variety of makes and models of anaesthetic machine. The noise level of the equipment when in use should be so low as to be inaudible under normal theatre conditions at distances of about 1 m. The equipment must be convenient in use and not add to the workload of the anaesthetist. Provision should be made for a means of indicating that the disposal line is connected and that an adequate scavenge flow is available in the system.

Attempts to use air break receiver units designed for low vacuum systems with high vacuum disposal lines are dangerous as they lack adequate provision for isolating the patient from excessive pressures under fault conditions. Such units are also noisy when used at high flow rates.

Since no equipment, designed for use on high vacuum systems and which met all the above requirements, existed commercially it was decided to develop an air break receiver system specifically to meet these requirements.

**DESCRIPTION OF THE AIR BREAK RECEIVER UNIT**

The Barnsley receiver is a co-axial air break unit (Houldsworth, O'Sullivan and Smith, 1983) and consists of three concentric tubes of which the inner two form the air break receiver unit proper and the outer slotted tube forms a safety sheath.

The discharged gases are introduced through the 30-mm conical socket S (fig. 1) and enter the inner tube A to be discharged at point G, 200 mm below the open end of the intermediate tube B. The open end of tube B communicates freely with the annular space between tube B and the outer slotted safety sheath (tube C) and via the slots D to the atmosphere. The lower end of the intermediate tube B is closed and attached by a suitable hose to the disposal system. Thus, air is drawn into the tube B through its open end, and having entrained the waste gases discharged from the centre tube A, the mixture is removed through the disposal line. The lower part of the tube B (below the point of discharge of the waste gases) is packed with a fibrous filter medium F retained between wire mesh discs. This acts as a silencer, reducing the hiss generated by the air flow in the disposal piping to an inaudible level.

The outer safety tube C has at its lower end six slots D, having a combined area of about 140 cm\(^2\), which are covered by 20-mesh gauze. In addition to these slots, 32 5-mm holes (H) drilled round the top of the safety tube provide a vent area of 6 cm\(^2\) and are in themselves adequate to provide a completely safe...
communication to the atmosphere even if all six of the main slots are obstructed. The large redundancy factor in the design of the vents and the relatively large area of the tube over which they are scattered make accidental occlusion of sufficient vents to prejudice safety unlikely. On this feature the great safety of the design depends.

*Overall dimensions and construction*

The overall length of the unit is 500 mm and the diameter 85 mm. The unit is mounted on the anaesthetic machine by standard dovetail shoes. Figure 2 shows the complete apparatus and figures 3 and 4 show something of its construction details. Figure 5 shows the unit installed on a B.O.C. Boyle’s Type M Anaesthetic Machine and it may equally easily be fitted to any other make of anaesthetic trolley.

The unit may be made of any suitable material, both stainless steel and chromium plated brass having proved excellent.

*Silencer packing*

The silencer unit is packed with 20 discs of Bondina P15/500 (Bondina Ltd, Ellistones Lane, Greetland, Halifax, West Yorkshire HX4 8NJ) cut to a diameter of 55 mm. This packing provides excellent noise reduction with a minimum resistance to flow and was more satisfactory than any of a wide range of materials tried.

*Monitor block*

In order to provide a convenient attachment for the hoses, a connector block fitted with a vacuum gauge may be provided on the anaesthetic trolley (fig. 6), although this feature is optional. The vacuum gauge measures the pressure decrease across the silencer unit and depends for its indication on the resistance of the silencer unit and on the scavenge flow rate. A full scale deflection of 10 kPa is suitable for this gauge and at a flow rate of 150 litre min
\(^{-1}\) in the scavenge line the normal reading is about 4 kPa when the silencer is packed as recommended. The gauge then gives a useful indication of the flow rate in the system.

*PERFORMANCE*

The efficiency of the unit was assessed by the application of a standardized input to the vessel whilst observing the least scavenge flow rate at which the unit just captured the gas flow introduced. The pulse component of the input was generated by a Polilog pulse generator and relay valve (Comp Air Maxam) used to interrupt an air flow of the desired rate (Houldsworth, O’Sullivan and Smith, 1983). For the “physiological” input tests a continuous flow of nitrous oxide 0.25 litre min
\(^{-1}\) was added to the output of the pulse generator as a convenient analyte for detection by an infra-red spectrophotometer. The continuous flow components of
Fig. 2. The Barnsley Anti-pollution Receiver complete.

Fig. 3. The Barnsley Anti-pollution Receiver with the base removed to give access to the silencer material.

Fig. 4. The Barnsley Anti-pollution Receiver dismantled into its component parts to indicate the construction of the unit.
the input gases when required were added to the output of the pulse generator through rotameters.

For the performance tests a variable scavenge flow of up to 250 litre min\(^{-1}\) was obtained by connecting a fine adjustment valve simultaneously to four points of the hospital vacuum system. The scavenge flow rate was measured on a rotameter placed in the line between the fine adjustment valve and the receiver under test.

Two types of standard input were used:

(a) "Physiological" input consisting of a square pulse of gas having a volume of 0.54 litre and entering the system at a peak flow rate of 130 litre min\(^{-1}\) with a duration of 0.25 s repeated every 3.0 s.

(b) Mixed steady state and pulse flow such that a steady flow of gas of 75 litre min\(^{-1}\) (air 65 litre min\(^{-1}\) + nitrous oxide 10 litre min\(^{-1}\)) was combined with a pulsed flow of air of 55 litre min\(^{-1}\) such that this flow was turned on for 0.25 s in each 3-s period. This gave a peak input flow of 130 litre min\(^{-1}\). The ability of the receiver to capture this input ensures that it meets the requirements of the Department of Health and Social Security (1981).

The physiological input was chosen arbitrarily so as to have the same peak flow rate and time relationships as the D.H.S.S. test. The tidal volume of 0.54 litre is of a size normally encountered and, although
the peak flow rate is at least twice the size encountered in practice, this will have little effect on receiver performance. The D.H.S.S. test is also somewhat artificial, but is intended to simulate the output of those ventilators which mix the patient's expirations with the air or other gas used to drive the machine.

The escape of gas was detected by an infra-red spectrophotometer (Perkin Elmer 157G) having a 22.5-m path-length gas cell. The input to the gas cell was taken from a point 5 mm from the lower vents of the vessel. The end-point was a detectable (1-p.p.m.) escape of nitrous oxide as recorded by the spectrophotometer.

Table I shows the results of these tests. The figure quoted is for minimum usable scavenge rate which is the breakdown scavenge rate as determined plus a safety factor of 10 litre min⁻¹.

**Noise level**

The noise level produced by the receiver as measured at a distance of 1 m from the unit is approxi-
BARNSLEY AIR BREAK RECEIVER UNIT

**Table I. Capture performance of Barnsley Receiver unit. Scavenge rate at breakdown + 10 litre min⁻¹**

<table>
<thead>
<tr>
<th>Type of test input</th>
<th>Minimum usable scavenge rate* (litre min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Physiological&quot; pulse volume 0.54 litre; peak flow rate 130 litre min⁻¹</td>
<td>35</td>
</tr>
<tr>
<td>Mixed input: 75 litre min⁻¹ continuous 55 litre min⁻¹ interrupted flow (on 0.25 s, off 2.75 s in each 3-s period)</td>
<td>90</td>
</tr>
</tbody>
</table>

sterilization and maintenance

The unit can be sterilized by autoclaving at 135°C. The silencer material showed some permanent deformation after this treatment, but not such as to obstruct the flow of air through the unit. It is, however, recommended that the silencer material be removed and discarded before autoclaving and replaced by fresh material before the unit is re-used.

The Barnsley receiver unit can easily be dismantled for internal cleaning, which is required about every 3 months. The silencer packing can be removed and renewed at any time by removing the base only (fig. 3). The unit contains no moving parts and no other regular maintenance is required.

**Disposal line requirement**

Table II shows the negative pressures required to induce various scavenge flows through the unit alone, the unit plus 4 m of 13-mm connecting hose and the unit plus 4 m of 13-mm connecting hose along with the monitor block unit described above.

At a scavenge rate below 60 litre min⁻¹ it might be possible to decrease further the resistance by decreasing the quantity of silencer material as the noise generated by the air flow in the pipework is much reduced at low flow rates. This matter has not been investigated.

**Table II. Scavenge line requirements for the Barnsley Receiver. Negative pressure required at the terminal unit of the fixed disposal system to produce various scavenge flow rates through the unit and its connections**

<table>
<thead>
<tr>
<th>Scavenge flow induced in unit (litre min⁻¹)</th>
<th>Scavenge line negative pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Receiver unit only</td>
</tr>
<tr>
<td>170</td>
<td>1.75</td>
</tr>
<tr>
<td>150</td>
<td>1.45</td>
</tr>
<tr>
<td>130</td>
<td>1.23</td>
</tr>
<tr>
<td>110</td>
<td>1.06</td>
</tr>
<tr>
<td>90</td>
<td>0.80</td>
</tr>
<tr>
<td>70</td>
<td>0.61</td>
</tr>
<tr>
<td>50</td>
<td>0.40</td>
</tr>
</tbody>
</table>

**SAFETY TESTS**

Figure 7 shows the negative pressure developed at the receiver input for various scavenge flow rates up to 250 litre min⁻¹ and, as can be seen, the maximum negative pressure developed is well below the D.H.S.S. recommended limit of −50 Pa (Department of Health and Social Security, 1981).

Figure 8 shows the negative pressure developed at the receiver input under simulated fault conditions plotted against scavenge line flow rates up to 250 litre min⁻¹. Fault A was produced by occluding all six slots in the outer sheath so that only the 32 5-mm holes were available to vent the unit to the atmosphere. Under these conditions the D.H.S.S. recommended limit (−50 Pa) of negative pressure was not
reached at any scavenge flow rate. Fault B was produced by additionally closing 16 of the 32 safety holes. Even under these totally artificial conditions, the limit of negative pressure was not reached with a scavenge rate of less than 120 litre min$^{-1}$. Even at 250 litre min$^{-1}$ scavenge flow rate the negative pressure developed in the system was only $-200$ Pa ($-2.0$ cm H$_2$O), a value not likely to do harm to a patient.

Table III sets out the results of a series of safety tests as recommended by the D.H.S.S. (Department of Health and Social Security, 1981) in which steady flows were presented to the receiver input at its normal maximum scavenge rate and also with the scavenge line disconnected. The third column of the table gives the maximum recommended values under these test conditions. When the scavenge line is disconnected the gases escape to the atmosphere. It can be seen from the table that the performance of the Barnsley receiver unit is, even under extremely unlikely fault conditions, satisfactory, since all the relevant pressures developed are well below the D.H.S.S. limits even for high scavenge flow rates.

**PERFORMANCE UNDER FIELD CONDITIONS**

Measurements of pollution obtained in the operating theatre have been made over a period of 2 months using a personal monitoring system (Houldsworth, Musgrave and O'Sullivan, 1982). This has allowed time-weighted average (TWA) readings to be obtained for either the duration of an operating list or for an 8-h shift exposure for all the staff of an operating theatre. Typical results for an anaesthetist during an E.N.T. list showed an average atmospheric concentration of 16 p.p.m. The remaining staff within the theatre showed values...
FIG. 8. Barnsley Receiver Unit showing the negative pressure developed at the inlet of the unit under simulated fault conditions for various flow rates in the scavenge line.

TABLE III. Safety tests on Barnsley Air Break Receiver System. Pressures presented at the receiver input under various test conditions as recommended by the D.H.S.S. Column 3 gives the maximum values recommended by the D.H.S.S. for comparison

<table>
<thead>
<tr>
<th>Test</th>
<th>Scavenge zero</th>
<th>Scavenge 150 litre min⁻¹</th>
<th>D.H.S.S. recommended maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input 30 litre min⁻¹ continuous flow</td>
<td>24</td>
<td>12</td>
<td>±50</td>
</tr>
<tr>
<td>Input 90 litre min⁻¹ continuous flow</td>
<td>196</td>
<td>196</td>
<td>+500</td>
</tr>
<tr>
<td>Input zero</td>
<td>—</td>
<td>-4</td>
<td>-50</td>
</tr>
<tr>
<td>Input 30 litre min⁻¹ continuous flow Fault A</td>
<td>27</td>
<td>12</td>
<td>+1000</td>
</tr>
<tr>
<td>Input zero Fault A</td>
<td>—</td>
<td>-22</td>
<td>-50</td>
</tr>
</tbody>
</table>
varying from 5 p.p.m. to 12 p.p.m. Similar or better results were obtained during general surgical operating sessions. These concentrations were well below the National Institute for Occupational Safety and Health (1977) recommended maximum value of 25 p.p.m. Spot checks using a Miran 104 computing infra-red gas analyser demonstrated that the bulk of the pollution arose from connection and disconnection of the patient from the anaesthetic line and from minor leaks around the anaesthetic mask.

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Une unite receptrice d'arrivee d'air amelioree

RESUME

Les avantages des circuits anti-pollution actifs sont discutes, en particulier ceux qui dependent d'une tuyauterie de faible calibre soumise a un vide pouss. Les necessites de conception d'un recepteur, pour un tel circuit, sont precisees et le schema decrit de l'un tel recepteur est decrit. Les performances d'une telle unite sont precisees avec une mention speciale en ce qui concerne l'efficacite et la securite.

Eine verbessererte Air-break-receiver-Einheit

ZUSAMMENFASSUNG

Es werden die Vorteile aktiver Anti-Verschmutzungssysteme diskutiert, insbesondere derer, die mit hohem Vakuum und engebohrtem Pfeifenwerk arbeiten. Die Erfordernisse fur das Design eines Receivers mit solch einem System werden dargelegt, das detaillierte Design eines solchen beschrieben. Die Funktion der Einheit wird besonders hinsichtlich ihrer Effizienz und Sicherheit beurteilt.

Una unidad receptora de ruptura de aire mejorada

SUMARIO

Se discute de las ventajas de los sistemas activos de anti-contaminación, en particular los que dependen de tuberías de alto vacío y de estrecho calibre. Se reseñan los requisitos de diseño de un receptor para tal sistema y se describe asimismo el diseño detallado del receptor. Se evalúa la performance de la unidad, con atención especial en la eficacia y la seguridad.