A SYSTEM OF DIFFERENTIAL DELIVERY PRESSURES AND HOSE DIAMETERS FOR USE IN HOSPITAL MEDICAL GAS INSTALLATIONS

K. A. HOSKEN, C. H. VAN HASSELT AND D. G. MOYES

SUMMARY

Medical gases can be identified simply if they are supplied at different pipeline pressures. Routine maintenance errors, accidental pipeline cross-connections, or gas failures, can be automatically detected by incorporating a pneumatic unit with pressure-sensitive valves into the anaesthetic machine. A fail-safe method of ensuring the delivery of the correct gases to the patient is described.

Tragedies have been reported throughout the world from errors in medical gas pipeline installations (Robinson, 1979) and, in addition to the reported mishaps, we have been aware of other instances where disaster has been narrowly averted. The commonest cause appears to be cross-connecting gas supply pipelines at some point between storage and the point of use (Klein and Lilburn, 1980; Cundy and Baldock, 1982). However, errors in outlet fittings and cross-connected lines within the anaesthetic machine have occurred also (Spurring and Shenolikar, 1978; Downing, 1981).

A system is proposed whereby gases are delivered at differential pressures. This allows the user to check correct connections visually and by audible alarm. The system will automatically interrupt the supply of all gases in the event of a fault in the oxygen supply line and that of other gases if they deviate from the standards set.

THE PRINCIPLE

It is customary to distribute medical gases at a pressure of about 400 kPa. The reason for the adoption of this specific pressure is obscure and is probably the result of common usage rather than deliberate design. The pressure of 400 kPa is by no means universal. The U.S.A. National Code for example, calls for a “Dynamic Pressure of 345 kPa (50 psi).”

We propose that each medical gas be assigned its own distinctive distribution pressure as suggested in table I. The pressure settings allocated to anoxic gases are lower than those of oxygen and air. Thus, in the event of crossed pipeline connections, there could be no retrograde contamination of the oxygen pipeline. For example, air at its pressure of 400 kPa could not displace oxygen with its greater delivered pressure of 500 kPa.

The adoption of this principle has several additional significant advantages. First, the use of line pressure gauges not only establishes that gas is available, but additionally provides a simple means of positively identifying each gas. Second, the use of a pneumatic interlocking device would provide an automatic safeguard against incorrect coupling and against failure of supply. There are other advantages such as the fact that the volume of reserve oxygen available within the pipeline system itself is increased by some 20%.

A further proposal which we make is that consid-

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<table>
<thead>
<tr>
<th>Gas</th>
<th>Nominal pressure (kPa)</th>
<th>Pressure limits (kPa)</th>
<th>Oxygen content &gt;20%</th>
<th>Flexible hose nominal bore (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air for power tools</td>
<td>700</td>
<td>730–650</td>
<td>Yes</td>
<td>6.3</td>
</tr>
<tr>
<td>Oxygen</td>
<td>500</td>
<td>540–490</td>
<td>Yes</td>
<td>6.3</td>
</tr>
<tr>
<td>Medical air</td>
<td>400</td>
<td>440–390</td>
<td>Yes</td>
<td>6.3</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>300</td>
<td>340–290</td>
<td>No</td>
<td>12</td>
</tr>
<tr>
<td>Entonox</td>
<td>300</td>
<td>340–290</td>
<td>Yes</td>
<td>6.3</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>200</td>
<td>240–190</td>
<td>No</td>
<td>12</td>
</tr>
<tr>
<td>Vacuum</td>
<td>—</td>
<td>Max. poss.</td>
<td>No</td>
<td>12</td>
</tr>
<tr>
<td>Scavenging</td>
<td>—</td>
<td>± 10</td>
<td>No</td>
<td>18</td>
</tr>
</tbody>
</table>

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eration be given to the size of flexible hoses and connections as presently specified in BS 5682 and which are used to connect gas equipment to the terminal units. It is, unfortunately, not practical to suggest that each gas have its own distinctive pipe size. None the less, some degree of size differentiation would be possible and desirable. Therefore, we propose that hoses and tail pipes for oxygen and mixtures with an oxygen content of not less than 20% oxygen (v.v.) retain the present size of 6.3 mm and that flexible hoses for anoxic gases have a nominal bore of not less than 12 mm (Table I). If this were standardized, we feel that it would be acceptable to distribute Entonox and nitrous oxide at the same pressure, knowing that they were dimensionally separated.

The "KENTEL" pneumatic control unit has been designed and incorporates this principle. It provides the user with visual and auditory identification of the gases being used at the point of delivery to the patient. The supply of all gases is dependent on the oxygen supply being maintained within the pressure range prescribed. Should the pressure of oxygen deviate outside this range, all gas supplies will be interrupted. The pressure of each other gas is also monitored and any variation outside its accepted limits will result in its being shut off. The control unit is operated pneumatically and does not require any external source of power. High and low pressure audible and visual alarms are built in and the correct functioning of each alarm is verified when the gas supply is connected.

The principle of the control unit is depicted in figure 1, which illustrates the low pressure protection fitted to the oxygen delivery line. The valve block, by common practice, shows both the un-activated and activated arrangement of gas passages within the valve. In the resting or un-activated state, the gas passages permit gas flow from A to B and from C to D. As soon as pressure from the inlet side reaches and exceeds the pre-set value of 480 kPa the pressure sensor causes the internal gas passages to change over, so that the gas flow will then be from A to C and from B to D. It will be seen that in its resting position, or if the inlet were to be connected to any gas at a pressure lower than 480 kPa, the valve would deliver directly to the alarm whistle. With the inlet correctly connected to oxygen with its pressure

![Diagram of the KENTEL pneumatic control unit](image)

**Fig. 1.** Plan of working of oxygen low-pressure cut-off and alarm. *Pressure-sensitive valve, "Festo" type (adjustable) LC-4-1/8-UV.
greater than 480 kPa, the pressure sensor activates the valve to silence the whistle and deliver oxygen to the oxygen rotameter tube. A pressure gauge is fitted to the inlet side, and connected into the delivery side is a pop-up indicator which shows that oxygen is available at its correct pressure. In the event of oxygen failure, the pressure sensor will revert the valve to its resting position and the residual gas will be connected to the alarm whistle.

Figure 2 illustrates a control unit protecting an anaesthetic machine coupled to oxygen, medical air and nitrous oxide. The oxygen at a nominal pressure of 500 kPa is fitted with low pressure protection valve No. 1 operating as described above. The medical air at its nominal pressure of 400 kPa is controlled by both low-pressure and high-pressure sensing valves. These valves No. 2 and 3 are respectively preset to activate at 380 kPa and 450 kPa. Air

![Figure 2. Control diagram for use with a three-gas system with reserve oxygen provision. Valve blocks 4, 6 and 7 are pneumatic valves “Festo” type VL/O-3-1/8. Valve blocks 1, 2, 3 and 5 are pressure-sensitive valves “Festo” type (adjustable) LC-4-1/8-UV.](image-url)
must, therefore, be at a pressure greater than 380 kPa in order to pass un-interrupted through valve No. 2 and less than 450 kPa to pass through valve No. 3. The pressure settings of the valves have intentionally been selected slightly outside the values given in table I to provide additional flexibility, bearing in mind that delivery pressures are subject to small variations as a result of changing demand. An additional valve No. 4 is inserted between valve No. 3 and the rotameter. This valve is activated by pressure from the oxygen delivery, thereby ensuring that oxygen is available at its correct pressure before air may flow. In the event of oxygen failure valve No. 4 will interrupt air flow and sound an additional alarm.

Nitrous oxide at its nominal pressure of 300 kPa is provided with high pressure protection by valve No. 5, which is pre-set to change into the alarm mode if the pressure is greater than 350 kPa. A second valve No. 6, fitted before the rotameter and activated by pressure from the air delivery, ensures that both oxygen and air must be correctly available before nitrous oxide can flow.

Valve No. 7 inserted into the reserve oxygen delivery provides that, in the event of a supply failure in the main oxygen pipeline, emergency oxygen from a cylinder attached to the anaesthetic apparatus will be supplied to the patient, but only in the presence of appropriate visible and audible warnings.

It is proposed that normal operating pressures be demonstrated by a clearly visible gauge. The gauge needle would occupy a green zone and a vertical position when correct pressure is in operation (figs 3, 4). The gauges are colour-coded as detailed in table II.

The prototype units were built into a metal box about 220 mm × 170 mm × 400 mm wide fitted onto the back of a Boyle's apparatus in such a manner that the gauges and indicators were clearly visible below the vaporizers and above the working surface. The gas connections were built into the permanent piping of the Boyle’s apparatus. The cost of the prototype units was of the order of £500. Final production costs have yet to be established.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Background</th>
<th>Lettering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>Grey</td>
<td>Black</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Blue</td>
<td>Black</td>
</tr>
<tr>
<td>Medical air</td>
<td>Black</td>
<td>White</td>
</tr>
<tr>
<td>Oxygen</td>
<td>White</td>
<td>Black</td>
</tr>
</tbody>
</table>

**DISCUSSION**

There is a long overdue need to display for anaesthetists the correct functioning of gas delivery systems and to protect patients from any possibility of exposure to anoxic mixtures. The proposed system provides a simple solution to both needs.

Maximum protection is achieved by fitting the pneumatic unit into the permanent piping of an anaesthetic machine immediately proximal to the rotameters. This obviates errors no matter where...
they may occur, and provides the anaesthetist with
an immediate visual check of gas supply pressure.
The unit does not require user compliance and is
pneumatically powered and totally automatic in op-
eration.

The adaptation of existing pipelines to the new
pressures is straightforward and can be undertaken
at moderate cost.

The use of existing gas-powered or gas delivery
equipment may need modification. We have investi-
gated the flowrates in rotameters (Medishield Lon-
don) and Quantiflex M.D.M. mixer (Cyprane,
Keighley). These devices do not exhibit any change
when the new recommended pressures are used.
However, all gas measuring devices will require
re-calibration after installation of the new system.

The “KENTEL” differential pressure safety system is manufac-
tured by: African Oxygen Limited, Smits Street, Industries
West, PO Box 207, Germiston: 1400, South Africa (Tel. No.
51-6111 (011), from whom further particulars can be obtained.

REFERENCES
Cundy, J., and Baldock, G. J. (1982). Safety check procedures to
eliminate faults in anaesthetic machines. Anaesthesia, 37, 161.
supply. Anaesthesia, 34, 66.