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A Silica-Gel Trap System for Dehumidification of Expired Gases in a Nonbreathing Anesthetic or Respiratory Circuit

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The need to humidify dry inspired gases during mechanical positive-pressure ventilation is especially important when a non-rebreathing system is employed in the Operating Room or in the Intensive Care Unit. Efficient humidifiers and nebulizers have been devised which, in some cases, provide supersaturation of the inhaled gases. However, the humidity of the expired gases is not influenced by the type of nebulizer used. Even if the patient is so dehydrated that his alveolar air is not totally saturated at 37° C., the expired air will be cooled to room temperature outside the body and thus will have a relative humidity of 100 per cent. Any kind of respirator circuit contains a certain amount of deadspace which extends into the expiratory limb. If the air is supersaturated in the inspiratory limb, part of this high humidity is present at the expiration valve.

Measuring respiratory parameters correctly is essential for monitoring patients adequately. On some ventilators these data are obtained by channeling the expiratory gases through a manometer, usually of an aneroid type, and a spirometer. These monitors are located in the expiratory limb proximal to the expiratory valve. Because of the difference in the temperature of the humidified exhaled gases and

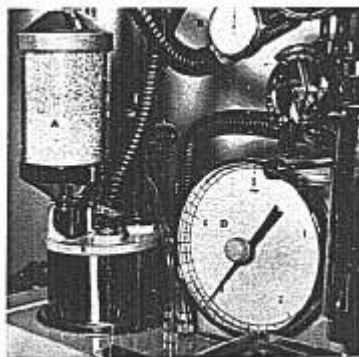


FIG. 1

that of the instruments, precipitation of water occurs. This renders the manometer, the spirometer, and any other devices, *e.g.*, an alarm device placed in the expiratory circuit, inaccurate. It also interferes with the proper functioning of the valves exposed to humidity. In addition to depositing salt, the use of saline in the nebulizers corrodes the metal parts of the instruments.

To prevent the valuable monitoring instruments from being ruined by the high humidity of the expired gases and to protect the valves, a silica gel trap system was devised by one of the authors (D. A.). The trap is placed in the expiratory limb of the circuit, between the patient and the monitoring instruments.

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TABLE 1. Results with Dry and Wet Silica Gel
(Note the definite increase in resistance when the silica gel is saturated with water and exposed to high peak flows. However, the increase is still within physiological limits)

Dry Silica Gel		Wet Silica Gel	
Peak Flow Liters	Differential Pressures (cm. H ₂ O)	Peak Flow Liters	Differential Pressures (cm. H ₂ O)
2.0	0.15	2.0	1.08
1.5	0.15	1.5	1.03
0.9	0.07	0.9	0.6

This report demonstrates a system which effectively dehumidifies and protects the monitoring instruments and the expiratory valve.

METHOD

We usually use Engstrom respirators equipped with Mivab Ultrasonic Nebulizers U-701 for administering anesthesia and for ventilating infants and small children in the Intensive Care Unit. A modified nonbreathing system is employed.¹ The CO₂-absorbing canister is placed in the expiratory line and serves as a container for the silica gel (fig. 1). In order to determine the effectiveness of the silica gel as a dehumidifier and to investigate its resistance to expiration the following study was performed.

In the first series of experiments, the canister was filled with dry silica gel † and exposed to

† Silica Gel. Activated silica gel is among the most useful adsorbents for a large number of organic and inorganic compounds. The adsorbing properties of the gel are determined entirely by the nature and extent of the particle surface.² Since it is a substance with a nonsymmetric electron distribution it has a polar character and will adsorb polar or readily-polarized substances effectively.³ The efficacy of the adsorption displayed by polar adsorbent depends on the position of the relevant homologous group of the substance adsorbed. The sequence of such groups in descending order of polarity is; water, alcohols, aldehydes, ketones, esters, aromatics, olefins, and paraffins.⁴ A comprehensive source of information on the surface properties of silica gel can be found in the work of Iler.⁵

There is controversy as to the best granule size of silica gel. With large granules there is less resistance to air flow, while smaller granules provide good contact between air and adsorbent. We used mesh size from 8 to 16. (Tel-Tale Activated Silica Gel Mil-Bo 3716, Grade H, Type 4, made by Grace Davison Chemical Company.)

different peak flows. Its resistance to flow was measured. Following this the silica gel was saturated with water. It was exposed to identical peak flows and resistance was examined (table 1).

In the second series of experiments, pressures in six patients were recorded in the expiratory line adjacent to the inlet and outlet of the canister with the Sanborn Differential Pressure Transducer #267BC. For recording flow rates a pneumotachograph with a screen surface of one square inch was incorporated in the expiratory line. A Sanborn 4-Channel Recorder (Model 760) coupled to a Carrier preamplifier (#350-1000C) was used for recording the data. The theoretical minute volume and respiratory rate for each patient were obtained with the help of the Engstrom nomogram and the respirator was adjusted appropriately. In each case the Mivab Ultrasonic Nebulizer was set to a six-drop-per-minute output (0.5 ml.) and the built-in Engstrom heated humidifier was also used. Relative humidity of the gases entering and leaving the canister was determined with an electrohygrometer (Lab Line Instruments, Inc.). The recording range of the electrohygrometer was 30-100 per cent relative humidity.

RESULTS

When the silica gel is saturated with water and exposed to 2 liter and 1.5 liter peak flows, the resistance is increased approximately 1 cm. H₂O (table 1). This is well within physiological limits.

Table 2 summarizes the findings in the second series of experiments. The ages of the patients ranged from 8 months to 15½ years. Resistance of the silica gel, measured as the pressure differences at specific flows, gave a mean of 0.825 cm. water. Flow rates varied from 0.50 to 0.90 liters per second depending on the nature of the surgery and relaxation required.

In each case the humidity of gases leaving the silica gel was reduced to below 30 per cent

The blue color of the activated silica gel is due to the cobalt chloride indicator which changes to pink when the gel has adsorbed water. The amount of silica gel available for dehumidification can be judged visually by checking the quantity of blue particles remaining.

until approximately full color change of the silica gel occurred. Beyond this point the level of humidity rose quickly until it reached 100 per cent with total color change. The CO₂-absorbing canister in the Engstrom machine has a content of 1,000 ml. A canister full of silica gel lasted approximately 19 operational hours and adsorbed 165 Gm. water. The active life span of the gel varies depending on the output of different nebulizers and the uptake of the patient. Its efficiency of function is 100 per cent up to the point of total saturation, which is indicated by complete color change and the appearance of water particles on the transparent wall of the container.

In another test, not included in the tables, the output of the Mivab Nebulizer was set at the highest permissible rate (0.72 ml. per minute). The efficiency of dehumidification was similar to that noted above.

DISCUSSION

Humidifiers and nebulizers are essential equipment in clinical anesthesia and inhalation therapy. Small water particle size and high output are particularly emphasized in the latest designs. Some of these particles are conveyed to the expiratory limb, as can be demonstrated by holding a mirror at the end of the expiratory line. Instead of ordinary condensation, a rain-out of large water particles can be observed. Small water particle size and high output automatically create a problem of corrosion and water precipitation in monitoring equipment being used as well as in the valve systems of various ventilators.

In the Bird system a spirometer is not built in and the manometer is in the inspiratory line. Therefore, the expiratory valve is the only one actually affected by the humidity. Due to the high cohesion forces of the fluid condensing on the valve surfaces after prolonged use, it often becomes sticky. Similar difficulties are encountered with the Emerson 1200 postoperative ventilator. Here the spirometer, the rubber diaphragm of the expiratory valve and the alarm device are involved. On the Engstrom respirator all the monitoring instruments, including the aneroid manometer, are in the expiratory line. The Bennet PR2 presents a

TABLE 2. Results of Experiments with Patients (The pressure difference at a specific flow is the measure of the resistance. This table illustrates that the silica-gel trap system represents an insignificant resistance to exhalation.)

Patients	Time of Recordings	Differential Pressure (cm. H ₂ O)	Flow (liters/sec.)
R. P.—10 mo. Humidifier on at 8:30 A.M. USN* on at 9:05 A.M.	8:35	0.76	0.65
	9:00	0.90	0.65
	10:50	0.96	0.75
M.A.—34 yrs. Humidifier on at 1:30 P.M. USN on at 2:00 P.M.	2:00	0.69	0.50
	2:30	0.69	0.55
	2:50	0.69	0.55
M.E.—14 yrs. Humidifier on at 9:00 A.M. USN on at 9:30 A.M.	9:15	0.80	0.70
	9:45	0.96	0.90
	10:45	0.96	0.80
D. S.—9½ yrs. Humidifier on at 8:30 A.M. USN on at 9:00 A.M.	8:30	0.69	0.65
	9:45	0.69	0.85
	10:45	0.69	0.75
	12:30	0.90	0.75
	1:05	0.69	0.75
W. T.—15½ yrs. Humidifier on at 9:40 A.M. USN on at 9:55 A.M.	9:45	0.69	0.70
	10:45	0.69	0.75
R. S.—8 mo. Humidifier on at 9:45 A.M. USN on at 10:30 A.M.	10:30	0.80	0.75
	11:30	1.00	0.75
	12:30	0.90	0.85
	1:30	0.96	0.90
	2:00	0.96	0.85
	3:00	0.96	0.90
4:00	0.96	0.90	
		Mean = 0.825 ± 0.172†	

* USN = ultrasonic nebulizer.
† Standard error of mean.

different problem. With the Puritan heated nebulizer or an ultrasonic nebulizer in use there is a backup of humidified gases to the inspiratory valve. Unless an additional one-way valve is placed in the circuit this inspiratory valve will become affected the same way as the expiratory valve on the other respirators. No doubt the extra one-way valve also will be damaged in time, but it is easier to change a valve located in the circuit than one inside the machine.

The results of this study show that the adsorbing capacity of the gel is impressive: 500 Gm. of silica gel can adsorb approximately 130 Gm. water. The resistance to expiration, measured as pressure difference between the existing pressures at the inlet and outlet of the container, varied from 0.69 cm. water to 1.00 cm. water depending on the flow. This represents a mean of 0.825 cm. water resistance.

The flow resistance of the pneumatic valve in the Engstrom respirator is 6 cm. water/liter/second according to Okmian's investiga-

tions.⁵ The data indicate that the trap system incorporated in the expiratory line with a granule size of 6 to 16 mesh does not represent an important addition to the overall resistance to exhalation.

The color change of the cobalt chloride indicator is a satisfactory index of the dehumidifying capacity of the gel. Since the device is placed in the expiratory limb of the circuit there can be no adverse effect on the patient due to inhalation of the chemicals, since a nonbreathing circuit was used. Possible toxicity of the chemicals for the respiratory tract has not been determined. Silica gel can be reactivated and reused by heating to remove moisture and adsorbed gases. It is questionable whether this procedure is economical.

Since we began the routine application of the silica gel on ventilators, very little trouble has been observed with the monitoring equipment and expiratory valves. They have not become sticky or been damaged.

SUMMARY

A silica-gel trap system has been devised to prevent damage to in-line monitors and valve

systems due to the high humidity. It is interposed in the expiratory limb of a nonbreathing circuit between the patient and the instruments. The silica gel is highly efficient as an adsorbent, and there is little resistance when granules of 6 to 16 mesh size are used in a 1,000-ml. container.

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Acute Hydration for Prevention of Hypotension of Spinal Anesthesia in Parturients

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Spinal anesthesia has been the most common choice for management of the uncomplicated cesarean section in the United States in the past decade.¹ The most frequent problem with this technique has been arterial hypotension.² Moya and Smith³ have shown that prompt treatment of even moderate hypotension is necessary to avert neonatal depression. Treatment of maternal hypotension with

peripherally-acting vasopressors, most commonly methoxamine (Vasoxyl)[®] and phenylephrine (Neosynephrine)[®], has been shown to reduce uterine blood flow.⁴ Prevention of hypotension with prophylactic administration of vasopressors has been questioned. Inadvertent hypertension can occur, with resultant decrease in uterine blood flow,^{5, 6} and prophylactic use of a vasopressor (ephedrine) is not consistently effective in preventing hypotension.⁷ Correction of hypotension with rapid infusion of balanced electrolyte solution has been recommended by Greiss and Crandell.⁸ However, it is our impression that, insofar as the fetus is concerned, hypotension is better avoided than treated symptomatically. Evi-

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