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The Construction of Linear Resistances for the Testing of Ventilators

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This report describes the construction of a range of linear resistance units from 5 to 1,000 cm H_2O/l/sec for use in testing ventilators in accordance with the *American National Standards for Breathing Machines for Medical Use* (ANSI Z79.7, 1976). Various filter materials housed inside a Bird water trap are employed to produce the desired resistance values. Pressure and flow measurements showed that the units were sufficiently linear (within ±20 per cent) over a flow range of from 0 to 1/l/sec. (Key words: Ventilation, mechanical.)

THE *American National Standards for Breathing Machines for Medical Use* (ANSI Z79.7, 1976), among other things, carefully defines the procedure for testing ventilators as to their waveform and volume outputs under various compliances and resistances. However, the *Standards* do not consider the construction of resistances.

Resistances of 5, 20, 50, 200, 500, and 1,000 cm H_2O/l/sec are employed to study the performances of ventilators against a range of compliances representing adult, pediatric and neonatal patients. It is required by ANSI that these resistances be linear over a certain range of flows. There is no readily available source of supply for these resistances, and they will have to be manufactured by the laboratory preparing to test ventilators. The system described below serves that purpose.

In testing ventilators, combinations of resistances,

TABLE 1. Materials Used to Construct the Resistance Units, and Their Dimensions

Designation	Material*	Mask Orifice Diameter (mm)	Actual Resistance (cm H_2O/l/sec)
R 5	Fram A	27	4.8
R 20	Fram B	23	21.5
R 50	Millipore	44†	62
R 100	Millipore	31.8	104
R 200	Millipore	22.5	202
R 1,000	Millipore	10	1080

* Materials:
Millipore = #NCWP 047 00 Millipore® Filter (47 mm diameter nylon disc, 14 μm pore size
Fram A = filter paper available in small quantities from this laboratory
Fram B = filter paper supplied courtesy of Fram Corporation
Mask = 5-mil acetate cast film
Screen = bronze mesh .0045 diameter, 100 mesh

† This is the largest diameter obtainable using Millipore in the Bird housing. Therefore, R50 has an actual resistance of 64 cm H_2O/l/sec.

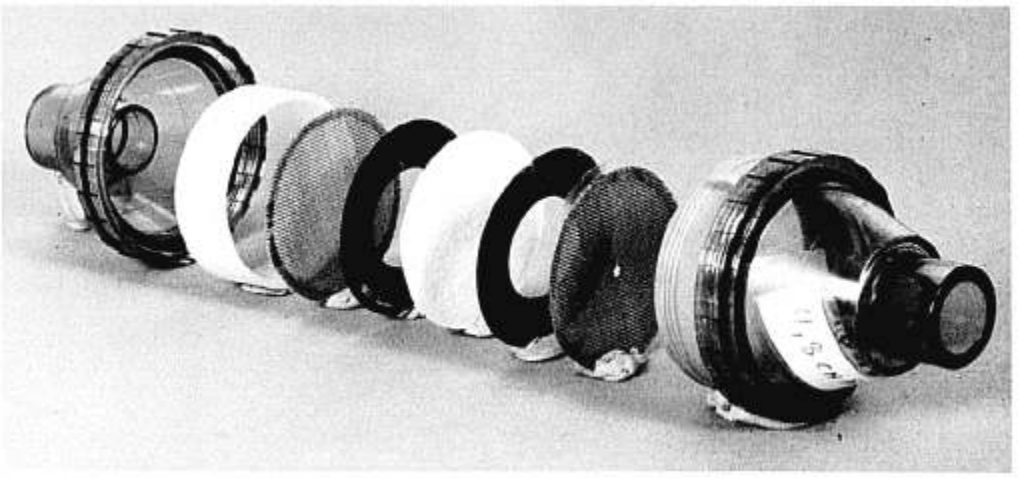

FIG. 1. Arrangement of the components making up a resistance unit, exploded view.

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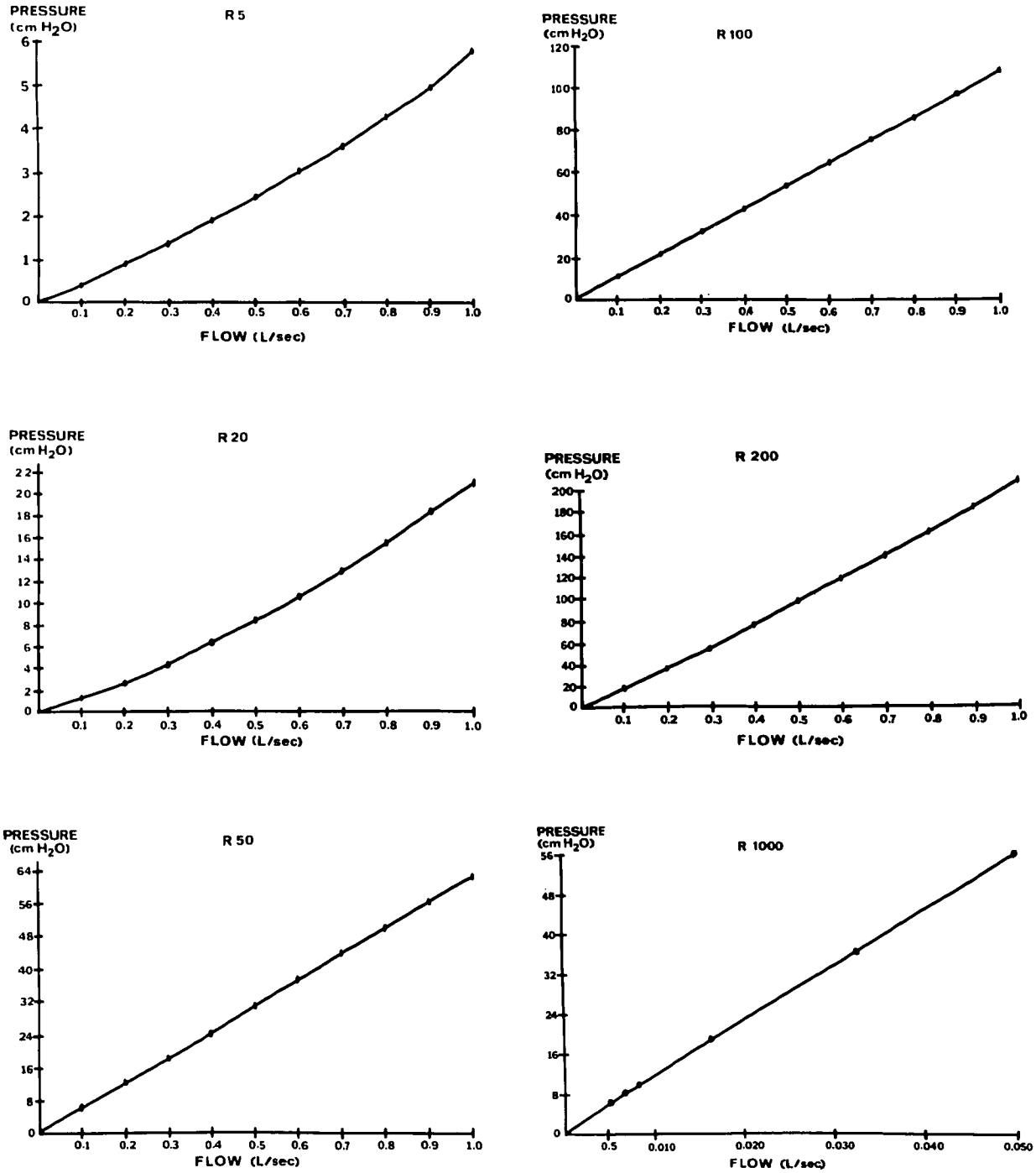

FIG. 2. Pressure/flow relationships of the resistance units (R5, R20, R50, R100, R200, R1,000), demonstrating linearity over a range of flows.

compliances, tidal volumes, and rates are employed. For example, to test a pediatric ventilator it is desirable to use the range of values for the four variables, *i.e.*, use a compliance of 0.003/l/cm H_2O, rates of 30 and 60/min, resistances of 50, 200, and 1,000 cm H_2O/l/sec, and tidal volumes of 50 and 150 ml.

Chambers producing the range of compliances offered no serious problem. A resistance unit that is not linear at different flow rates is easily constructed, but has one limitation: the exact properties causing the nonlinearity are difficult to quantitate. Even though the physiologic resistance encountered by the ventilator is not linear, it was decided to make the units as linear as possible for the purposes of testing. The construc-

tion of resistance units that were linear and readily reproducible was more difficult. Varying the sizes of orifices and employing parallel tubes both caused nonlinearity. Tests of various types of porous filter material, however, showed that more linear characteristics could be obtained.

A range of six resistances, five closely approximating those recommended in the design of the lung model and a sixth (R-100), were constructed by employing different filtering materials and varying the surface areas of the filter material in the air stream. Construction is based upon the use of a Bird water trap to house the resistance units. Figure 1 shows the sequence of components. Figure 2 shows the pressure/flow relationships. The materials employed to produce the resistances are of three different types, designated Fram A, Fram B, and Millipore®. The filter material is cut to a diameter of 47 mm to fit the inner part of the Bird trap. Two discs of thin plastic material of the same diameter have central orifices cut out to vary the sizes of the filter exposed to the flow of air. One of these plastic orifices is placed on each side of the filter material. This sandwich is supported by a bronze mesh of the same diameter. The entire five-layer unit is clamped between two nylon spacers when the housing unit is assembled. In order for the wire mesh to seal properly, it is necessary to dip the outer edge in melted paraffin.

Table 1 lists the materials and orifices used in construction of these units and the actual resistances in cm H_2O/l/sec for each of the resistance units. Although there is some nonlinearity, the tolerance is within the allowable error (±20 per cent) set by ANSI Z79.7.