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PRESSURE DROP ACROSS INHALATION AEROSOL ACTUATORS. INFLUENCE OF POSITION AND AREA FOR AIR PASSAGE

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SUMMARY

When a patient inhales through an aerosol actuator, there is a resistance to air flow causing a pressure drop across the unit. The pressure drop can be reduced by increasing the area for air passage either in the space between container and actuator, or by using openings in the actuator wall. Both alternatives were investigated and there were only small differences among the positions tested. The area for air passage was the main determining factor.

The pressure drop across a new actuator design could be predicted accurately by using a friction loss factor obtained from available results for the original actuator.

INTRODUCTION

Pressurized inhalation aerosols are widely used to administer bronchodilator drugs to patients with airway obstructions. The patients are instructed to release the metered dose while inhaling through the actuator. Many patients complain about difficulty to inspire through the actuator, and therefore it is desirable to reduce any unnecessary resistance to air flow. For a random selection of thirty asthmatic patients, Coady et al. (1976) found that the maximum inspiratory flow rate varied from 50 to 400 litre $\cdot$ min^{-1}, equivalent to 0.83×10^{-3}–$6.67 \times 10^{-3}\ m^3 \cdot s^{-1}$. In this study we selected volume flow rates of about the same range. We considered a pressure drop up to 1.0 kPa to be acceptable at a flow rate of $4.0 \times 10^{-3}\ m^3 \cdot s^{-1}$. The pressure drop across the available inhalation unit was about three times higher and consequently it was desirable to reduce the resistance to air flow. This could be done by increasing the area for air passage either in the space between container and actuator or by way of holes in the actuator wall as suggested by Dunn (1976).

For testing purposes the increase in space was obtained by using containers of smaller

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diameters in the original actuator. The reduction in pressure drop with that following the use of openings in the actuator wall or in an external tube connected to the actuator was compared. The availability of drug substance into the airways could be improved by an external tube (Morén, 1978), and such a tube was therefore included in the experimental set-up; the effect of introducing holes in the tube was also studied. For the design of a new actuator with an increased inner diameter the height of the splines inside the wall had to be considered. These splines are useful for the patient when inserting the container into the actuator. With the moulding technique used it was not possible to make the front splines too high, therefore the increase in space between container and actuator was limited by the possibility of increasing the height of these splines in the production unit. We increased the inner diameter of the new actuator by 1.5 mm to obtain as low a pressure drop as possible. A further increase in space could possibly be obtained by a deviation from the circular form of the actuator, but this was not performed. Before making an expensive production tool we found it valuable to calculate the pressure drop across the new actuator. For this purpose a friction loss factor was used as it is related to the losses originating from the pressure drop in a system. This procedure is normally used in fluid mechanics (Bird et al., 1960). When a production sample of the new actuator was available we compared the calculated results with the measured results.

MATERIALS AND METHODS

Materials tested

A pressurized aerosol container was used with its original plastic actuator (Bricanyl, AB Draco, Sweden). We attached an external glass tube to this unit (see Fig. 1). The inner diameter of the actuator was 26.5 mm and by inserting the standard container or containers of smaller diameters, the space between the walls was varied to form the areas 80, 125 or 168 mm^2 (see Table 1). We chose one of the actuator and container combinations (125 mm^2) for testing the reduction of pressure drop as holes were made at the same level as the oral opening at the back of the actuator and/or perpendicular to the spray direction. The holes were combined to obtain the additional areas 57, 113 and 227 mm^2 (Table 1). For one of the hole areas, 113 mm^2, we tested three different positions for a

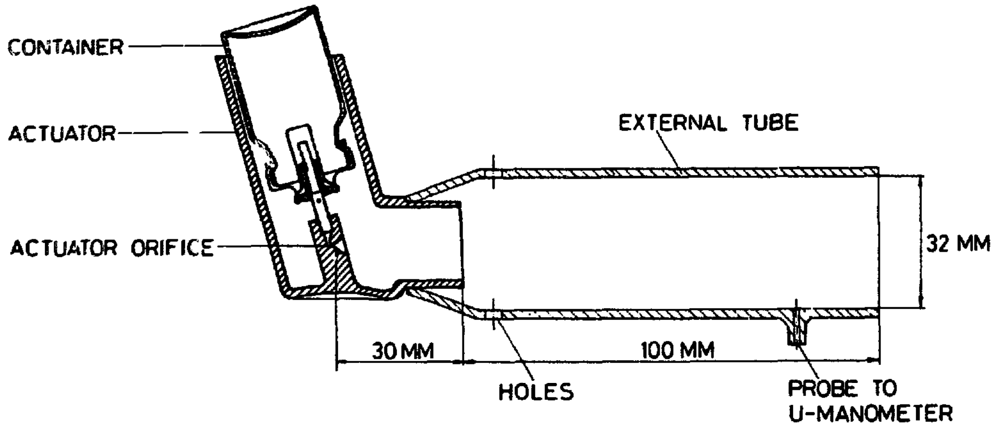

Fig. 1. Actuator, container and external tube.

possible influence on pressure drop. Furthermore, the same additional areas were obtained from 6 holes around the external tube close to the attachment of the actuator. By using silicone rubber we combined the openings in the tube to form the desired areas (Table 1). In the new design of the actuator we increased the inner diameter by 1.5 mm. When the standard container was inserted into this actuator an area of 144 mm^2 was achieved.

Fig. 2 describes the principle of the experimental design for determination of pressure drop and volume flow rate. Air was supplied from a 5 m long tube with an inner diameter of 303 mm. Because of the large area the velocity of air could be neglected in this tube compared with the velocity in the space between container and actuator or in the holes.

The pressure drop across the actuator and the external tube, Δp, was measured as a difference between the static pressures by using a U-manometer containing water. We calculated the volume flow rate from the dynamic pressure in a measuring tube next to the external tube. There was one probe in the centre towards the direction of air flow and another at the periphery perpendicular to the air flow. The dynamic pressure, Δp_f, was measured by micromanometer as the pressure differential.

Methods for calculation

Symbols used:

A_{tube} = area of measuring tube, m^2
A_{space} = area of space between container and actuator walls, m^2
b = width of space between container and actuator walls, m
D = diameter of measuring tube, 24.85×10^{-3} m
Δp = pressure drop across actuator and external tube, Pa
Δp_f = dynamic pressure in measuring tube, Pa
u_{max} = maximum velocity of air in measuring tube, $m \cdot s^{-1}$
u_{space} = average velocity of air in space between container and actuator walls, $m \cdot s^{-1}$
Re = Reynolds number
$\dot{V}$ = volume flow rate, $m^3 \cdot s^{-1}$
ζ = friction loss factor
μ = viscosity of air, 17.98×10^{-6} $kg \cdot m^{-1} \cdot s^{-1}$
ρ_{air} = air density, $kg \cdot m^{-3}$

Maximum velocity of air in the measuring tube and related Reynolds number were determined from the equations

$$u_{max} = \left[\frac{2\,\Delta p_f}{\rho_{air}}\right]^{1/2} \tag{1}$$

$$Re_{u,max} = \frac{\rho_{air} u_{max} D}{\mu} \tag{2}$$

Because of the small pressure drop compared with atmospheric pressure we used air

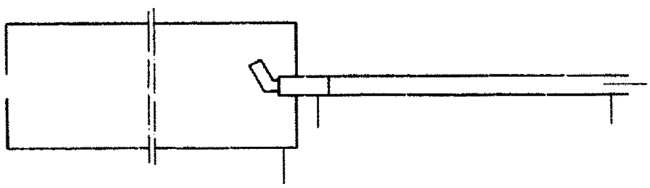

Fig. 2. Principle of experimental design.

density, ρ_{air}, as a constant in the equations. For determination of average velocity of air in the measuring tube, u_{tube}, an iterative calculation was performed by using a diagram for average velocity to maximum velocity as a function of Reynolds number for average velocity (Nikuradse, 1932). The relation between Reynolds numbers for average velocity and maximum velocity in the measuring tube was:

$$Re_{u,tube} = Re_{u,max} \frac{u_{tube}}{u_{max}} \quad (3)$$

Volume flow rate was calculated from the equation

$$\dot{V} = u_{tube} A_{tube} \quad (4)$$

For each container and each combination of holes we determined the pressure drop across actuator and external tube for about 20 observations of volume flow rate in the range around 0.8×10^{-3} to 6.7×10^{-3} $m^3 \cdot s^{-1}$.

To forecast the pressure drop across the new actuator combined with the standard container we treated the results from each combination of the original actuator and the three containers in the following way. Average velocity of air in the space between container and actuator and the corresponding Reynolds number were calculated from the equations

$$u_{space} = \frac{\dot{V}}{A_{space}} \quad (5)$$

$$Re_{u,space} = \frac{\rho_{air} u_{space} 2b}{\mu} \quad (6)$$

The friction loss factor related to this Reynolds number was given by

$$\zeta = \frac{2 \Delta p}{\rho_{air} u_{space}^2} \quad (7)$$

In a diagram we plotted friction loss factor as a function of Reynolds number. For the new actuator combined with the standard container the Reynolds number was calculated from Eqns. 5 and 6 at a selected volume flow rate. We used the diagram t. estimate the friction loss factor and, from Eqn. 7, we calculated the corresponding pressure drop.

RESULTS AND DISCUSSION

Fig. 3 shows pressure drop as a function of volume flow rate for the original actuator and the standard container. The corresponding diagrams for the other combinations tested were of the same principal appearance. For the characterization of the diagrams we found it suitable to read the pressure drop at a selected volume flow rate. The flow rate 4.0×10^{-3} $m^3 \cdot s^{-1}$ was chosen as it was about the middle of the range for maximum inspiratory flow rate in asthmatic patients. The pressure drop across the original actuator combined with the three various containers is given in Table 1. The increase in space resulted in a reduction of the pressure drop. The acceptable level 1.0 kPa was only reached by the greatest areas (168 mm^2) but could also be obtained by additional holes.

Table 1 shows that holes at the back of the actuator resulted in a lower pressure drop compared with holes perpendicular to the spray direction. This was expected because of less change in flow direction of air. Furthermore the number of holes to obtain the area

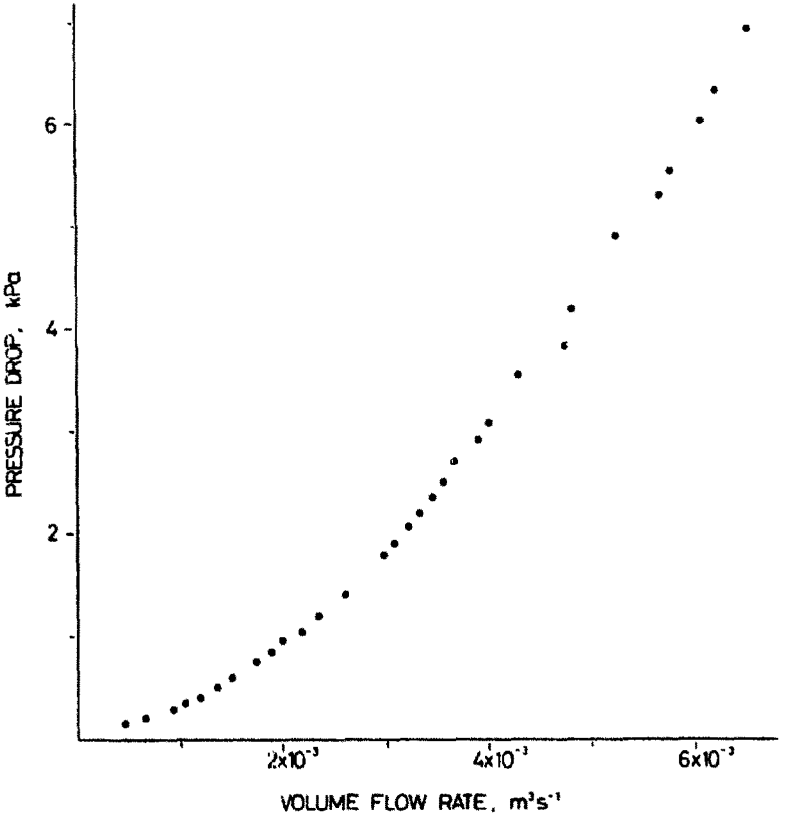

Fig. 3. Pressure drop as a function of volume flow rate. Original actuator, inner diameter 26.5 mm, combined with standard container, outer diameter 24.5 mm.

TABLE 1

SPACE BETWEEN ORIGINAL ACTUATOR, INNER DIAMETER 26.5 mm, AND CONTAINERS OF 24.5, 23.3 AND 22.1 mm DIAMETER; ADDITIONAL HOLES IN THE WALL OF THE ACTUATOR OR IN AN EXTERNAL TUBE ATTACHED TO THE ACTUATOR

Pressure drop across the unit at volume flow rate 4.0×10^{-3} $m^3 \cdot s^{-1}$.

Space (mm^2)	Additional holes			Position	Pressure drop (kPa)
	Area (mm^2)	Number	Diameter (mm)		
80					3.04
125					1.12
168					0.66
125	57	2	6.0	a	0.66
125	113	2	8.5	a	0.47
125	113	2	8.5	b	0.53
125	113	4	6.0	a,b	0.50
125	227	4	8.5	a,b	0.37
125	57	2	6.0	c	0.55
125	113	2	8.5	c	0.41
125	227	{4, 2}	{6.0, 8.5}	c	0.26

[a] At the back of the actuator.
[b] At the side of the actuator.
[c] In the external tube.

of 113 mm^2 had a minor influence on pressure drop. The location of holes in the external tube was the most efficient for reduction of pressure drop. This was explained by the fact that only part of the air flow was then passing through the actuator. However, most of the area for air passage should be located before the actuator orifice, since deposition of drug substance in the actuator is probably reduced by the air flow passing through the oral tube. The pressure drop was lower for an additional area in the space between container and actuator compared with a corresponding hole area in the actuator wall. This was probably dependent on different air flow in the space and in the holes. Even if the degree of reduction of pressure drop was influenced by the alternative positions tested for air passage, the magnitude of the area was the main determining factor.

For the new actuator design the inner diameter was increased as much as possible with regard to the limited height of the front splines. The prediction of pressure drop was made by using the results for the original actuator and the three various containers. Friction loss factor for these combinations was plotted as a function of Reynolds number, see Fig. 4. For a Reynolds number lower than 3.0×10^3, corresponding to a volume flow rate lower than about 1.7×10^{-3} $m^3 \cdot s^{-1}$, the value for the friction loss factor increased rapidly. This change indicated a shift from turbulent to laminar flow in the system. The influence of the space between container and actuator on the friction loss factor was not considerable for the same Reynolds number. Therefore it was correct to use the diagram for calculations of new combinations as long as width and area of the space were in the

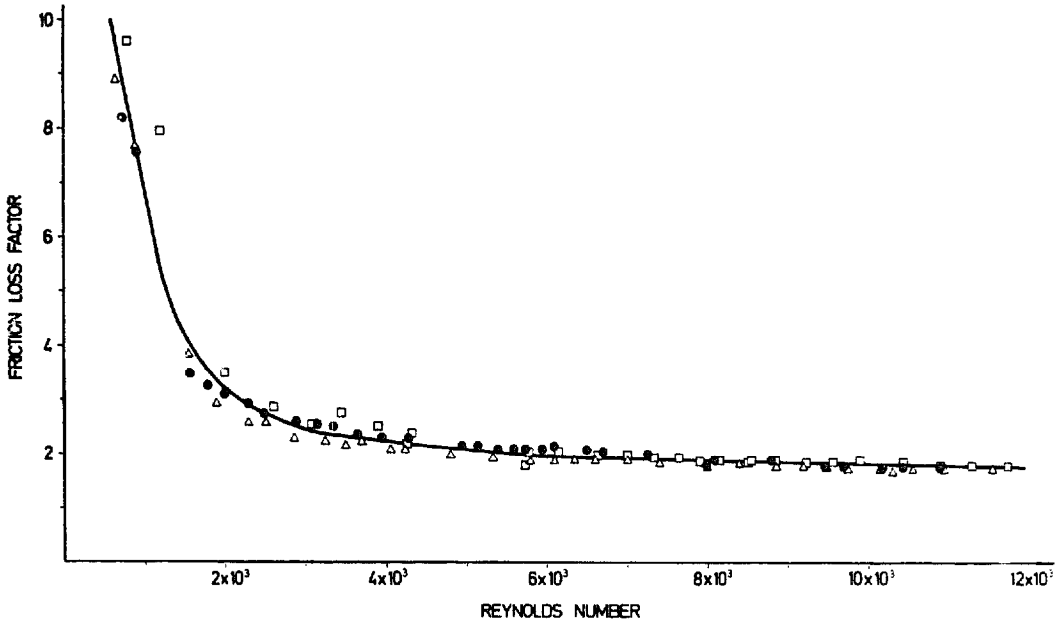

Fig. 4. Friction loss factor as a function of Reynolds number in the space between original actuator, inner diameter 26.5 mm, and containers of different diameters. •, 24.5 mm; △, 23.3 mm; □, 22.1 mm.

same region as those on which the diagram was based, and the length of the air passage was unchanged.

Fig. 5 shows the predicted pressure drop across the new actuator and the standard container for volume flow rates between 0.8×10^{-3} and $6.7 \times 10^{-3}\ m^3 \cdot s^{-1}$. By analysis of regression we found a simple equation for the part of the diagram corresponding to turbulent air flow

$$\Delta p = 15.1 \times 10^6\ \dot{V}^{1.76} \quad (8)$$

The correlation coefficient was 1.00. Thus it seemed that this part of the diagram could

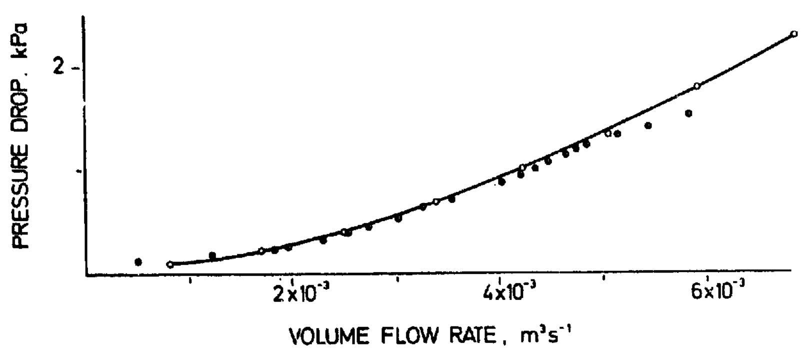

Fig. 5. Pressure drop as a function of volume flow rate. New actuator, inner diameter 28.0 mm, combined with standard container, outer diameter 24.5 mm. o——o, calculated results; •, measured results.

be accurately established. Fig. 5 also shows the measured pressure drop for a production sample. At a volume flow rate of 4.0×10^{-3} $m^3 \cdot s^{-1}$ the pressure drop across the new actuator was 0.86 kPa.

Seeing that the calculated and the measured results agreed, we found it suitable to use the friction loss factor as an instrument for predicting the pressure drop in possible container and actuator combinations.

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