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PAPER NO. 19

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EXHAUST SYSTEM REINFORCED BY JET FLOW

by

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NOMENCLATURE

d	(mm)	diameter of the exhaust opening
D	(mm)	diameter of the flange
x	(m)	distance to exhaust
y	(m)	distance to longitudinal axis
u_i	(m/s)	average inlet velocity
u_o	(m/s)	average exhaust velocity
u_{cr}	(m/s)	critical inlet velocity
u_x	(m/s)	velocity in the distance x (m)
q_i	(m^3/h)	inlet flow rate
q_o	(m^3/h)	exhaust flow rate
I		ratio between inlet and exhaust momentum
K		constant
n		exponent
S	(mm)	height of inlet slot in radial jet
α	(%)	capture efficiency
C_e	(ppm)	concentration in exhaust
C_{oc}	(ppm)	mean background concentration
C_r	(ppm)	reference concentration

INTRODUCTION

The conventional exhaust is well-known. It is characterized by air flowing towards the exhaust opening equally from all directions in the space surrounding the exhaust. A conventional exhaust must therefore be described as non-selective as the air is not removed from a selected area. If contaminants which are emitted from a restricted area should be removed, it cannot be avoided that clean air from the surrounding areas will be evacuated.

In practice the missing selectivity means that the velocity of the air in a flow towards the exhaust opening decreases strongly with the increasing distance to the opening. This is convenient in case of comfort ventilation because it will be easy to install the exhaust in normally ventilated rooms without causing draught. In industrial environment it is of great importance for the internal working environment that contaminants are removed quickly and efficiently. Local exhaust must therefore be located very close to the source of contamination in order to be efficient. In practice working routines will often prevent an ideal position; the consequence will be a reduced capture efficiency. The prospects of improving the capture efficiency of conventional exhaust, e.g. by optimizing the flanges and the geometry, are limited.

REEXS - REINFORCED EXHAUST SYSTEM

Since 1985 the University of Aalborg and Nordfab A/S have been working on an exhaust principle which is quite different from traditional exhaust systems. The REEXS principle (Reinforced Exhaust System), which originally was designed for the agricultural sector, is particularly well-suited for industrial ventilation purposes. With the REEXS principle it is possible to create a flow pattern in front of the exhaust opening which will have a considerable influence on the general flow in a given room.

The system is a double-device system combining air inlet and exhaust. Figure 1 shows the principle of the system.

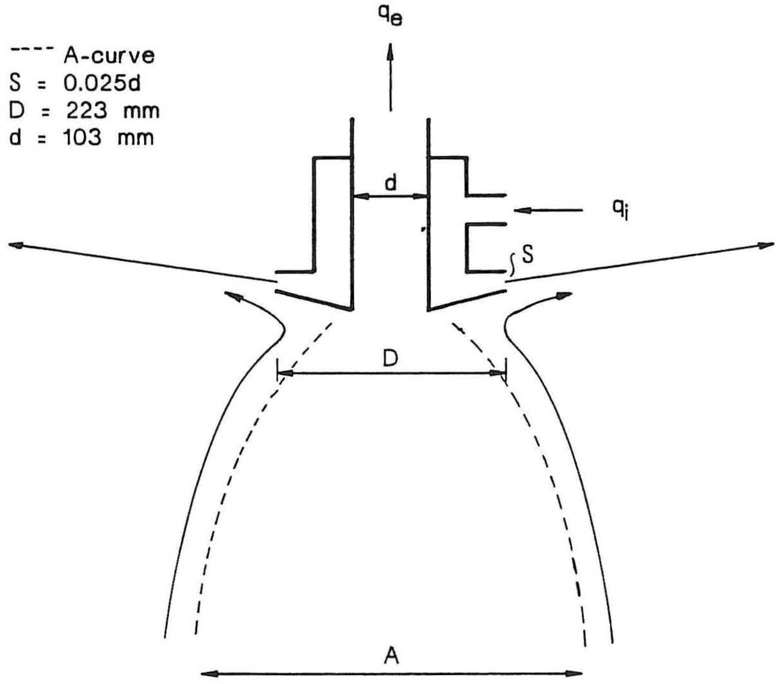

Figure 1: The REEXS principle. The inlet air is supplied along the edge of the exhaust opening through a narrow slot.

Geometrically the system may have various shapes. The characteristic of the system is that the flow pattern may be oriented towards a specific direction which increases the range significantly. The directional effect is created by radial air inlet along the edge of a circular exhaust opening through a narrow slot. The air is ejected with a relatively high velocity, but the operation of the system is determined by the ratio of the inlet air and the exhaust air.

The air does not flow towards the opening evenly from all directions but is concentrated in a zone in the longitudinal axis of the exhaust. In this way the velocity is increased and the exhaust achieves greater working depth. Figure 2 shows the basic difference between a traditional flanged exhaust and the REEXS principle. The areas with high capture efficiency have markedly very different shapes and working depth.

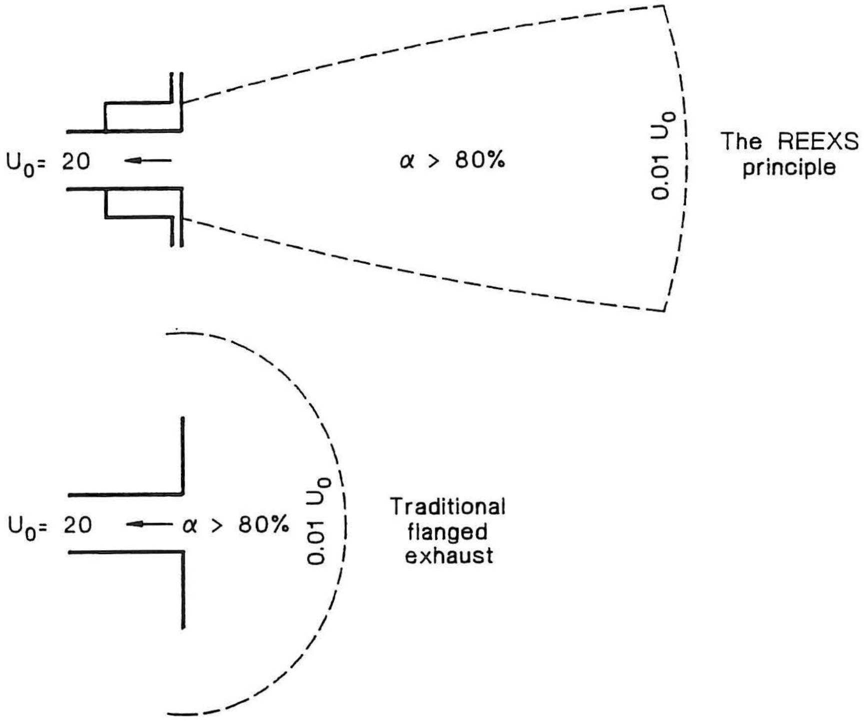

Figure 2: The basic difference between a traditional flanged exhaust and the REEXS system. The dashed line illustrates the capture zone (1% of u_o).

In front of the system an area A /2, 3/ is created where the air will flow directly towards the exhaust opening with an efficiency close to 100%. The area is surrounded by a volume where the flow is entrained into the radial jet and the exhaust efficiency in this volume is approximately 0. The form and working depth of the efficient area are determined by the ratio I between the momentum flow in the inlet and the momentum flow in the exhaust where:

$$I = \frac{u_i \, q_i}{u_o \, q_e} \qquad (1)$$

The face velocities u_i and u_o are determined as average velocities based on the area and the air flow.

The REEXS principle was to our knowledge invented and first described by Aaberg /1/

in 1965.

CRITICAL INITIAL VELOCITY OF THE RADIAL JET

The critical velocity of inlet air u_{cr} is defined as the velocity needed to prevent the inlet air from being captured by the exhaust opening /2/. In other words, it is the minimum initial inlet velocity which determines whether the system will short-circuit or it will work as a REEXS. Below the critical velocity the efficiency of the system is lower than of a conventional exhaust system.

The critical velocity is directly proportional to the exhaust flow rate. Figure 3 shows the critical velocity as a function of the exhaust flow rate at different values of the slot height.

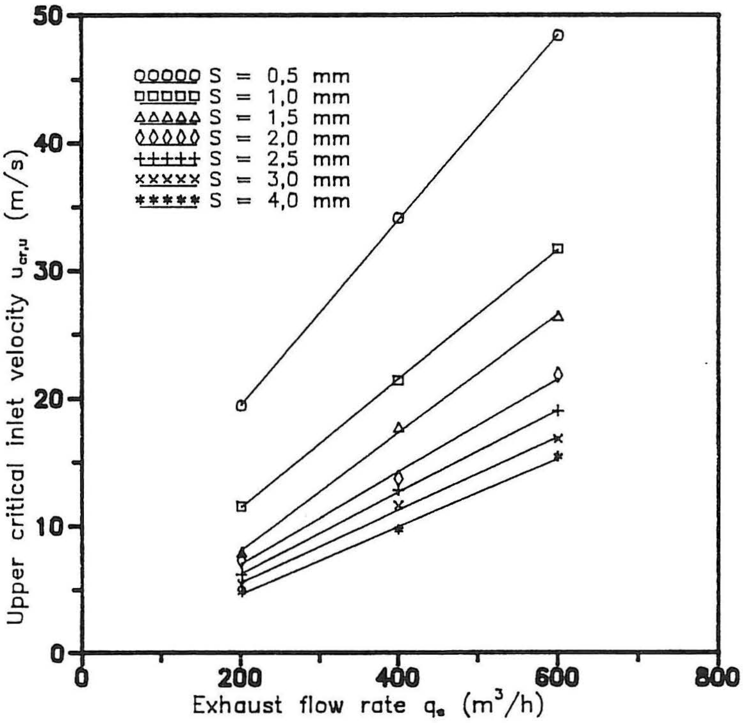

Figure 3: Critical velocity of inlet air as a function of exhaust flow rate. The slot height is the parameter.

The critical velocity has a hysteresis effect because two different values of u_{cr} may create the same flow pattern. The upper critical value, $u_{cr,u}$, is defined as the velocity needed to break the short circuit in a system where the inlet air is drawn into the exhaust opening. The lower critical velocity, $u_{cr,l}$, is defined as the velocity where a short circuit takes place if the inlet velocity is reduced.

$u_{cr,u}$ is higher than $u_{cr,l}$. In practice it is necessary to use $u_{cr,u}$ only. In this case it will not matter whether the ventilator used for the inlet air is started before or after the exhaust ventilator.

CAPTURE VELOCITY

Figure 4 shows the development of the centre line velocity decay in front of a 103 mm REEXS. The velocity is measured in a free flow. The exhaust flow rate is 600 m³/h and the slot height is 2.5 mm.

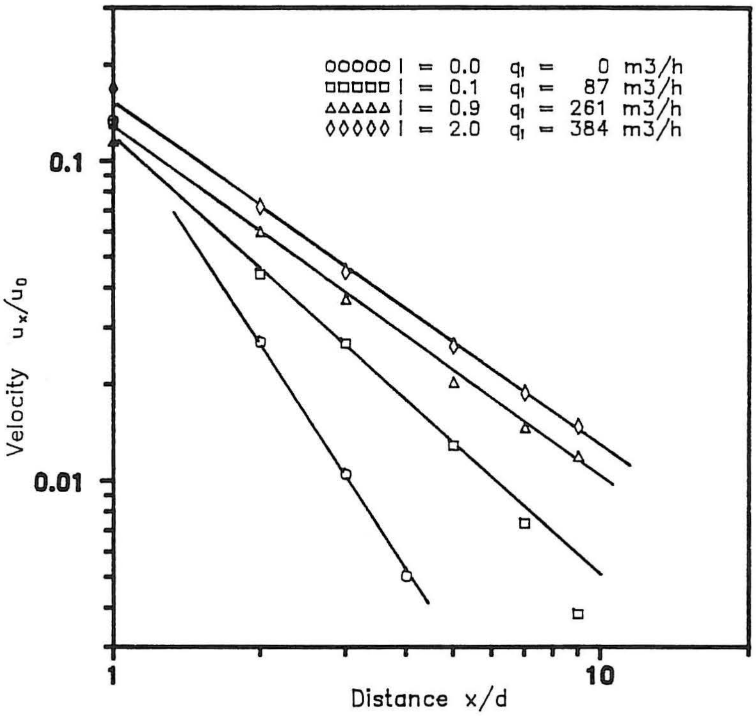

Figure 4: Measured decay of the dimensionless centre line velocity for a 103 mm REEXS. q_e = 600 m³/h, S = 2.5 mm.

As it appears the exhaust velocity depends on the momentum ratio between inlet air and exhaust air. An I value less than 0.1 is the lowest possible if short circuit is to be avoided.

It also appears that the velocity is significantly higher for I = 0.1 than for I = 0.0 which corresponds to a 103 mm traditional exhaust opening with flange (D = 223 mm). At a distance of e.g. 6 x d, the velocity may vary between 0.009 and 0.027 or a factor 3. By way of comparison it may be mentioned that the exhaust flow rate in a traditional exhaust in theory should be increased by the factors 4 and 11, respectively, in order to obtain the same velocity.

Looking at figure 4 the centre line velocity decay in front of the REEXS may be expressed as:

$$\frac{u_x}{u_o} = K(x/d)^{-n} \tag{2}$$

where K is a constant and n is the geometric inclination, which can be read from figure 5.

The exponent depends on the momentum ratio. At a constant exhaust flow rate it can be varied by changing the inlet flow rate. A high momentum ratio will cause a high velocity and consequently a small n-value. A series of experiments has indicated that the non-dimensional velocity decay is independent of the height of the slot S and the diameter of the exhaust opening if the momentum of the inlet air remains unchanged.

It is necessary for the proper functioning of the system that the inlet air does not hit obstacles of any kind. In that connection it makes no difference whether the value of the inlet slot S is high or low since the structure of the flow in a radial jet only depends on the momentum, not on the velocity of the inlet air.

If the exhaust is placed at a table or similar with the x-axis parallel to the surface, the flow changes from axis-symmetric flow (axi) to a three-dimensional flow (3D). The velocity can still be expressed according to formula (2) but the exponent changes as the 3D flow is identical to an axis-symmetric flow with twice the area of the exhaust opening. The same thing happens if the inlet air is supplied along a plane surface (3D, radial wall jet). Figure 5 on page 7 shows how the exponents depend on the momentum ratio when placed in 3 different positions.

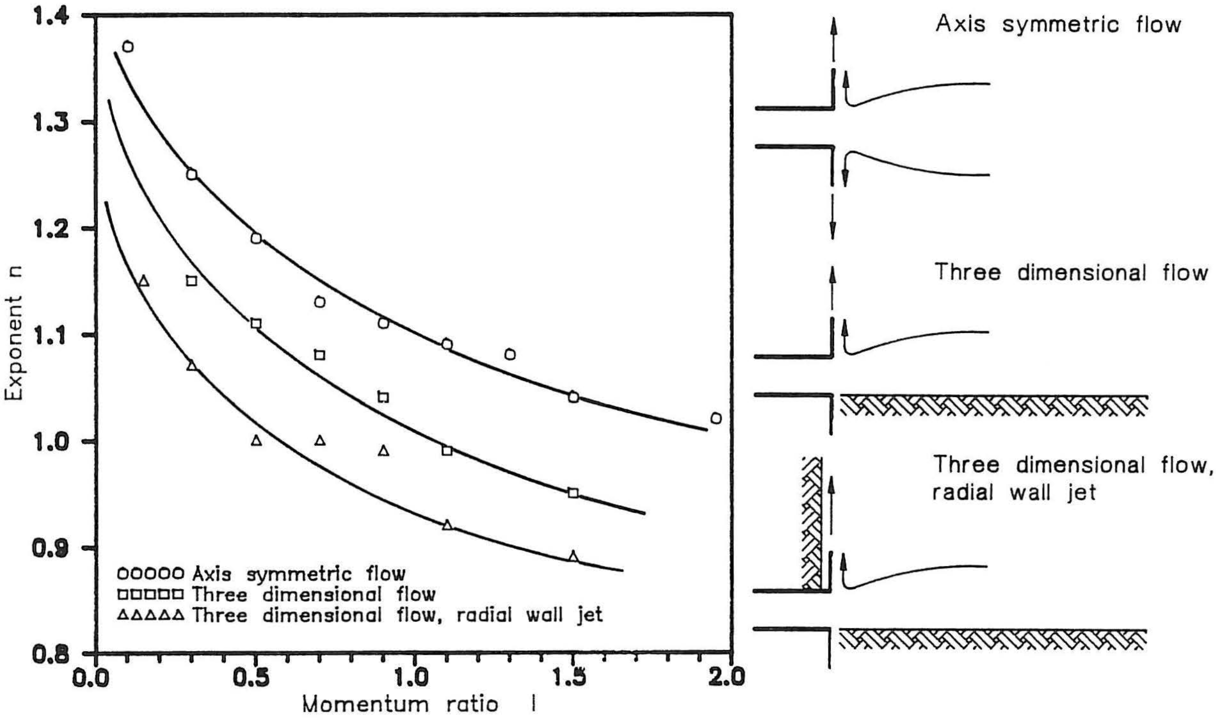

Figure 5: The exponent as a function of the momentum ratio for a 103 mm REEXS at 3 different positions.

When comparing measured data for the 3 different positions it appears that:

$$I_{axi} \cong 0.5\ I_{3D} \cong 0.25\ I_{3D,\ radial\ wall\ jet} \tag{3}$$

The above connection between the momentum ratios is valid when the radial jet is geometrical fitted to the shape of the area to be exhausted. If the exhaust is located close to a plane surface it is necessary to shield the bottom half of the supply slot facing the surface.

Formulas (2) and (3) also apply to other geometrically identical REEXS systems. To a certain extent they also apply to non-geometrically identical shapes, but in such cases the exponent will be different.

CAPTURE EFFICIENCY

The position of the A-curve - the limit between high and low capture efficiency - does not appear from the measurement of the velocity of the air flowing towards the exhaust opening.

For distances more than 5 x d, the velocity in a cross section in front of the exhaust will be approximately constant. Whether contaminants will be removed by the exhaust or be entrained into the radial jet will not be shown directly. For this reason, measurements of the capture efficiency of the exhaust have been added to the velocity measurements.

The capture efficiency of the exhaust system is measured by tracer gas technique (sulphurhexafluoride SF_6). The direct capture efficiency of the exhaust is defined as:

$$\alpha = \frac{C_e - C_{oc}}{C_r} \tag{4}$$

The tracer gas is induced at a constant flow and the reference concentration C_r is determined by capturing the tracer gas 100%. The gas is induced through a perforated sphere. The capture efficiency of a number of positions in front of the exhaust is determined by moving the sphere.

For a conventional circular unflanged exhaust it can roughly be assumed that the capture efficiency of the exhaust is equal in all directions. The REEXS system creates its own field of efficiency. An area around the longitudinal axis has a high capture efficiency while it decreases strongly in the remaining area. The experiments mentioned were carried out without interference from the surroundings. In other words, the results represent the maximum theoretical capture efficiency for a given source. In practice the size of the disturbances, e.g. cross draught etc., must be part of the calculations of the capture efficiency.

From figure 6 on page 9 it is seen that different values of the momentum ratio result in different profiles of the capture efficiency in the region in front of the exhaust opening. As it appears the system has a wide profile and a longer range at a low value of the momentum ratio. From this it seems to be expected that it always would be an advantage to choose the low level of momentum ratio, but the capture velocity necessary to catch the contaminants must be sufficient (the higher momentum ratio the higher capture velocity).

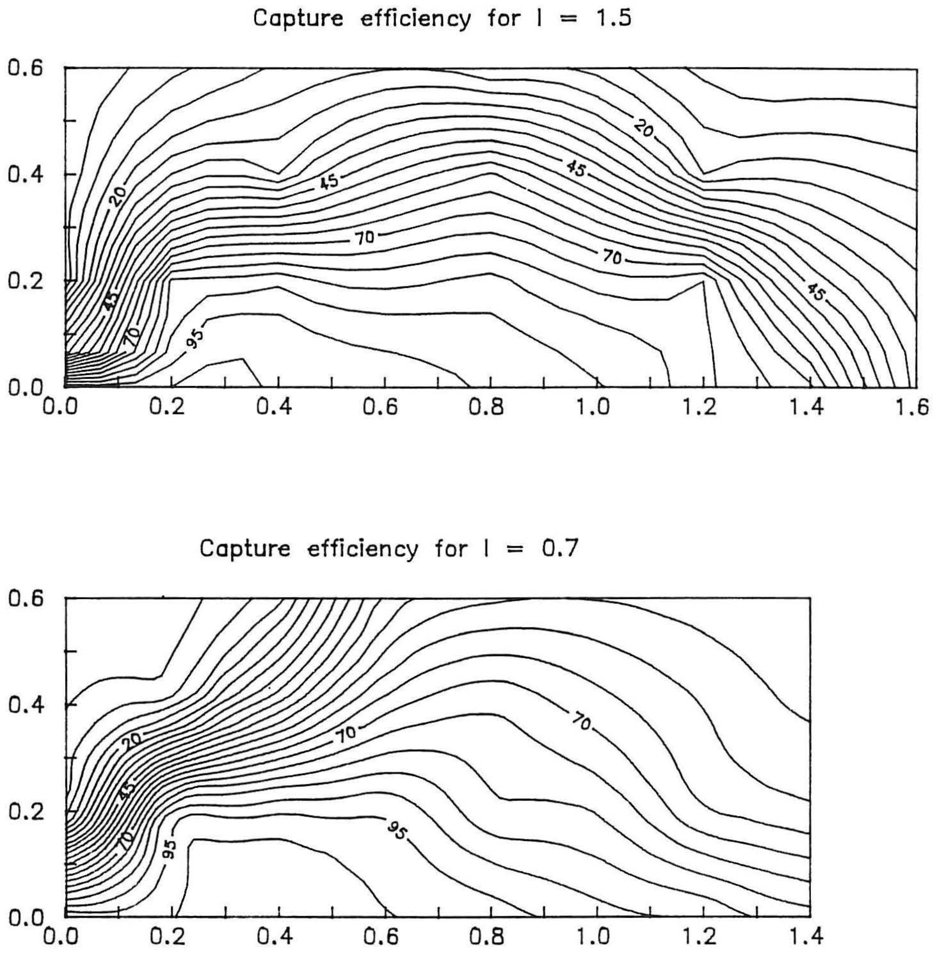

Figure 6: Capture efficiency profiles for an axis-symmetric REEXS. The exhaust is located in x = 0.0 and y = 0.0. The longitudinal axis of the exhaust is the x-direction. q_o = 600 m³/h in both cases.

The distance from the theoretical A-curve to the longitudinal axis of the exhaust can be calculated from:

$$q_e = 2\pi \int y \, u_x \, dy \tag{5}$$

where u_x is the measured velocity in the cross section in the distance x to the exhaust.

The connection between the capture efficiency profile and the A-curve can be seen from figure 7. Due to the fact that the flow pattern to the exhaust opening circles around the longitudinal axis the efficiency profile is not constant inside the A-curve. The A-curve is calculated from mean velocities. The turbulence of the flow reduces the captured efficiency close to the A-curve which is observed from figure 7.

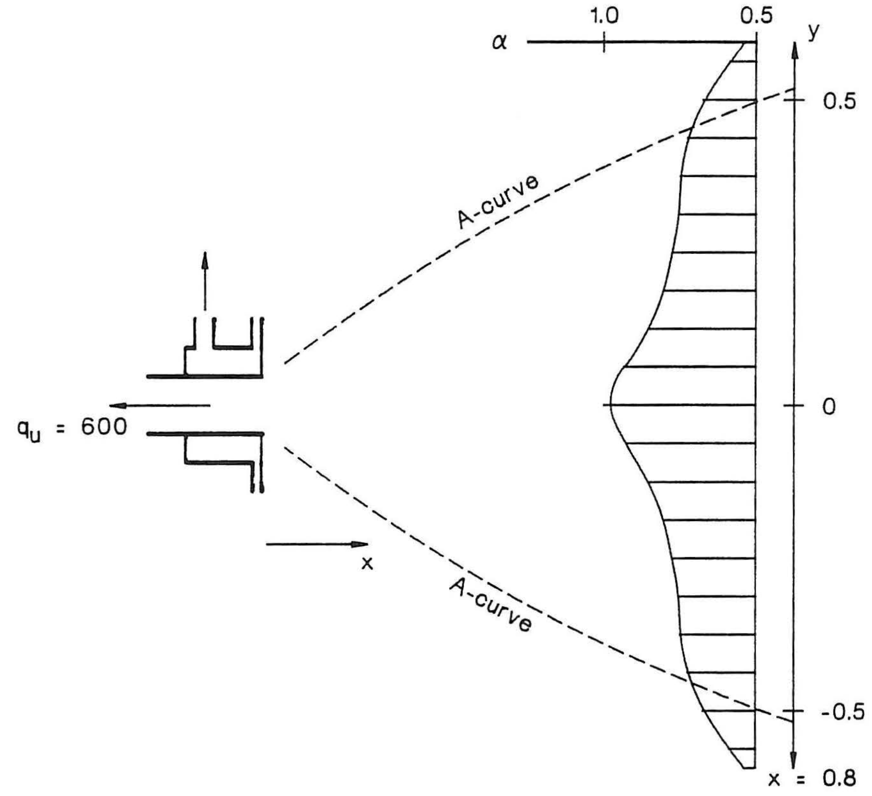

Figure 7: The A-curve, calculated by means of the measured velocity in a cross section, and the capture efficiency profile in the distance 8 x d from the exhaust. I = 0.7, q_e = 600 m^3/h.

Because of the high capture velocity the REEXS principle is able to maintain a high capture efficiency in disturbed surroundings where the capture efficiency of a traditional exhaust will be approximately 0.

CONCLUSION

The REEXS principle results in a completely different velocity distribution in front of the exhaust opening compared with the traditional exhaust. The centre line velocity can be increased by a factor 10 in a distance of 5 times the diameter of the exhaust opening.

The momentum ratio determines the velocity decay and the region with high capture efficiency. The range of the capture zone is increased significantly and is limited to a restricted zone near the longitudinal axis of the exhaust. The capture efficiency is not constant inside the theoretical A-curve but decreases with the y-distance.

Because the capture velocity is increased the REEXS principle is able to maintain a high capture efficiency in disturbed surroundings where the capture efficiency of a traditional exhaust will be approximately 0.

LITERATURE

1. Aaberg, C.P.: Specific Flow Distribution, 1970 (in Danish).

2. Hyldgård, C.E.: Aerodynamic Control of Exhaust. ROOMVENT '87. International Conference on Air Distribution in Ventilated Spaces, Stockholm, 1987.

3. Høgsted, P.: Air Movements Controlled by Means of Exhaustion. ROOMVENT '87. International Conference on Air Distribution in Ventilated Spaces, Stockholm, 1987.

4. Dalle Valle, J.M.: Exhaust Hoods. The Industrial Press, New York, 1952.

5. Breum, N.O. and Skotte, J.: National Institute of Occupational Health. Measuring of capture efficiency. ReproTryk A/S, Skive, Denmark, 1987 (in Danish).

6. Høgsted, P. and Germann, L.: Ventilation in fibre-glass industries. Arbejdsmiljøfondet, 1990 (in Danish).

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