OPERATION CHARACTERISTICS OF A VENTURI SCRUBBER WITH VARIATION OF THE DIFFUSOR GEOMETRY

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ABSTRACT

Venturi scrubbers are used for the separation of solid particles from gases. With the help of this rig, it is possible to separate particles smaller than 1 μm in diameter , although it involves a high energy consumption. To reduce the high energy consumption the influence of different diffusor geometries upon the performance characteristics, i.e. the pressure drop for equal separation efficiency was investigated. For this purpose experiments were conducted to measure the pressure drop and the grade efficiency for three diffusors by varying the air velocity and the water-air ratio.

INTRODUCTION

Wet type collectors are dust collectors in which the impurities of the waste gas are removed from the gasflow by means of a washing liquid. This is based on the idea that small particles,which may not or only be separable mechanically, are added on droplets (disperged washing liquid) to effect separation. The agglomerate particle-droplet is largely enough to be separated by a mechanical drop separator (e.g. cyclone). In this paper the Venturi scrubber is employed to perform an effective separation for smaller particles. The method provides an advantage in separating adhesive material with high moisture content and very fine particle sizes.

In the design of the Venturi scrubber or a wet separator the gas flow is accelerated by a nozzle and the washing liquid is added into the narrowest cross-section (throat), as in most cases. Due to the high shear forces and high relative velocity the liquid is disperged to droplets and the dust particles are attached onto the droplets, respectively. In the diffusor section following the throat, the gas velocity is slowed down and subsequently fed to a droplet separator. Normally for attaining a good separation of small particles (< 1 μm) a high gas velocity in the scrubber throat is necessary (up to ~ 110 m/s). However, even though the velocity is reduced in the diffusor, it is still high enough to perform the task and exert high pressure drop which is related with a high energy consumption.

The largest part of the pressure drop is consumed for the acceleration of the droplets (~ 75 %) [1]. This is because that for the inertia separation of the dust particles a high relative velocity must be maintained along with the trajectory of the droplets as long as possible. In this connection, there is no difference in principle whether the relative velocity is obtained by the acceleration of the droplets (pressure drop) or retardation of the droplets in the diffusor (pressure gain).

In this paper the influence of three different types of Venturi scrubber diffusor geometries are investigated in the separation of small particles to achieve a high grade efficiency and low pressure drop which is associated with low energy consumption.

DESCRIPTION OF THE EXPERIMENTAL UNIT

Figure 1 shows the structure of the experimental set-up of the scrubber. At the inlet part of the unit, air is sucked from the surrounding by means of a dust dosing system [1]. During the process a defined amount of dust can also be added to the air. For measuring the raw gas concentration and particle size distribution, a branch current is drained off isokinetically at the inlet pipe [2] and fed to a scattered light particle size analysator [3]. In the scrubber [7] the dust particles are added to the washing liquid fed to the throat. The pressure drop occurring over the whole scrubber is measured by means of a U-tube manometer [9]. The Venturi scrubber is followed by a drop separator, in which the water droplets containing the dust particles are separated in a vortex flow. The cleaned air with the remaining dust particles is

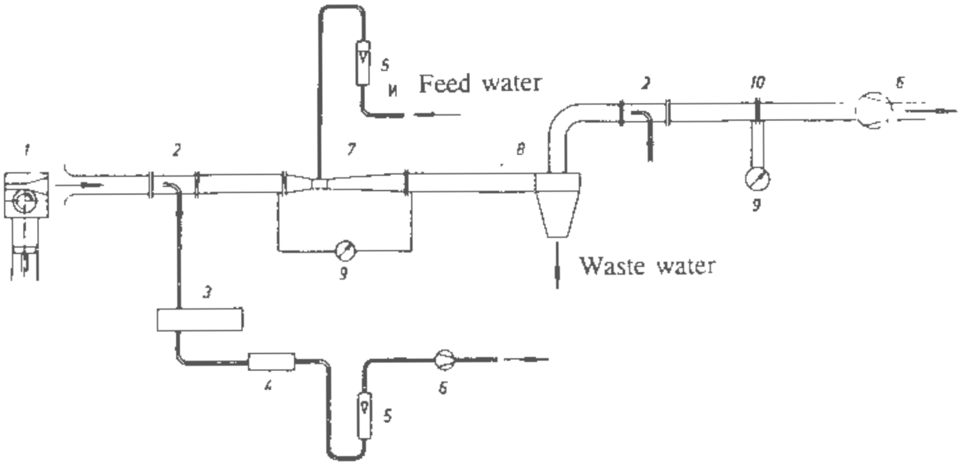

Figure 1 Structure of the Experimental Unit; 1-Dust dosing system, 2-Sampling, 3-Scattered light measuring unit, 4-Filter, 5-Rotameter, 6-Blower, 7-Venture scrubber, 8-Drop separator, 9-Manometer, 10-Measuring shade

taken via a following sampling pipe [2] and led to the blower [6]. By means of a measuring shade [10], the volume flow rate and the gas velocity adjusted in the throat of the scrubber are measured. Since only one particle size analysator was available, after reaching steady state operations conditions, branch currents were taken before and after the Venturi scrubber and the grade efficiency determined.

CARRYING OUT THE TESTS

For measuring the pressure drop and the grade efficiency, the following three parameters were varied:

1. the air velocity u_{LK} in the throat
2. the water-air ratio L [m^3 water/m^3 air]
3. the diffusor geometry

The air velocity was varied from 70 to 110 m/s in steps of 10 m/s. For each adjustment, the water-air ratio (L) was also varied from 0.75 to $1.5 \cdot 10^{-3}$. These operating conditions had to be investigated for all the three available diffusor geometries.

The three diffusor geometries employed are represented in Fig. 2. The diffusors have the same length and the same opening ratio of 1:4. The conical diffusor having a length of 229 mm has a half opening angle of 2°. The parabolic diffusor has a maximum opening angle of 4° at the end and the diffusor criteria for flow separation is justified. The same is valid for the inverse parabolic geometry (a large opening angle at the inlet of a diffusor is regarded as comparatively uncritical [2].

The amount of dust added to the air was 0.5 g/... The test material used was a limestone fraction having a number median diameter of 1.8 μm.

MEASUREMENT OF THE PRESSURE DROP

It is important that in the separation process a large proportion of the washing liquid added should be evenly distributed over the cross section of the scrubber. In the experiment a number of nozzle rings differing in number and diameter of holes are employed to obtain optimum injection conditions. The optimum operation conditions were adjusted by means of the following two criteria:

1. The distribution of the washing liquid was checked visually and compared with pictures published by H. Günteroth [3].
2. The pressure drop measured is for most part dependent on the droplet acceleration. The largest pressure drop is achieved for the same L and u_{LK}. The portion of water accelerated by the air is also largest for this condition.

In the results presented in the paper, the nozzle ring having the highest pressure drop was used.

Figure 3 shows the pressure drop dependence both on the air velocity and the water-air ratio as for a conical diffusor. As can be seen, the pressure drop increases both with increasing L and with increasing u_{LK}. For a larger L, more water must be accelerated (Δp increases). For a higher velocity in the throat, the relative velocity is higher (Δp

increases). This result is also valid for the other diffusor geometries.

In Fig. 4, the pressure drop of the three diffusor geometries is compared under the same conditions. At constant air velocity, the parabolic diffusor shows the highest pressure drop for all values of L. Since the cross sectional area of this diffusor remains small over a larger length than for the other designs, the air velocity decreases more slowly. This results both in a higher friction loss and a larger acceleration pressure loss as the dropplets accelerated over a longer distance. A change of the sign of the relative velocity occurs very late, that means, a retardation of the droplets.

GRADE EFFICIENCY MEASUREMENTS

The separation behaviour of the scrubber grade efficiency is investigated using the influence of the three parameters: throat velocity u_{LK}, water-air ratio L and the diffusor geometry. The grade efficiency is defined for each particle size x and the ratio of the amount separated in the scrubber in relation to the amount contained in the raw gas[4]. It applies:

$$T(x) = g \cdot \frac{q_G(x)}{q_A(x)} = 1 - f \cdot \frac{q_F(x)}{q_A(x)}$$

Where:

$T(x)$ - grade efficiency

g, f - mass fractions of coarse and fine product (clean gas) respectively

$q_G(x)$, $q_F(x)$ - density distribution of coarse and fineproduct, respectively

$q_A(x)$ - density distribution of the feed (raw gas)

In the experiment a scattered light particle size analysator is used for the investigation of the grade efficiency and the latter is determined according to the following equation:

$$T(\bar{x}_i) = 1 - \frac{\Delta N_F(\bar{x}_i) \cdot t_A}{\Delta N_A(\bar{x}_i) \cdot t_F}$$

Where:

$\Delta N(x_i)$ - particle number counted in the i-th interval

t_A, t_F - measuring time at the raw and clean gas side, respectively

The grade efficiency are measured for all the test conditions and are demonstrated just as in the case of pressure drop. Figure 5 shows the measurement of grade efficiency against particle sizes for different water-air ratios using conical diffusor at a throat velocity of 80 m/s. The diagram clearly demonstrates that increasing water-air ratio promotes grade efficiency.

The grade efficiency curve for $L = 1.25 \cdot 10^{-3}$ showed an extraordinary result. This happened due

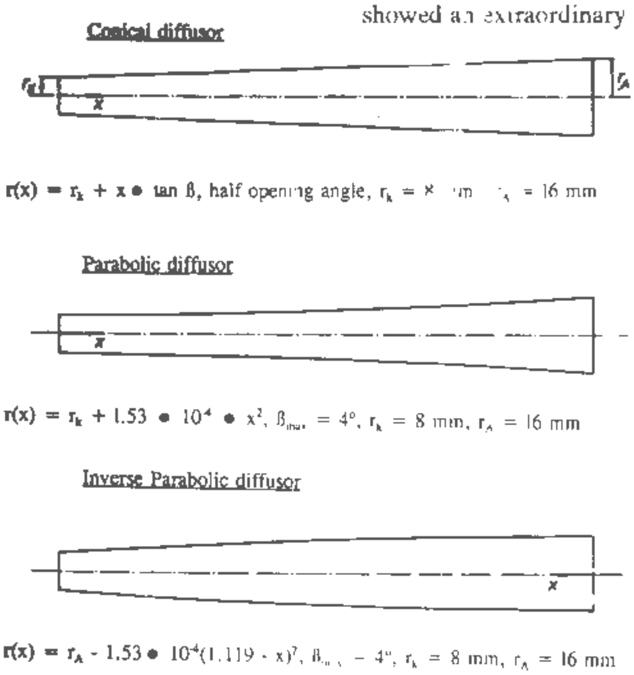

Figure 2 Diffusor Geometries

to the experimental condition since it was difficult to construct a suitable nozzle ring for $L = 1.5 \cdot 10^{-3}$ that allows an optimum water spraying conditions.

Figure 6 represents the grade efficiency for the same diffusor with an air velocity of u_{LK} = 110 m/s. Here a better grade efficiency is registered for all L and improves with increasing L without any exceptional results. It can be seen, that particles having a particle size of 1 μm are separated to 95 % at $L = 1.5 \cdot 10^{-3}$.

A comparison between the three diffusor geometries at a low throat velocity is represented in Fig.7. The grade efficiency is improved for the same water-air ratio and the same throat velocity in the order of parabolic, conical and inverse parabolic diffusor geometries.
Figure 8 illustrates the influence of the three diffusor geometry for a throat velocity of 110 m/s. Here again the maximum grade efficiency is registered with the parabolic diffusor followed by the inverse parabolic diffusor. The least separation behaviour is observed on the conical diffusor.
Comparing the performance of conical and inverse parabolic diffusor, which the results are not shown here enables us to come to the following conclusion: for velocities up to 90 m/s and for L up to $1.25 \cdot 10^{-3}$ the conical diffusor registered better grade efficiency. However, for higher velocities and for $L > 1.25 \cdot 10^{-3}$ the inverse parabolic diffusor results in better performance. However, the differences are often small. For all conditions best grade efficiency is always obtained with parabolic diffusor.

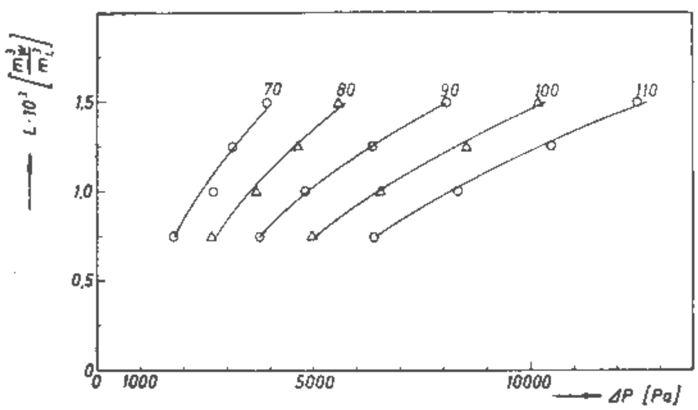

Figure 3 Influence of the Water-Air Ratio and the Throat Velocity on the Pressure Drop for a Conical Difusor with u_{lk} = 70 ÷ 110 m/s

Analysing the energy demand (pressure drop) with the separation obtained, the parabolic diffusor shows the best separation efficiency although it demands highest pressure drop. The inverse parabolic diffusor gives the smallest pressure drop but considering the grade efficiency it goes from

slightly worse to slightly better as compared to the conical diffusor.

CONCLUSIONS

A gas Venturi scrubber is used to separate small particles (< 1 μm) and the process is associated with high energy consumption. To minimize this high energy consumption, the influence of conical, parabolic and inverse parabolic diffusor geometries upon the pressure drop and grade efficiency is investigated. Comparing the three diffusors at constant air velocity and water-air ratio the parabolic diffusor shows the highest pressure drop. The lowest pressure drop is recorded with the inverse parabolic diffusor.

In analaysing the grade efficiency at all ranges of the throat velocity, the parabolic diffusor shows the best separation behaviour. It is also shown that in the case of conical and inverse parabolic diffusors the grade efficiency depends highly on throat velocities. At low throat velocities, the conical diffusor shows a high separation efficiency but for higher throat velocities the reverse effect is registered in the case of the inverse parabolic diffusors.

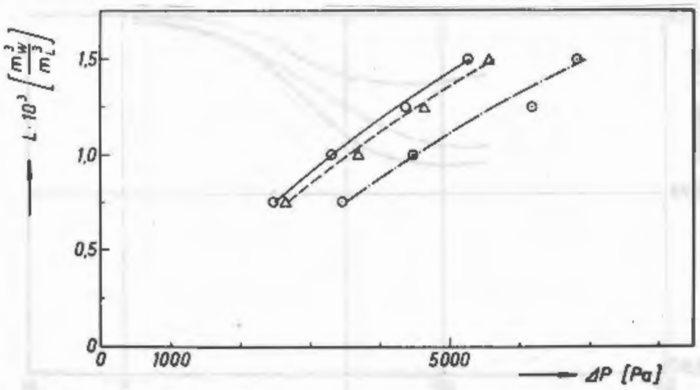

Figure 4 Comparison of the Diffusor Geometries as to the Pressure Drop at the same u_{lk} 80 m/s and L; Inv. Parabolic (○), Conical (Δ) and Parabolic (⊙)

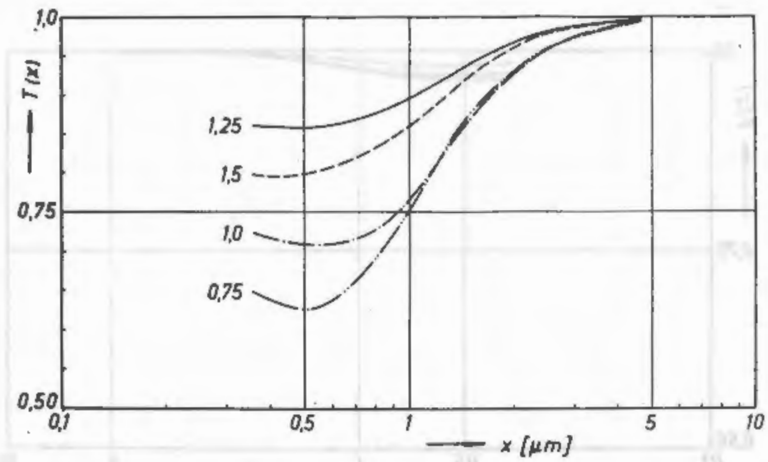

Figure 5 Grade Efficiency with Conical Diffusor Installed at u_{LK} = 80 m/s and $L = 0.75 \div 1.5.10^{-3}$

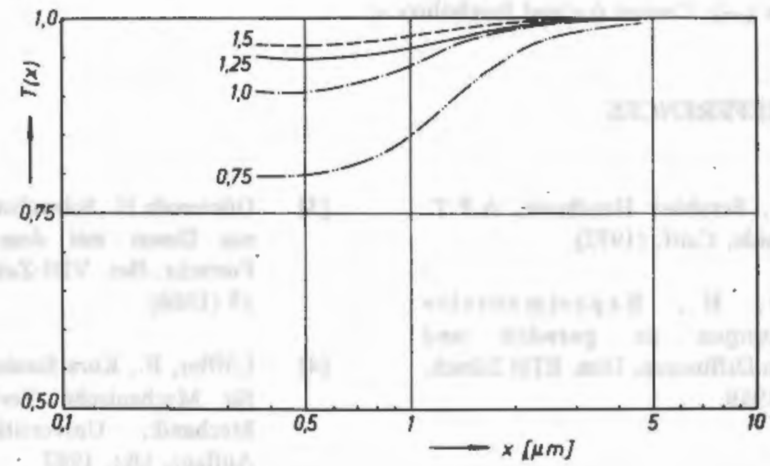

Figure 6 Grade Efficiency with Conical Diffusor Installed at u_{LK} = 110 m/s and $L = 0.75 \div 1.5 \cdot 10^{-3}$

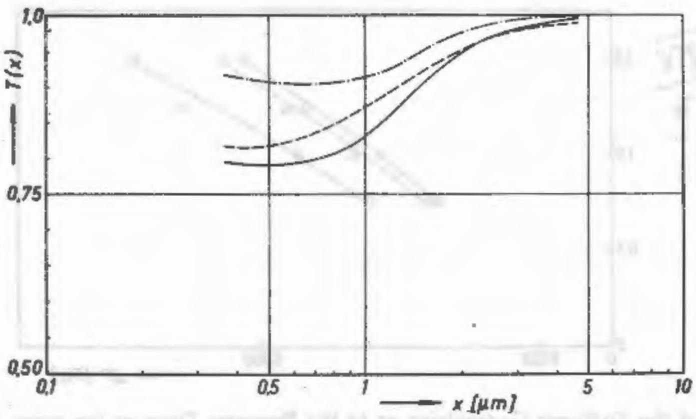

Figure 7: Dependence of the grade efficiency on the diffusor geometry, u_{LK} = 70 m/s, L = 1.51 • 10^{-3}; Inv. Parabolic (——), Conical (---) and Parabolic (- -)

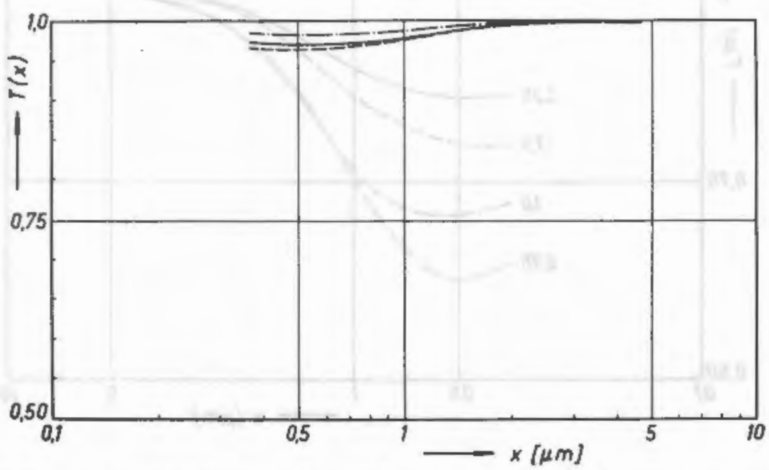

Figure 8 Dependence of the Grade Efficiency on the Diffusor Geometry, u_{LK} = 110 m/s, L = 1.5 x 10^{-3}; Inv. Parabolic (—), Conical (---)and Parabolic(- -)

REFERENCES

[1] Calvert, S., Scrubber Handbook, A.P.T. Inc., Riverside, Calif. (1972)

[2] Sprenger, H., Experimentelle Untersuchungen an geraden und gekrümmten Diffusoren, Diss. ETH Zürich, Nr. 2803, 1959

[3] Günteroth, H., Schwebstoff-Naßabscheidung aus Gasen mit dem Venturi-Scrubber, Fortschr.-Ber. VDI-Zeitschrift Reihe 3 Nr. 13 (1966)

[4] Löffler, F., Kurs Staubabscheiden, Institut für Mechanische Verfahrenstechnik und Mechanik, Universität Karlsruhe, 5. Auflage, Okt. 1982