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THE STAMICARBON STRIP VENTURI SCRUBBER A NEW CONCEPT OF DUST AND FUME EXTRACTION (Patent Pending)

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SUMMARY

A new scrubber design has been developed by Stamicarbon for the dedusting of large-scale particulate emissions such as from fertilizer prilling towers and rotary dryers.
This paper discusses the operating principle and a number of improvements such as the use of two interactive auxiliary media and of strip venturis, which make for high flexibility with respect to capacity, pressure drop and collection efficiency.
Re-entrainment of the concentrated wash liquor is negligible thanks to a specially designed demister.

The upscaling factor is unity, which means that commercial units are essentially identical to the pilot unit. Consequently, the pilot unit can be used for the purpose of determining the maximum energy economy at the desired collection efficiency for any service. Higher capacities can be attained through paralleled operation.
A number of experimental results are discussed.

INTRODUCTION

Environmental legislation that has been introduced in recent years has had a profound impact on the fertilizer industry in that particulate emissions need to be dedusted more thoroughly than ever.

This has prompted Stamicarbon, the licensing subsidiary of DSM, to develop a new scrubbing system for its fertilizer processes such as urea and high-density ammonium nitrate.
First, an inventory was made of emissions in these processes and their particle size distributions.
Evaluation of proven dust control technologies soon showed that there was no commercial design that completely filled the bill, particularly in respect of physical weight and operating cost for proper collection of submicron particles.

PRELIMINARY INVESTIGATION

In the past few years Stamicarbon has tested many small-scale dust collectors in a number of urea plants. The performance figures so collected were brought under the following common denominators in order to allow meaningful comparison of the running cost per 1000 m3/h air stream versus collection efficiency.

- Air flow	100,000 m3/h
- Airstream inlet temperature	70 °C
- Relative humidity of airstream	5 %
- Dust concentration	150 mg/m3
- Dust granulometry, see Fig. 1	70 % wt < 1 micron

Granulometry of urea prilling tower dust

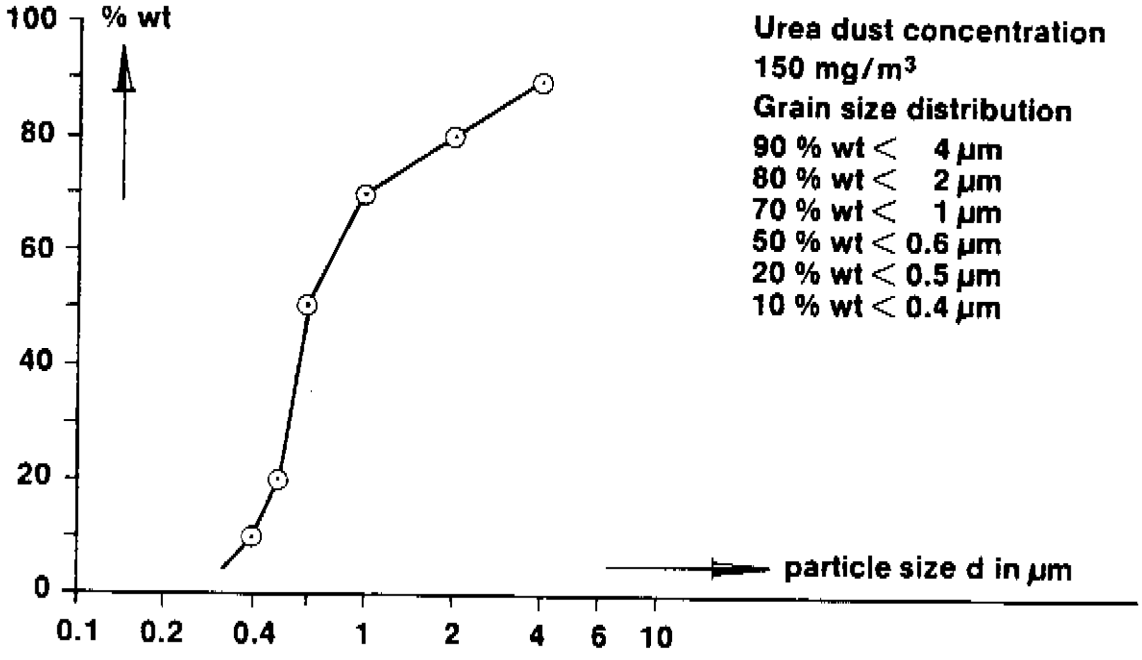


Fig. 1

Also calculated were:

- The energy required per 1000 m3 of airstream.
- The cost of cleaning 1000 m3 of airstream in terms of depreciation and energy.

The installed cost of the equipment has been assumed to be twice the F.O.B. cost, including for fan, pumps and motors. Depreciation is over 10 years, so 80,000 hours, and the cost of 1 kWh is 15 Dutch cents, which equals 6 dollar cents.

The relation between cost and dust collection efficiency is shown in Fig. 2.

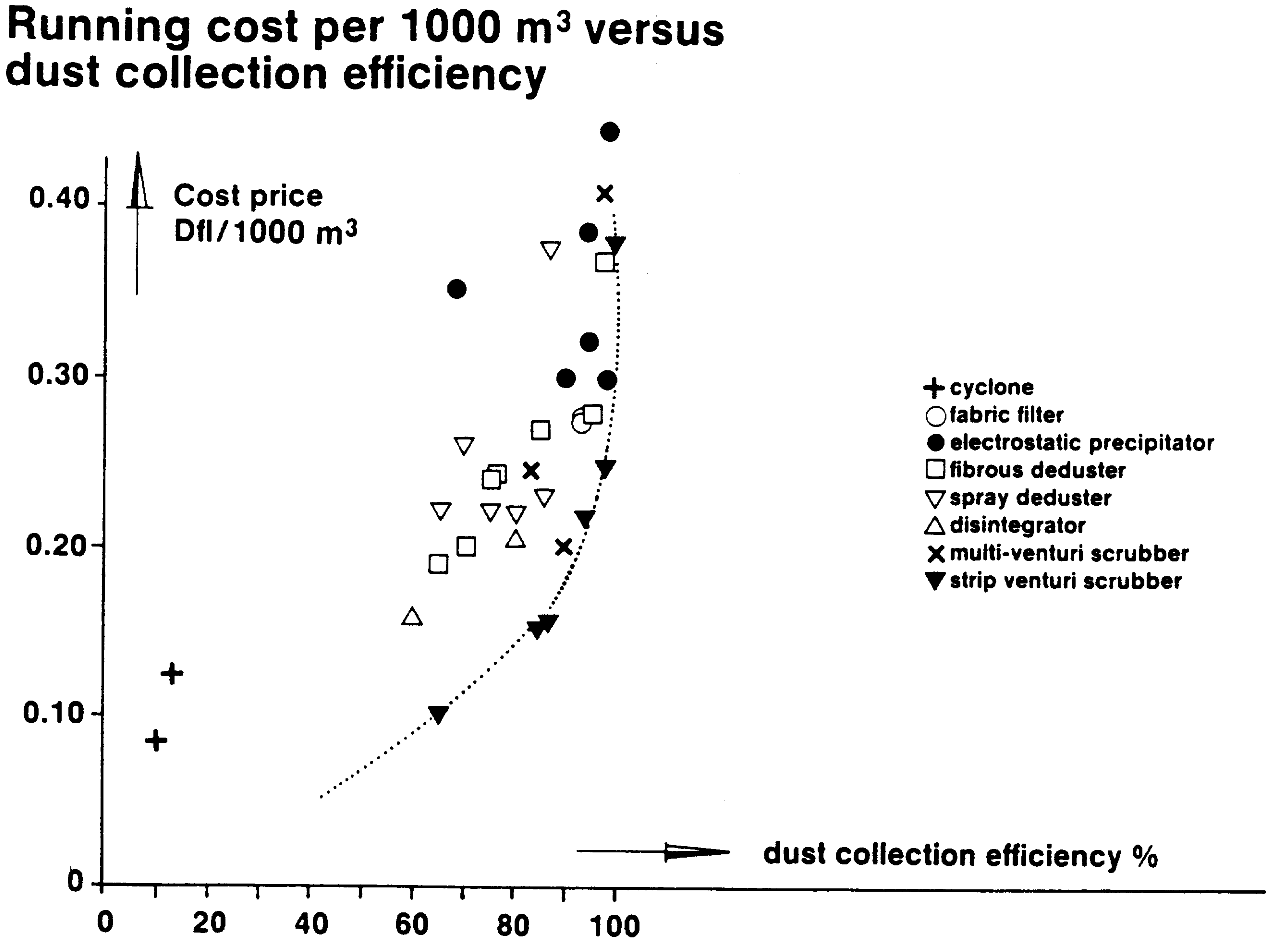


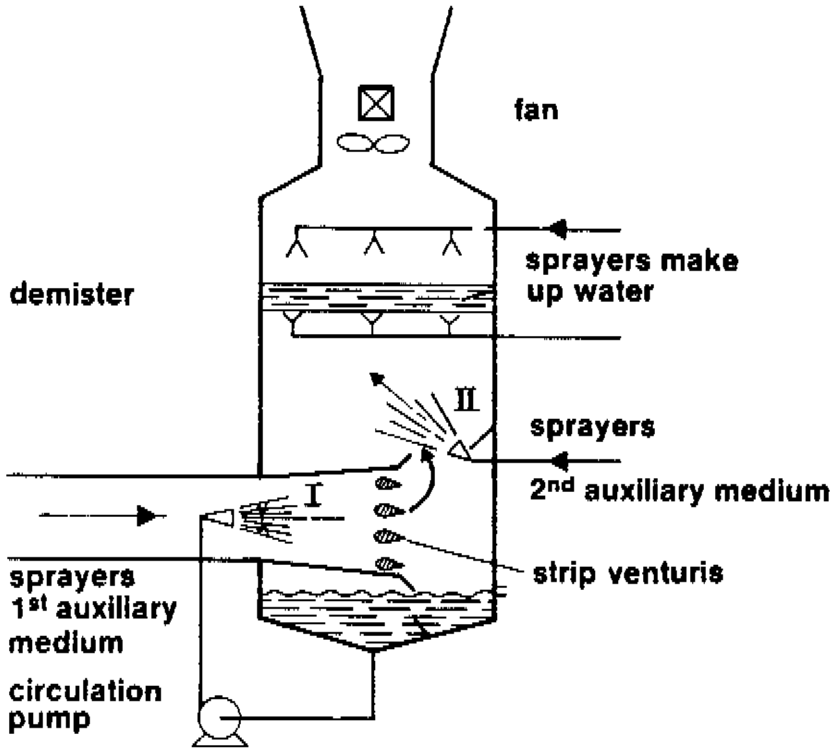
Fig. 2

All in all, the preliminary investigation indicated that fundamental conceptual improvements were needed if compliance with the environmental regulations was not to be too heavy a financial burden.

The new design had to be light-weight so that it could be placed atop existing prilling towers, so obviating the need for piping to return the off-gases to ground level. Also, it had to offer wide flexibility with respect to capacity and collection efficiency but yet low energy consumption. These requirements and considerations have resulted in the development of the Stamicarbon Strip Venturi Scrubber.

OPERATING PRINCIPLE

The design of the pilot unit is shown in Figure 3.



Pilot strip venturi scrubber

Fig. 3

The scrubber consists essentially of a spray zone where the dry airstream is humidified by means of the recirculating spray liquor, being the first auxiliary medium. In this way, the bulk of particulates is scrubbed out.

The wash liquor is largely separated from the air stream and a second auxiliary medium is injected in zone II. This interacts with the remaining fine droplets of the first auxiliary medium entrained in the air stream.

Interaction between the two auxiliary media is an essential feature of the design. One auxiliary medium may already be present in the feed stream whilst low-pressure steam is often used as the other.
As water vapour condenses on the fine droplets of the first auxiliary medium (the recirculating wash liquor) the fine dust particles in the air stream are driven to the cold liquor droplets by thermoforetic and diffusioforetic forces. This is why the collection efficiency is higher than it would be without the interaction.

The second auxiliary medium may also be a gas, for instance ammonia, that reacts with the acidified first auxiliary medium to produce a similar interaction. The higher collection efficiency so achieved is apparent from the results of Tests 2, 6 and 7.

Finally, the fine liquid droplets are removed in a multi-layered demister package, the smallest submicron particles being caught in an intermediate agglomeration package and separated in a subsequent demister package. Evaporated water is replenished by condensate being sprayed intermittently onto the demisters.

The geometry and overall design of the venturi strips is the same for the pilot unit and the commercial unit except that the numbers of sprayers and venturi strips should be related to the capacity ratio.

The residence time and gas and liquid velocities are the same for both units.

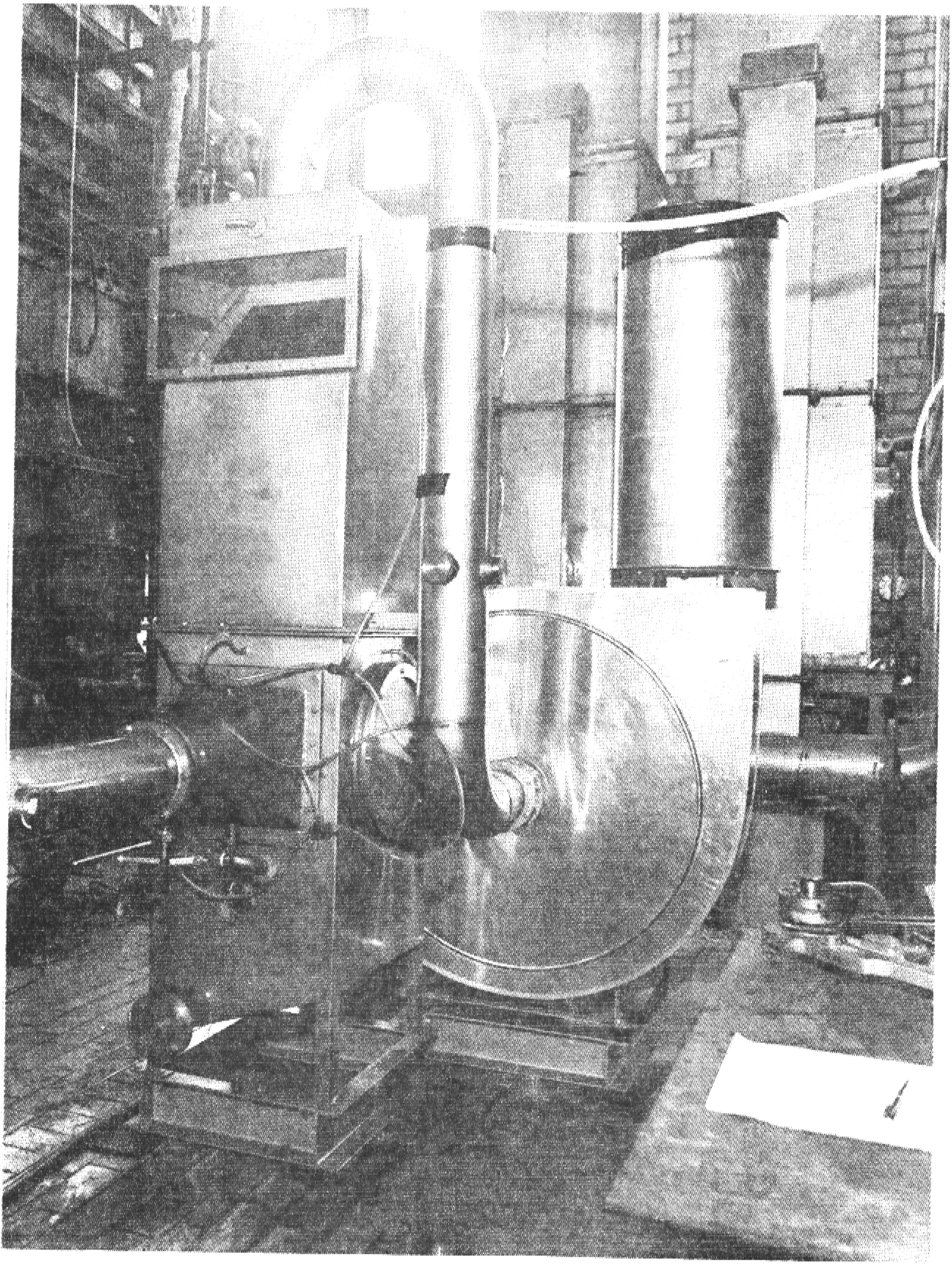


Figure 4

Strip venturi scrubber

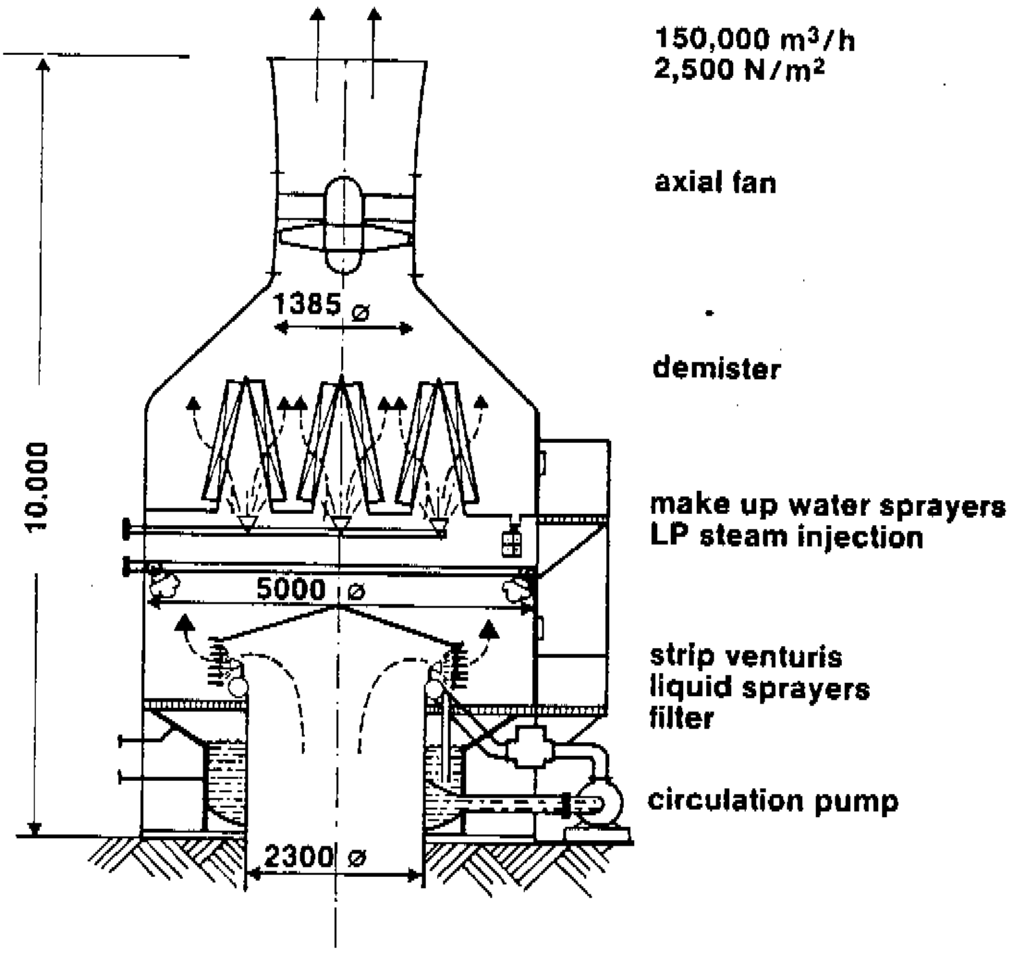


Fig. 5

DUST COLLECTION PERFORMANCE AND EFFICIENCY, THEORETICAL ASPECTS

The dust collecting effect of the Strip Venturi Scrubber is based on a combination of the following principles:

- Saturation of the airstream with water vapour and wetting of the dust particles for better adhesion to the liquid surface. The droplets will evaporate in a dry gas atmosphere so that the chances of the dust particles impacting will be significantly smaller than in a humidified gas stream.

- Impaction of dust particles on droplets as a result of inertia, interception and diffusion, stimulated by the interaction of the auxiliary media. The collection efficiency is the sum total of the individual impactions and can be predicted fairly accurately as discussed in literature.

Figure 6 shows the single-sphere efficiency, which is the calculated impaction probability in a sphere with a given porosity, as well as the improvement in collection efficiency to be expected from utilizing the diffusion effects.

Calculated single-sphere efficiency versus particle diameter

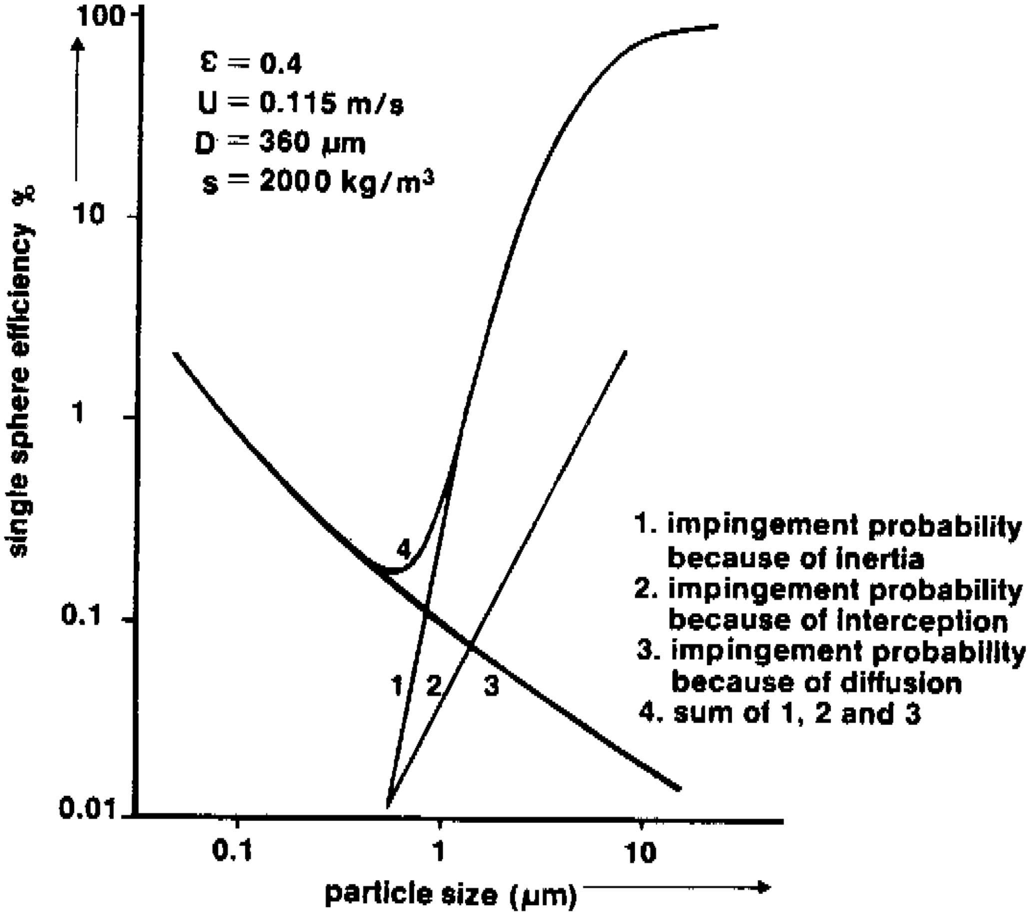


Fig. 6

The dimensional analysis indicates that collection performance through inertia and interception depends mainly on five parameters.

$$\eta \text{ scrubber} = f\,(K,\ R_e,\ W,\ Fr,\ N)$$

where

$$K = \frac{sd^2U}{18v\ D} \qquad Fr = \frac{U^2}{g\ D}$$

$$R_e = \frac{S\ U\ D}{v} \qquad W = \frac{s}{S} \qquad N = \frac{Q\ q}{f\ v\ d^2\ D\ U}$$

An approximative equation has been developed for the collection efficiency where R_e lies between 0.50 and 50, while ignoring electrostatic influences and diffusion.

$$\eta_1 = \left(\left[1 + (1.53-0.23\ \ln R_e + 0.0167\ \ln^2 R_e)\ \ (2.K)^{-1}\right]^{-2} + \sqrt{\frac{2}{R_e W}}\right)\left(1+3\ \frac{2K}{R_e W}\right)$$

The electrostatic effects are significant mainly where $K < 1$ and $R_e < 10$.

The contribution of Coulomb forces to the collection efficiency is approximately as follows:

$$\eta_2 = \left[1.22\ (2 - \ln R_e)N\right]\left[\left(\frac{K}{2\sqrt{R_e}}\right)^{1.5} + 1\right]^{-1}$$

The diffusion effect is important for particles smaller than 0.5 microns; its contribution to the collection efficiency is approximately:

$$\eta_3 = \frac{2.9}{Ko^{1/3}\ Pe^{2/3}} + \frac{0.624}{Pe}$$

where

$$Ko = -\ 1/2\ \ln\,(1 - \varepsilon\,) - 0.5$$

The diffusion coefficient Dc is inversely proportionate to the particle diameter d; hence

$$\eta_3\ :\ :\ (U\ D\ d)^{-\ 2/3}$$

In other words, the collection efficiency through diffusion decreases with increasing velocity U and/or particle size D and d.

The overall collection efficiency then is

$$\eta \text{ total} = \eta_1 + \eta_2 + \eta_3$$

While not all effects can be fully explained yet, current theoretical and practical research has yielded valuable information on the correlation and influence of the variables mentioned above.
By keeping the shape factors constant, the pilot scrubber makes it possible to measure the collection efficiency and power consumption for a given airstream.
Furthermore, the performance of the pilot unit can be optimized selectively by means of the equation last mentioned.
Consequently, the fractional collection curve for a given airstream and the energy requirement per 1000 m^3 for a given overall collection efficiency and equal particle size distribution can be applied to a commercial design without any adjustment.

TEST RESULTS OF PILOT UNIT

Tables 1 and 2 shows the averaged results of a large number of tests with and without two interacting auxiliary media.
For convenience, the fractional collection figures are compared for the whole submicron area.

Table 1 first shows the process variables relating to Tests 1 through 4.

TABLE 1

Volume flow	: 1000 m3/h
Pressure	: atmospheric
Temperature	: approx. 40 °C
Relative humidity	: approx. 70 %
Particles	: urea dust
Particle concentration	: 250 mg/m3
Particle size distribution	: 100 % wt < 100 micron
	: 90 % wt < 10 micron
	: 75 % wt < 5 micron
	: 50 % wt < 1 micron
	: 5 % wt < 0.5 micron
Airstream velocity	: 10 m/s
Air velocity at Venturistrips	: 50 m/s
Air velocity before demister	: 2 m/s
Total pressure drop across	: approx. 1500 N/m2
Energy consumption	: approx. 0.4 kWh/1000 m3

	Test 1	Test 2	Test 3	Test 4
Aux. medium I	20 % wt urea solution	20 % wt urea solution + 1 % H_2SO_4	20 % wt urea solution	20 % wt urea solution
- amount	1 m3/h	1 m3/h	1 m3/h	1 m3/h
- temperature	20-40 °C	20-40 °C	20-40 °C	20-40 °C
Aux. medium II	steam	NH3 (vapour)	20 % (m/m) urea sol.	-
- amount	1 kg/h	0.2 kg/h	1 m3/h	-
- pressure	2 bar	12 bar	-	-
- temperature	120 °C	5 °C	40-60 °C	-
- collection efficiency submicron particulate	55 %	60 %	50 %	50 %

The collection efficiency is calculated on the basis of the particle concentration measured at the scrubber outlet. The spray nozzles used for the auxiliary medium in zone I were commercially available full-cone nozzles, producing droplets in the range of 100 - 500 microns. The spray nozzles used for introduction of the second auxiliary medium in zone II in Tests 1 and 2 were of the "Laval" nozzle type, those in Test 3 of the full-cone nozzle type referred to above.

As can be seen, the collection efficiency in Test No. 1, with interaction of steam, is 5 % better than in Test No. 3 under otherwise equal test conditions.
In Test No. 3 the second auxiliary medium was not steam but the first medium was re-used.

No second auxiliary medium was used in Test No. 4.

In Test No. 2 the second auxiliary medium was gaseous ammonia and the first was acidified with sulphuric acid. Here, the fractional collection efficiency in the submicron range is 10 % higher than in Tests 3 and 4.

Table 2 shows process variables relating to Tests 5, 6 and 7.

For these tests, ammonia vapour was introduced in zone II and an acid liquor in zone I. The size distribution of the particles to be removed from the gaseous medium and of the removed particles are given in the graph of Fig. 7.

In Fig. 7 the curves A and B represent the particle-size distribution of the feed material in Tests 5 and 6 and in Test 7, respectively. Curve C represents the particle size distribution at the scrubber outlet.

TABLE 2

Volume flow : 1000 m3/h
Pressure : atmospheric
Temperature : approx. 30 °C
Relative humidity : 40 %
Particles : urea dust
Particle concentration : 250 mg/m3
Particle size distribution : see Fig. 7
Energy consumption : 0.2 kWh/1000 m3

	Test 5	Test 6	Test 7
Aux. medium II	Ammonia	Ammonia	Ammonia
amount fed	250 ppm	250 ppm	250 ppm
Aux. medium I	20 % wt urea solution	20 % wt urea solution + 0.7 % wt H2SO4	20 % wt urea solution + 1.0 % wt H2SO4
amount fed	1 m3/h	1 m3/h	1 m3/h
collection efficiency sub-micron particles	50 %	52 %	55 %

In Test No. 5, the second auxiliary medium was ammonia but the first was not acidified. As a result, the level of interaction was significantly lower, which explains why the collection efficiency is 10 % lower than in Test No. 2.

In Test No. 6, the first auxiliary medium was acidified only lightly, corresponding with a 2% improvement of the collection efficiency in the submicron range.

Also in Test 7, the recirculating wash liquor was made more acid, resulting in a greater improvement of the submicron collection efficiency.

CONCLUSIONS

Injection of a second auxiliary medium after the strip venturis improves the collection efficiency for sub-micron particles by about 10 %.
A similar improvement without the interactive effects of a second auxiliary medium would call for a significantly higher pressure drop.
Consequently, the running cost per 1000 m3 is lower than for other dedusting systems, assuming equal service conditions.
The Strip Venturi Scrubber is particularly suitable for airstreams whose submicron fractions need to be reduced.

Particle size distributions

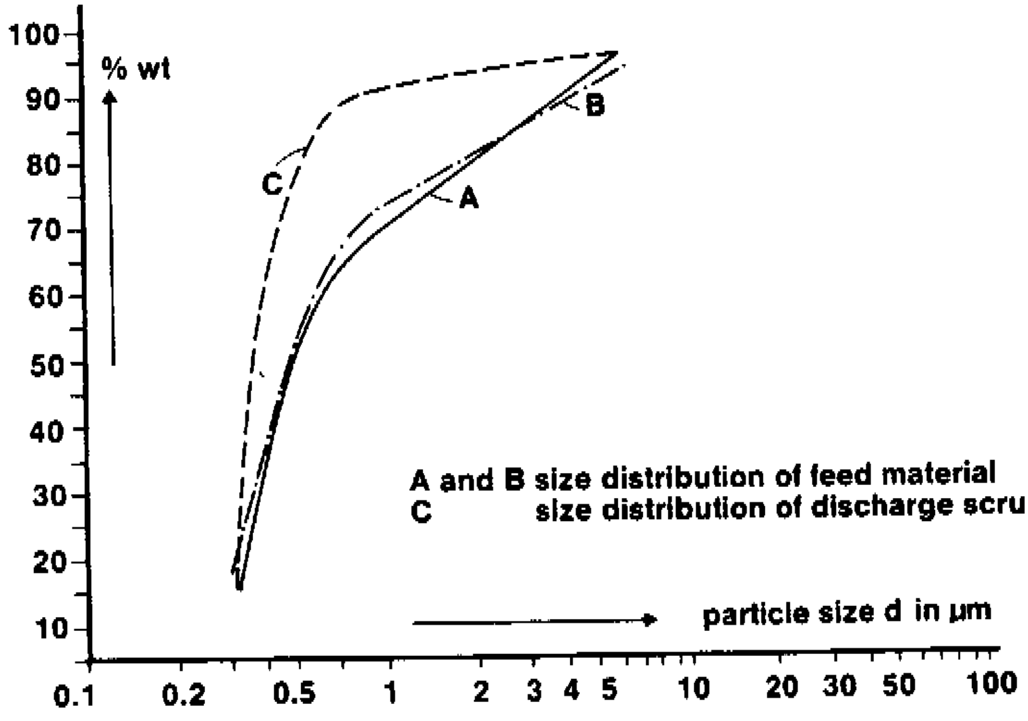


Fig. 7

NOMENCLATURE

D	= drop diameter	m
Dc	= diffusion coefficient	m2/s
U	= relative velocity	m/s
Re	= Reynolds number $\frac{SUD}{v}$	-
W	= specific mass rate	-
s	= specific mass of the particles	kg/m3
S	= specific mass of the gas	kg/m3
Fr	= froude number	-
g	= acceleration due to gravity	m/s2
K	= inertia parameter	-
v	= viscosity of the gas medium	N sec/m2
N	= parameter for electrostatic forces $N = \frac{\text{elecst. force}}{\text{inertial force}}$ $N = \frac{Q \cdot q}{f\ v\ d2\ D\ U}$	-
Q	= electrostatic charge of droplet per unit area	C
q	= electrostatic charge of dust particle	C
f	= constant	-
ε	= porosity	-

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TA/86/18 The Stamicarbon strip Venturi scrubber. A new concept of dust and fume extraction (Patent pending) by J.P. Nommensen, Stamicarbon, Netherlands

DISCUSSION : (Rapporteurs Messrs A. Bourgot & M. Sart, Prayon-Rupel, Belgium)

Q - Mr. MEZGHANI, SAEPA, Tunisia

Could the Venturi scrubbers with two interactive auxiliary media be used for recovering DAP dust?

If so, what would be the auxiliary media?

A - In principle, my answer would be yes. We could use cold washing liquors and LP steam.

Q - Mr. P. LAMMI, Kemira Oy, Finland

What is the amount of NH_3 required to have improvement on scrubbing efficiency? Please specify in mg/m3? What are the reasons for improvement?

A - The amount of ammonia depends on the recovery rate desired. In the pilot plant it is possible to increase the amount of ammonia to obtain the desired recovery. Thus I cannot answer specifically without knowing the desired recovery. In the case of urea dust containing already some ammonia in the exhaust gases, one should add about 100 ppm. The reason is that, if ammonia is used, the recycle liquor should be acidified more or less at the rate of 1% H_2SO_4 or HNO_3. Then the recovery rate would be improved since ammonia in the vicinity would be attracted by the droplet(s) already formed. F.ex. to recover 1 g urea, it represents 1500 one micron particles; the recovery is, then, very difficult. The presence of a very high number of droplets is necessary, and particles are often much smaller than one micron. This must be taken into account in the design of the system. There must be very fine condensation droplets to improve the recovery rate.

Q - Mr. G. BRUSASCO, Agrimont, Italy

1. Have you tested the strip Venturi scrubber for NPK powders?

2. If not, are you planning to study it in the future?

A - We have not tested that pilot unit on prilling towers for ammonium nitrate, but we did several tests with calcium ammonium nitrate, at screen exhaust. The overflow of the cyclones flows through the venturi. We did not go further and we did not obtain the same results as those described in the paper. A small fraction of fairly large insolubles (5 to 14 micron) still remained. We did another test on ammonium nitrate in a plant in Norway. These two tests were satisfactory.

Q - Mr. V. SCHUMACHER, BASF, Germany

After washing out urea by adding NH3, how high are the NH3 emission rates?

A - Ammonia emissions in 100 mg/m3 injections are very low, about 5 ppm. But sufficient acidification of the recycle liquor is necessary.

If ammonia neutralizes the droplets, there is no recovery. Thus one must either reduce ammonia or acidify. But in principle it is easy to recover ammonia with an acidified liquor, especially if the area of the demister is important.

Q - Mr. B. DROCOURT, SPIE Batignolles, France

What is the pressure drop in your gas scrubber in given efficiency conditions for applications such as exhaust gases in a urea prilling tower?

A - The pressure drop in the scrubber would be about 100 mm water for a urea prilling tower. It is possible to reduce it; it depends on the amount of particles below one micron.

If you have 70% or more, then a very efficient venturi scrubber is necessary before the diffusion, since the latter cannot add much improvement in the recovery rate.