Reprinted from

Chemical
Engineering
and
Processing

Chemical Engineering and Processing 34 (1995) 283–288

Operating results and aerosol deposition of a venturi scrubber in self-priming operation

F. Mayinger, M. Lehner *

Lehrstuhl A für Thermodynamik, Technische Universität München, Arcisstr. 21, 80290 München, Germany

Dedicated to Prof. Dr. Dietmar Werner on the occasion of his 60th birthday

ELSEVIER

CHEMICAL ENGINEERING AND PROCESSING

Editor-in-Chief:
Prof. Dr.-Ing.Dr.h.c./INPL Ernst U. Schlünder
Universität Karlsruhe
Institut für Thermische Verfahrenstechnik
Postfach 6980, D-76128, Germany

Managing Editor:
Dr.-Ing. V. Gnielinski
Universität Karlsruhe
Institut für Thermische Verfahrenstechnik
Postfach 6980, D-76128, Germany

Associate Editors:
Prof. G. Astarita
Istituto di Principi di Ingegneria Chimica
Piazzale Tecchio 1, 80125 Naples, Italy

Prof. Dr. inz. A. Burghardt
Instytut Inzynierii Chemicznej i
Konstrukcij Aparatury PAN
Ul, Baltycka 5, 44100 Gliwice, Poland

Dr. Jan Clucupcrclermák
Czechoslovak Academy of Sciences
Institute of Chemical Process Fundamentals
165 02 Prague 6, Czech Republic

Prof. Dr. W. Frey
BASF A.G.
67056 Ludwigshafen, Germany

Dr. J. Gyenis
MTA Mükki
Research Institute of Chemical Engineering
Hungarian Academy of Sciences
H-8201 Veszprém, Egyetem u.2., P.O. Box 125
Hungary

Prof. T. Hertzberg
The University of Trondheim
The Norwegian Institute of Technology
Department of Chemical Engineering
N-7034 Trondheim, Norway

Dr. Ing. K. Jelemensky
Strojnickej fakulty STU
v Bratislava, Czech Republic

Prof. N. N. Kulov
Head of Laboratory
Theoretical Fundamentals of Chemical Technology
Kuruakov Institute of General & Organic Chemistry
of the Russian Academy of Sciences
Leninsky Prospekt, 31
Moscow 117907, Russia

Prof. Dr.-Ing. K. Leschonski
Technische Universität Clausthal
Institut für Mechanische Verfahrenstechnik
und Umweltverfahrenstechnik
Leibnizstrasse 15, 38678 Clausthal-Zellerfeld
Germany

Prof. Dr.-Ing. R. Marr
Technische Universität Graz
Institut für Thermische Verfahrenstechnik
und Umwelttechnik
Inffeldgasse 25, 8010 Graz, Austria

Prof. Dr.-Ing. O. Molerus
Universität Erlangen-Nürnberg, Lehrstuhl
für Mechanische Verfahrenstechnik
Martensstrasse 9, 91058 Erlangen, Germany

Prof. H. Müller-Steinhagen
Department of
Chemical & Process Engineering
University of Surrey
Guildford, Surrey GU2 5XH, UK

Prof. Dr. W. Nitsch
Techn. Universität München, Institut für
Technische Chemie, Lichtenbergstrasse 4
85748 Garching, Germany

Prof. Morio Okazaki
Kyoto University, Department of
Chemical Engineering
Kyoto 606, Japan

Prof. A. Olcay
Ankara University Faculty of Sciences
Department of Chemical Engineering
06100 Tandogan, Ankara, Turkey

Prof. Dr. L. Puigjaner
Universitat Politècnica de Catalunya
Department of Chemical Engineering
ETSEIB, Diagnoal 647
E-08028 Barcelona, Spain

Prof. Dr.-Ing. L. Reh
Institut für Verfahrens- und Kältetechnik
ML F 26
ETH Zentrum
8092 Zürich, Switzerland

Prof. M. Shacham
Ben Gurion University of Negev
Dept. of Chemical Engineering
P.O. Box 653
IL-84105 Beer Sheva, Israel

Prof. Dr.-Ing. K. Stephan
Universität Stuttgart
Institut für Technische Thermodynamik
und Thermische Verfahrenstechnik
Pfaffenwaldring, 9, 70569 Stuttgart
Germany

Prof. M. Streat
Head of Department
Department of Chemical Engineering
Loughborough University of Technology
Loughborough
Leicestershire, LE11 3TU, UK

Prof. A. Tavares da Silva
Departamento de Engenharia Quimica
Faculdade de Ciências e Technologia
Universidade de Coimbra
3000 Coimbra, Portugal

Prof. Dr. M. N. Tekić
University of Novi Sad
Faculty of Technology
Bulevar Cara Lazara 1
YU-21000 Novi Sad, Serbia

Prof. J. Villermaux
Laboratoire des Sciences du Génie
Chimique — ENSIC, 1 rue Grandville
54042 Nancy-Cedex, France

Prof. D. D. Vortmeyer
Technische Universität München
Lehrstuhl B für Thermodynamik
Arcisstrasse 21, 80333 Munich 2, Germany

Prof. Dr. K. R. Westerterp
Twente University of Technology
Department of Chemical Technology
P.O. Box 217, 7500 AE Enschede
Netherlands

Prof. R. Wimmerstedt
Chemical Center, Chemical Engineering
P.O. Box 740, 200 07 Lund 7, Sweden

Aims and Scope

Chemical Engineering and Processing is a journal intended for practising engineers. The aim of the articles published is to demonstrate how theory and experience should be meshed in order to analyse or design chemical engineering equipment and processes at reasonable cost in terms of time and effort. The manner in which theoretical subjects are written allows them to be easily and rapidly understood. The state of the art is reviewed in the individual fields of activity, and process descriptions illustrate technological progress. Advanced knowledge is presented in the form of essays on applied scientific fundamentals.

The Journal offers space for articles on any branch of chemical engineering and is particularly concerned with mechanical, thermal and chemical unit operations and their application in the process industries.

Subscription Information 1995

Volume 34, containing 6 issues, is scheduled for publication. Prices are available from the publishers upon request. Subscriptions are accepted on a prepaid basis only. Issues are sent by SAL (Surface Air Lifted) mail wherever this service is available. Airmail rates are available upon request. Please address all requests regarding orders and subscription queries to:

ELSEVIER SCIENCE S.A.
P.O. Box 564, 1001 Lausanne, Switzerland
Telephone: +41 21 320 73 81
Fax: +41 21 323 54 44
Telex: 450 620 ELSA CH

Customers in the United States and Canada may obtain information from:

ELSEVIER SCIENCE PUBLISHING CO., INC.
Attn.: Journal Information Center
655 Avenue of the Americas
New York, NY 10010, USA
Telephone: +1 212 633 3750
Telex: 420-643 AEP UI
Telefax: +1 212 633 3764

ELSEVIER

Chemical Engineering and Processing 34 (1995) 283–288

Chemical Engineering and Processing

Operating results and aerosol deposition of a venturi scrubber in self-priming operation

F. Mayinger, M. Lehner *

Lehrstuhl A für Thermodynamik, Technische Universität München, Arcisstr. 21, 80290 München, Germany

Dedicated to Prof. Dr. Dietmar Werner on the occasion of his 60th birthday

---

Abstract

This study deals with behaviour and washing efficiency of a venturi scrubber in self-priming operation. Usually the washing liquid is injected into the throat by means of a pump, in such a way that the amount of liquid added per cubic metre of gas is adjustable independent from the gas flow rate. In contrast to this kind of design, the venturi scrubber used works via a self-priming operation, i.e. the washing liquid is injected by means of a pressure difference between the inside and outside of the venturi throat as a result of the hydrostatic pressure of the liquid and the static pressure of the flowing gas.

As is well known from the literature, the cleaning efficiency of a venturi scrubber improves with the amount of liquid added per volume of gas and with increasing gas velocity in the throat. However, high gas velocities and high charges of washing liquid cause a large pressure drop. Hence, the separation efficiency and energy consumption of the scrubber have to be optimized. It is shown that the separation efficiency could be improved by a multistage injection of the washing liquid. Due to the self-priming operation, the separation efficiency remains at a high level even if the gas velocity decreases, and thus requires no regulation from the outside.

Liquid separation after the venturi scrubber is realized by an immersion tube in combination with swirl promotors in the diffuser section of the scrubber which increase the rotation of the gas–liquid flow. Thereby, droplets are pushed aside to the diffuser walls and are deposited.

Keywords: Aerosol deposition; Venturi scrubber; Self-priming operation; Washing efficiency

---

Synopsis

Es wird das Betriebsverhalten und die Feinstaubabscheidung eines Venturiwäschers untersucht, der im Selbstansaugbetrieb arbeitet. Die Waschflüssigkeit wird in den Kehlenbereich des Venturiwäschers nicht wie üblich über eine Pumpe zwangsbeladen, sondern der Wäscher saugt aufgrund einer Druckdifferenz zwischen Kehleninnen- und -außenseite das umgebende Waschwasser ein. Den prinzipiellen Aufbau eines Venturiwäschers zeigt Abb. 1.

In Abb. 2 ist der verwendete Versuchsaufbau dargestellt. Aus einem höherliegenden Behälter läuft die Waschflüssigkeit in das die Kehle umgebende Wasserreservoir. Durch verschiedene Höhendifferenzen H kann ein unterschiedlicher geodätischer Flüssigkeitsdruck eingestellt werden. Die Flüssigkeitsabscheidung nach dem Venturiwäscher wird über Drallbleche, die im Diffusorteil das Wäschers lokalisiert sind, und über ein Tauchrohr vorgenommen. Die in ihrem Querschnitt rechteckige Kehle wird über gerade, scharfkantige und senkrecht zur Gasströmmung stehende Bohrungen mit Waschflüssigkeit bespeist. Dabei kommen Geometrien mit einer, drei und fünf im Abstand weniger Millimeter übereinanderliegenden Bohrungsreihen zum Einsatz. Als Testaerosol wird Titandioxid verwendet, das sehr fein fraktioniert ist (90% der Masse wird von Partikeln mit Durchmesser kleiner 1 μm eingenommen).

Der Waschflüssigkeitsvolumenstrom ist im Selbstansaugbetrieb nicht unabhängig vom Gasdurchsatz einstellbar, sondern nimmt mit steigendem Durchsatz ab (Abb. 3). Maßgebend für die einbringbare Flüssigkeitsmenge ist die treibende Druckdifferenz zwischen

---

* Corresponding author.

SSDI 0255-2701(94)04015-X

Kehleninnen- und -außenseite, die aufgrund des ansteigenden statischen Druckes in der Kehle mit größerer Kehlengeschwindigkeit abnimmt. Durch höhere Füllhöhen H kann der Flüssigkeitsdurchsatz vergrößert werden (Abb. 4).

Wichtig zur Beurteilung der Wäschergüte ist der Druckverlust. Dabei bewirkt eine Verdoppelung der Gasgeschwindigkeit einen Anstieg des Druckverlustes um mehr als das Doppelte (Abb. 5), wogegen eine Verdoppelung der Flüssigkeitsbeladung lediglich einen Anstieg um etwa 15% nach sich zieht (Abb. 6). Aus beiden Abbildungen ist ablesbar, daß unter sonst gleichen Bedingungen der Druckverlust im 5-Ebenen-Betrieb etwa um 10% geringer ist als im 3-Ebenen-Betrieb, was im wesentlichen auf eine günstigere Verteilung der Flüssigkeitsmenge über den Kehlenraum zurückzuführen ist.

Die Abscheideleistung des Wäschers kann durch eine Erhöhung der Waschflüssigkeitsbeladung deutlich verbessert werden (Abb. 7). Der kleinste gemessene Grenzkorndurchmesser liegt bei 0,1 μm. Aus Abb. 8 geht hervor, daß die beste Abscheideleistung mit der höchsten Geschwindigkeit in der Kehle erreicht wird. Aufgrund der Betriebsweise Selbstansaugung nimmt die Flüssigkeitsbeladung mit abnehmender Kehlengeschwindigkeit stark zu. Dies bewirkt eine Verbesserung der Abscheideleistung im niederen Geschwindigkeitsbereich. Dieses Phänomen verdeutlicht Abb. 9, in der der erreichbare Grenzkorndurchmesser über der Kehlengeschwindigkeit aufgetragen ist. Kleine Grenzkorndurchmesser und damit gute Abscheideergebnisse werden bei hohen und niedrigen Gasgeschwindigkeiten in der Kehle erreicht, so daß über einem weiten Geschwindigkeitsbereich die Abscheideleistung auf einem hohen Niveau bleibt. Entscheidender Vorteil des Venturiwächers im Selbstansaugbetrieb ist, daß diese Effekte ohne einen Regeleingriff von außen wirken, der Venturiwäscher also selbstregulierend arbeitet.

Die Abscheideleistung des Wäschers kann durch eine Erhöhung der Zahl der Eindüsungsebenen erheblich verbessert werden (Abb. 10). Dafür ist das Zusammenwirken mehrerer Umstände verantwortlich. Mayinger et al. [2] konnten nachweisen, daß die Waschflüssigkeit unmittelbar nach der Eindüsung zunächst nicht in Tropfen, sondern in sehr oberflächenintensive Membran- und Lamellenstrukturen zerfällt, die sich erst später zu Tropfen agglomerieren. Durch mehrstufiges Eindüsen werden solche oberflächenintensiven Strukturen immer wieder neu erzeugt. Zudem wirkt sich eine höhere Relativgeschwindigkeit zwischen Gas und Tropfen positiv auf die Abscheideleistung aus, durch Aufteilen der Flüssigkeitsmenge auf mehrere Ebenen werden immer neu hohe Geschwindigkeitsdifferenzen erzeugt. Schließich bewirkt eine versetzte Anordnung der Düsenbohrungen eine gute Überdeckung des Kehlenquerschnittes mit der Waschflüssigkeit.

Aus Abb. 11 geht hervor, daß der Einsatz von Drallseparatoren die Tropfenabscheidung nach dem Venturiwäscher nur geringfügig verbessert. Ein großer Teil der eingedüsten Waschflüssigkeit legt sich schon bald an die Diffusorwände an und kann auf diese Weise in den Sammelbehälter zurücklaufen.

1. Introduction

Wet scrubbers are frequently used for removing fine dust particles and aerosols from exhaust gases. Since the separation process becoming more difficult with decreasing particle size, particles with mean diameters d_P between 0.1–1 μm can be deposited in venturi scrubbers. The design and working principle of a venturi scrubber is shown in Fig. 1. The exhaust gas carrying the dust is accelerated in the converging part of the nozzle to velocities up to 120 m s^{-1}, and in this investigation up to 70 m s^{-1}. After such acceleration, water or another washing liquid is injected perpendicularly to the flow direction of the gas in the so-called throat, where the cleaning process takes place. After emerging from the throat, the gas–liquid mixture is decelerated in a diffuser. The energy necessary for cleaning the exhaust gas, i.e. the pressure loss of the venturi scrubber, has to be compensated by a blower or compressor.

In the literature one often encounters the opinion that the washing liquid is dispersed into droplets in the throat [1]. However, Mayinger and Neumann [2] showed that the liquid is at first fragmented into tiny lamellar-like sheets due to the high shear stress. Subsequently, at the end of the throat, droplets begin to develop. The lamellar structure of the liquid–gas mixture guarantees a high separation efficiency [3,4].

2. Experimental set-up

A scheme of the test facility is shown in Fig. 2. The fan sucks air from the environment and blows it through the experimental set-up. The gas flow rate $\dot{V}_G$ is measured by an orifice plate. Charging the gas with

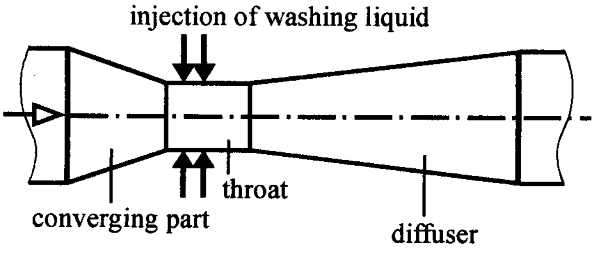

Fig. 1. Principle of a venturi scrubber.

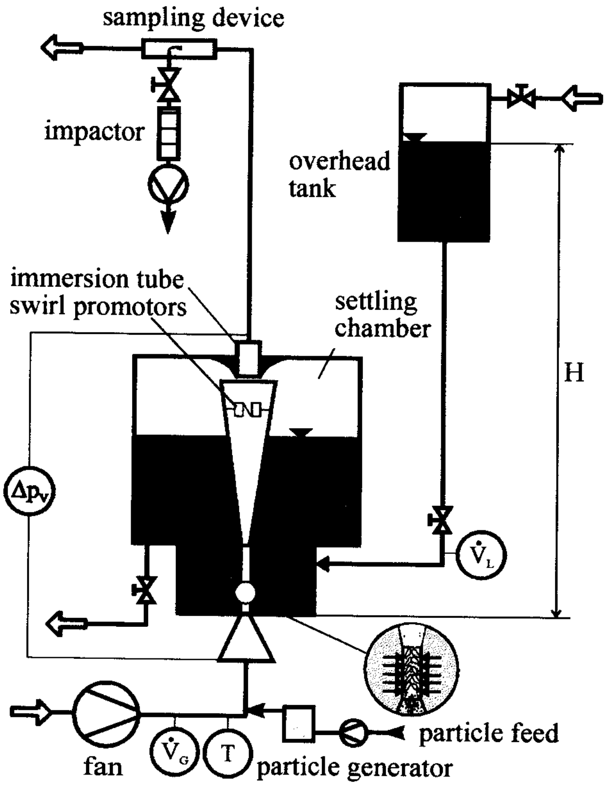

Fig. 2. Scheme of test facility.

tiny particles was accomplished by injecting titanium dioxide (TiO_2) into the loop. This substance was used as a test aerosol due to its very small particle diameters of 0.1–1.4 μm. The mean particle diameter was 0.8 μm.

The liquid is injected in several planes through cylindrical nozzles in the throat of the venturi which are located perpendicular to the gas stream. The throat of the venturi was rectangular in order to achieve a uniform distribution of the washing liquid over all the cross-section. Contrary to the usual design where the washing liquid is injected by a pump, the venturi scrubber in Fig. 2 worked in a self-priming mode. The washing liquid was injected due to a pressure difference Δp between the outside and inside of the venturi throat arising from the hydrostatic pressure of the liquid and the static pressure of the gas flow. The water was supplied from an overhead tank; the hydrostatic pressure would be varied by using different filling levels, H. The water flow rate $\dot{V}_L$ was measured by means of a magnetic flow meter.

The liquid droplets formed at the end of the throat were removed by means of an immersion tube in combination with swirl promotors in the diffuser section of the scrubber [5]. The swirl promoters increased the rotation of the gas–liquid flow, the droplets being thus pushed aside to the walls where they were dragged along to the end of the diffuser. They then deposited in the settling chamber. The gas which still contained a finite particle concentration escaped through the immersion tube.

For measuring the particle distribution and evaluating the fractional separation efficiency $\eta_F(d_P)$, a low-pressure impactor was used in which an isokinetic partial flow was sucked-off by means of a sampling device [6].

3. Results and discussion

3.1. Behavioir in self-priming operation

As is well known from the literature, the cleaning efficiency of a venture scrubber improves with the amount of liquid added per volume of gas and with increasing gas velocity in the throat [3,7,8]. However, high gas velocities and high charges of washing liquid cause large pressure drops. Hence the separation efficiency and energy consumption of the scrubber must be optimized. Consequently, it is of particular interest to understand the operating behaviour of the scrubber.

As described in Section 2 above, the scrubber worked in a self-priming mode whereby the liquid flow rate was not adjustable independently from the gas flow rate. This flow rate was rather a function of the gas velocity in the throat and the filling level H of the liquid in the overhead tank, as shown in Fig. 3. This figure shows that the liquid flow rate decreased with higher gas velocities in the venturi throat and could be enhanced significantly if higher filling levels were provided in the tank. This was due to an increased driving pressure difference between the outside and inside of the throat at higher filling levels. On the other hand, the static pressure of the gas rose with increasing gas velocity in the throat (Fig. 4). Hence, high filling levels and low gas velocities were favourable for achieving high liquid charges.

The pressure drop is the most important criterion from the economic viewpoint. It is well known that the pressure drop increases with higher liquid charges of the gas and with increasing gas velocities in the throat. Nevertheless, it was of interest to investigate which

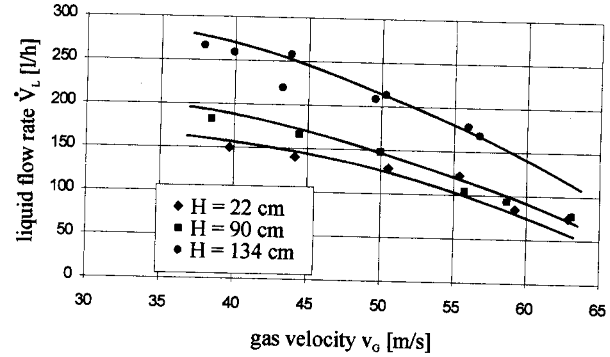

Fig. 3. Liquid flow rate $\dot{V}_L$ as a function of the gas velocity in the throat at different filling levels H.

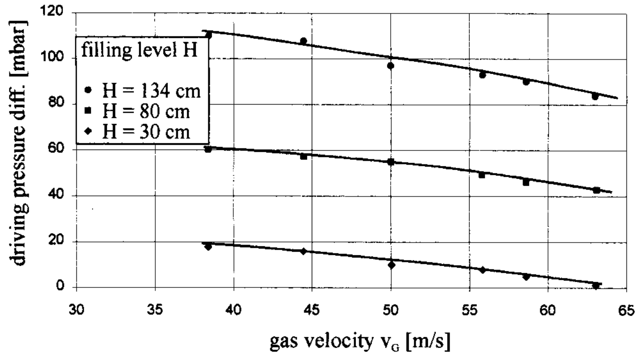

Fig. 4. Driving pressure difference between the outside and inside of the venturi throat as a function of the gas velocity and the liquid filling level.

operating conditions had a significant impact on the pressure drop.

Variation of the gas velocity in the throat significantly influences the pressure drop. Figure 5 reveals that an increase in the gas velocity from 40–60 m s^{-1} more than doubled the pressure drop. The figure also demonstrates that the pressure drop was about 10% lower using five-plane- instead of three-plane injection. This phenomenon was caused by a better liquid–gas ratio in each cross-section, because the same amount of liquid was divided up between five injection levels instead of three.

Increasing the liquid charge also increased the pressure drop as expected (Fig. 6). However, doubling the amount of liquid caused only a 15% increase in the pressure drop. Again one recognizes the same effect as can be seen in Fig. 5: the energy consumption was lower with five-plane injection relative to three-plane injection.

To sum up, one may conclude that as far as the pressure drop is concerned, an increase in the liquid charge is preferable to an increase in the gas velocity from an energy-saving point of view.

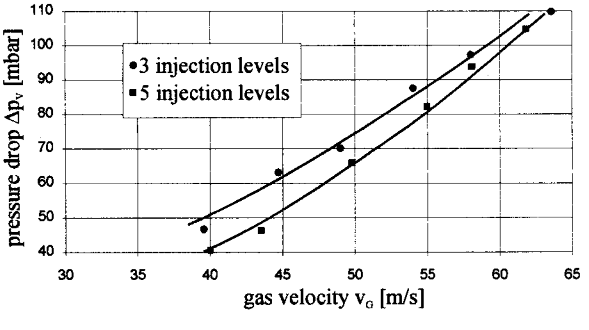

Fig. 5. Pressure drop as a function of gas velocity for a constant liquid charge L of 1 l m^{-3}.

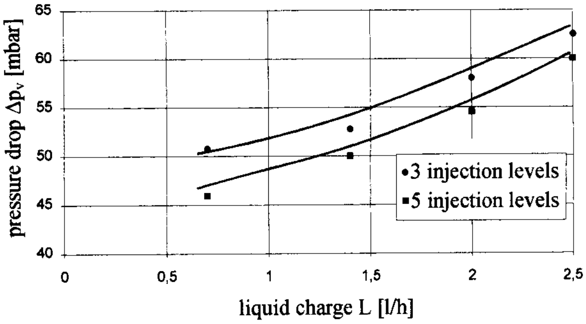

Fig. 6. Pressure drop as a function of liquid charge for a constant gas velocity v_G of 44 m s^{-1}.

3.2. Aerosol deposition in the venturi scrubber

Figure 7 shows the different operating conditions achieved for variable liquid charges resulting from different filling levels (see Fig. 3), but maintaining the gas velocity and injection geometry constant. Evidently, the fractional separation efficiency was significantly improved when higher liquid charges were imposed. This was due to the increase in the interfacial area for mass transfer at higher liquid charges. For five-plane injection, a near-mesh diameter d_{50} of 0.087 µm was accomplished.

The effect of variable gas velocity in the throat for a filling level of 145 cm and five injection planes is shown in Fig. 8. Optimum separation was achieved for the highest gas velocity. High gas velocities caused large relative velocities between the gas and the washing liquid immediately after injection, thus improving the separation efficiency. Good separation results were obtained even with the lowest imposed gas velocity as a result of the large liquid loading of 5.6 l m^{-3} due to the small static pressure in the throat (see Fig. 4). As mentioned above, the improvement in washing efficiency at high liquid charges may be attributed to the increased interfacial area for particle deposition.

In this context, it is important to point out that the separation efficiency was improved in the range of lower gas velocities without any control of the washing process from the outside, with high liquid loadings

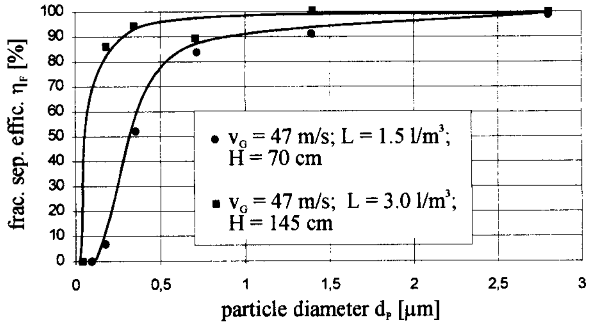

Fig. 7. Influence of different liquid charges on the fractional separation efficiency (five-plane injection).

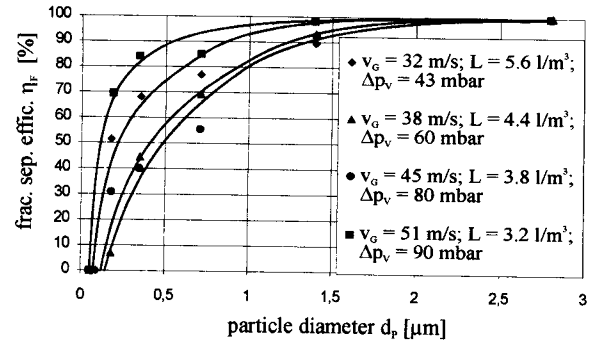

Fig. 8. Change in the fractional separation efficiency with decreasing gas velocity in the throat (five-plane injection).

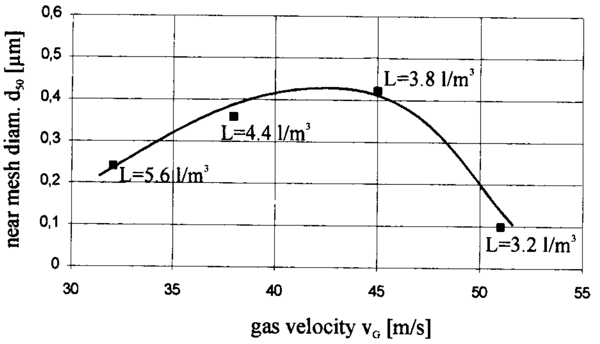

Fig. 9. Plot of near-mesh diameter versus gas velocity.

resulting automatically. Hence, a venturi scrubber operating in a self-priming mode works in a self-regulating fashion. Figure 9, in which the near-mesh diameter d_{50} is plotted against the gas velocity v_G in the throat, also illustrates this effect. The near-mesh diameter is equivalent to the diameter of those particles of which 50 mass% are separated. Initially the near-mesh diameter increased with decreasing velocity, i.e. the separation process was impaired. However, with a further decrease in the velocity, the washing efficiency improved once more as a result of higher liquid charges. This self-regulating behaviour is the main advantage of the venturi scrubber operating in self-priming mode, especially under transient working conditions [9].

From the operating behaviour, it may be concluded that five-plane injection is preferable to three-plane injection from an energy point of view. With regard to the separation efficiency, a significant improvement can be noticed with five-plane injection (Fig. 10). This results from the interaction of several factors:

1. As mentioned in Section 1, the liquid did not disintegrate directly into droplets but into a large number of sheet-like structures. Only towards the end of the throat were droplets formed. The greater interfacial areas of these lamellar-shaped sheets caused by renewed formation after each injection improved the separation efficiency.

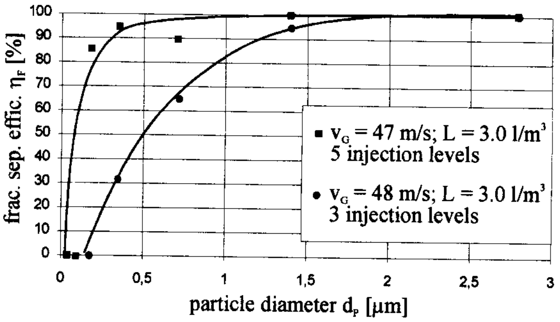

Fig. 10. Separation efficiency for three- and five-plane injection.

2. The high relative velocities between the injected liquid and the flowing gas enhanced the washing effect of the scrubber. By injecting the washing liquid in several planes, high relative velocities could be achieved continuously.
3. By staggering the nozzles between each injection level, a uniform distribution of the washing liquid was attained over all the cross-section of the throat, and liquid-free areas in the throat were reduced.

Hence, multistage injection provides an efficiency improvement in the design of venturi scrubbers.

4. Separation of the washing liquid

After the washing process, it is necessary to divide off the liquid droplets carrying the collected dust particles. For this purpose cyclone separators are usually employed. As described in Section 2, this investigation was carried out with an immersion tube in combination with swirl promotors in the diffuser section of the scrubber to increase the rotation of the gas–liquid flow. Due to their higher inertia, the droplets were pushed aside to the diffuser wall. Augmented from the parallel gas flow, the liquid film was carried along the wall to the end of the diffuser and deposited into the settling chamber. As reported by Azzopardi et al. [10], who observed the gas–liquid flow in the throat and diffuser section of a venturi scrubber optically, the liquid initially showed up in the form of droplets, which subsequently attached to the wall and formed a film there. The situation in the diffuser was similar to that observed during annular gas–liquid flow in vertical tubes.

In Fig. 11, the droplet separation efficiency, i.e. the separated liquid volume divided by the overall liquid volume injected into the gas flow, is plotted against the gas velocity in the throat. From the graph, which depicts measurements without swirl promotors, it can be seen that the separation efficiency improved with higher gas velocities. For velocities higher than 45 m s^{-1}, more than 90% of the injected liquid was separated. These observations confirm the assumption that the vast majority of the liquid flows as a film at the

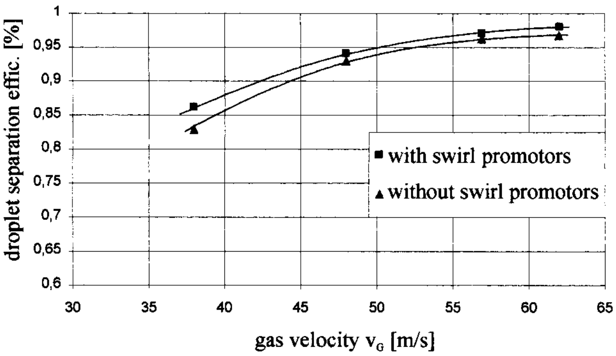

Fig. 11. Droplet separation efficiency versus gas velocity in the throat.

wall of the diffuser. Only a slight improvement in the droplet separation could be achieved if swirl promotors were located in the diffuser, and this was at the expense of an increase of 20% in the pressure drop.

5. Conclusions

From the above results, the following conclusions may be drawn:

1. Venturi scrubbers operating in self-priming mode are ideal for the separation of fine dust particles. Near-mesh diameters below 0.1 μm and pressure drops mainly below 100 mbar can be achieved.
2. The separation efficiency improves with high liquid loadings which can be realized via large driving pressure differences, i.e. high filling levels.
3. Multistage injection of the washing liquid is superior to single-stage injection from an energy-saving point of view as well as that of separation efficiency. A further increase in the number of injection levels is only advantageous where there is sufficient liquid supply per level, since the separation efficiency is most sensitive to the liquid loading.
4. It has been shown that under self-priming operation the liquid loading increases with decreasing gas velocity, i.e. a venturi scrubber operating in self-priming mode works in a self-regulating manner.
5. The injected liquid forms a film at the diffuser wall. About 90% of the liquid can be separated from the gas flow if an immersion tube is used.

Nomenclature

d_{50}	near mesh diameter, μm
d_P	particle diameter, μm
H	filling level of the overhead tank, cm
L	liquid charge ($= \dot{V}_L/\dot{V}_G$), $\mathrm{l\,m^{-3}}$
Δp	pressure difference between outside and inside of the venturi throat, hPa
Δp_V	pressure drop over the scrubber, hPa
v_G	gas velocity in the throat, $\mathrm{m\,s^{-1}}$
$\dot{V}_G$	gas flow rate, $\mathrm{m^3\,h^{-1}}$
$\dot{V}_L$	liquid flow rate, $\mathrm{l\,h^{-1}}$
η_F	fractional separation efficiency, %

References

[1] W. Sell, Staubabscheidung an einfachen Körpern und in Luftfiltern, *VDI-Forschungsh.*, *347* (1931).

[2] F. Mayinger and M. Neumann, Dust collection in venturi scrubbers, *Ger. Chem. Eng.*, *1* (1978) 289–293.

[3] K.D. Tigges and F. Mayinger, Experiments with highly efficient venturi scrubbers for aerosol separation from gases under multiplane water injection, *Chem. Eng. Process.*, *18* (1984) 171–179.

[4] H. Nomine, Untersuchungen zum Abscheideverhalten des Hochleistungs-Venturiwäschers, *Dissertation*, Universität Hannover, 1978.

[5] S. Muschelknautz, Mechanische Phasentrennung bei Entspannungsverdampfung, *VDI-Fortschritt-Berichte*, *Series 15*, *No. 71*, VDI-Verlag, Düsseldorf, 1990.

[6] VDI 2066, Staubmessung in skömenden Gasen. Gravimetrische Bestimmung der Staubbeladung, VDI-Kommission Reinhaltung der Luft, Düsseldorf, 1975, Blatt 1.

[7] K. Holzer, Naßabscheidung von Feinstäuben und Aerosolen, *Chem.-Ing.-Tech.*, *51* (1979) 200–207.

[8] K.D. Tigges, Untersuchung zur Schweißrauchabscheidung am Hochleistungsventuriwäscher, *Dissertation*, Universität Hannover, 1983.

[9] M. Lehner, U. Glückert and F. Mayinger, Aerosolabscheidung im Venturiwäscher mit mehrstufiger Eindüsung der Waschflüssigkeit im Selbstansaugbetrieb, *Chem.-Ing.-Tech.*, *65* (1993) 1355–1357.

[10] B.J. Azzopardi, S.F.C.F. Teixeira, A.H. Govan and T.R. Bott, An improved model for pressure drop in venturi scrubbers, *Trans. Inst. Chem. Eng.*, *Part B*, *69* (1991) 237–245.

INSTRUCTIONS FOR AUTHORS

Submission of Papers

Three copies of the manuscript and relevant correspondence should be sent either to the Editor-in-Chief or one of the Associate Editors, for postal addresses see the inside front cover.
Contributions are accepted on the understanding that authors have obtained the necessary authority for publication. Submission of an article is understood to imply that the article is original and unpublished and is not being considered for publication elsewhere. Upon acceptance of an article by the journal, the author(s) will be asked to transfer the copyright of the article to the publisher. This transfer will ensure the widest possible dissemination of information.

Language

Papers will be published in English. *Synopsis*, To authors whose mother tongue is not English, the opportunity is offered to have their paper accompanied by a Synopsis in their own language of two to three manuscript pages. The *Synopsis* shall refer to equations, Figures and Tables in the main text. It will appear following the Abstract and preceding the Introduction.

Manuscript Preparation

Three copies of the manuscript should be submitted in double-spaced typing on pages of uniform size with a wide margin on the left.
Some flexibility of presentation is allowed, but authors are urged to arrange the subject matter clearly under such headings as *Introduction*, *Experimental*, *Results*, *Discussion*, etc.
All manuscripts should include an *Abstract* of 50–200 words.
References in the text to be published literature should be given by numbers in square parentheses on line, and these references should be listed together in the Reference section at the end of the article in the order in which they occur in the text. Double spacing, as for the main text, should be used throughout. The preferred conventions for references are illustrated by these examples:

[1] A. W. Nienow, Agitated vessel particle-liquid mass transfer, a comparison between theories and data, *Chem. Eng. J.*, *9* (1975) 153–60

[2] J. O. Hinze, *Turbulence*, McGraw-Hill, New York, 2nd edn., 1975, pp. 223–225.

[3] J. Yerushaimi, M. J. Gluckman, S. Dobner, R. A. Graff and A. M. Squires, in D. L. Keairns (ed.), *Fluidization Technology*, Vol. 1, Hemisphere, Washington, DC, 1976, p. 437.

Articles not yet published should be given as 'in press', 'submitted for publication', 'in preparation' or 'personal communication'.
Abbreviations of journal titles should conform to an international standard, as adopted by the Chemical Abstracts Service in the *Bibliographic Guide for Editors and Authors*, American Chemical Society, Washington, DC, 1974.
Nomenclature and Units: Nomenclature and abbreviations should conform to those most commonly used in the field concerned. All units should be SI. Where existing conventions or industrial practice indicate that other unit systems be used, the equivalent SI values must be given in parentheses. When these are omitted, manuscripts will be returned to authors to be rectified. All Greek letters and unusual technical symbols, when they first occur in the manuscript, should be explained in the margin.

A list of symbols must be supplied for each paper, including the meaning of any indices used. Where necessary, the definition of a physical quantity in terms of other quantities should also be given. In particular, this applies to dimensionless groups such as the Reynolds number for which the characteristic linear dimension or the reference temperature for the physical properties can be in doubt. When an adequate definition cannot be given in the Nomenclature, a reference to the text, where a definition can be found, should be given instead.

Illustrations. Line drawings should be in a form suitable for reproduction, drawn in Indian ink or drawing paper. They should preferably all require the same degree of reduction and should be submitted on paper of the same size as, or smaller than, the main text to prevent damage in transit. Each illustration must be clearly numbered. Legends to the illustrations must be submitted in a separate list.
All tables and legends should be numbered consecutively and separately throughout the paper.
Authors in Japan please note that information about how to have the English of your paper checked, corrected and improved (*before submission*) is available from: Elsevier Science Japan, 20-12 Yushima 3-chome, Bunkyo-ku, Tokyo 113; Tel: +81 03 3833-3821; Fax: +81 03 3836-3064.

Proofs

Authors will receive proofs which they are requested to return as soon as possible. No new material may be inserted in the text at the time of proof-reading.
All joint communications must indicate the name and full postal address of the author to whom proofs should be sent.

Further information

All questions arising after the acceptance of the manuscript, especially those relating to proofs, should be directed to: Elsevier Editorial Services, Mayfield House, 256 Banbury Road, Oxford OX2 7DH, UK (tel. +44 1865 314900; fax. +44 1865 314990).

Reprints

Twenty-five reprints of each paper will be supplied free of charge to the author(s). Additional reprints can be ordered at prices shown on the reprint order form which accompanies the proofs. There are no page charges.

Abstracting Services

Articles in this journal will be indexed and abstracted by Chemical Abstracts, Chemical Engineering Abstracts, Current Contents, Engineered Materials Abstracts, Engineering Societies Library, INSPEC, International Pharmaceutical Technology and Product Manufacture Abstracts, International Powder and Bulk Solids Abstracts, International Process Technology Abstracts, Material Business Alerts, Metals Abstracts, PASCAL M (C.D.S.T.), Science Abstracts, Verfahrenstechnische Berichte, and World Aluminum Abstracts.

Printed in The Netherlands