AUTOMATED SHOTCRETE TECHNIQUES ARE IMPROVING THE WORKING CONDITIONS

Dipl-Ing. Univ. Rudolf Scholbeck
Director of the Technical Inspection Service of the Tiefbau-Berufsgenossenschaft and
Head of the "Civil Engineering" Technical Committee
Am Knie 6, D-8000 Munich 60

SUMMARY

Employees in the construction industry are exposed to exceptional physical burdens and accident and health risks. Extensive research projects conducted in the past or currently in progress have provided practical solutions for reducing these burdens and hazards.

Shotcreting is used here as an example to demonstrate how improvements in equipment and the development of new construction processes and building materials can play a crucial role in humanizing working conditions. The use of remote-controlled systems and the state of development of a robot for applying shotcrete are described.

1. PROTECTION OF EMPLOYEES IN THE CONSTRUCTION INDUSTRY

1.1 REVIEW

The accident rate in companies in the construction industry is still disproportionately high in comparison with the rest of industry. Statistics show that one person in 8 employed in construction will suffer an injury at work during the course of a year.

If one observes the accident statistics over a long period it becomes apparent that the further development of construction processes and the technical perfection of building equipment, coupled with the growing safety awareness of employees have also resulted in a marked reduction in the accident risk on construction sites. This trend must not, however, be allowed to hide the fact that the accident rate in the construction industry is still twice as high as the average for other branches of the economy.

This can be explained at least in part by the special conditions applicable to the construction industry. In contrast to factory production, construction objects must generally be purpose-built as individual items. Series production is only possible in construction in exceptional cases. Building production is heavily dependent on external influences and factors. Weather and building land can be quoted here as examples. It must also be mentioned that severe fluctuations in the economy have often meant that it was not possible to employ qualified personnel on a permanent basis. Many experienced construction workers have therefore moved permanently to other industries. There is now evidence of this shortage of skilled workers everywhere in the construction sector. The employment of inadequately trained workers can also be one of the reasons for the higher accident risk.

1.2 EXPOSURE TO HAZARDS ON CONSTRUCTION SITES

Work on construction sites is frequently associated with particular forms of stress. Employees often perform heavy physical work. When working outdoors they can be exposed to heat, cold and wet and they also face additional pollution in the form of dirt, noise and dust. As extreme examples of the range of activities in this industry and consequently of the particular types of stress encountered, one could mention working at great heights, for example on the construction of television towers or bridges or work underground in tunnelling.

The use of efficient construction machines has to some extent substituted mechanical power for heavy physical labour. Working with these machines can, however, create additional accident risks.

Another major problem area on which those of us concerned with the safety of employees are working intensively are the risks involved in handling dangerous materials. Construction workers are particularly exposed to pollution in two forms here.

Firstly, among the materials used in construction work there are some which release gases, dust or vapours which are harmful to the health or can cause diseases on contact with the skin. Paints, adhesives, concrete additives and other such materials are examples of these. When working with various building materials such as quartzose rock or beechwood, particles are released which have been proved capable of causing serious, often fatal occupational diseases in humans. The problems caused by the careless handling of asbestos in the construction industry up until a few years ago are now generally familiar.

Secondly, in addition to the risks arising from working with building materials, it must be borne in mind that construction work frequently has to be carried out in contaminated areas. Harmful substances in building structures or in the ground have to be removed and disposed of. Construction workers may, for example, be given the job of removing sprayed asbestos from schools, gymnasiums and swimming pools, repairing leaking sewerage pipes or disposing of contamination at former waste dumps.

Many of these hazards can be avoided or at least reduced if appropriate personal protective equipment is provided and used at all times. The aim of development in the field of industrial safety cannot and should not be, however, to develop more and more sophisticated protective clothing or breathing equipment which are an additional burden to workers wearing them. We must rather concentrate on finding technical solutions which enable the required work to be performed in the danger area without the direct deployment of people. For this reason automatic, remote-controlled systems will become increasingly important in the construction sector as well in the future.

1.3 FUNCTIONS OF THE STATUTORY ACCIDENT INSURANCE INSTITUTES

Under the provisions of German social security legislation, the Berufsgenossenschaften (statutory accident prevention and insurance institutes) have responsibility for "using all suitable means to prevent industrial accidents".
The Tiefbau-Berufsgenossenschaft (statutory insurance institute for the civil engineering industry) encompasses the companies in Germany involved in civil engineering. The TBG has taken overall charge of the "Civil engineering" technical committee at the Association of Industrial Berufsgenossenschaften. Its tasks include the elaboration of accident prevention regulations, advising equipment manufacturers and operators in matters of safety and testing technical working materials under the equipment safety legislation. The visible sign of this test is the award of the GS safety mark.

The employees in the "Civil engineering" technical committee also play an important part in standardization work in Europe and worldwide in CEN and ISO respectively. All these efforts are aimed at protecting employees in the construction industry against accident risks and to reduce the stresses to which they are exposed to a humane level commensurate with present day technology.

As part of its work of accident prevention the TBG puts forward suggestions for research work which it carries out jointly with institutes, machine manufacturers and construction companies. Several research projects have been conducted in the field of shotcreting in particular. Details of the results of these projects are given in the following.

2. SHOTCRETING - STATE OF DEVELOPMENT

2.1 PRINCIPLES

Shotcrete is a construction material employed in many areas of building construction and civil engineering. It is used, for example, to stabilize rock walls and embankments, to line the sides of excavations, to construct thin-walled plane load-bearing structures using minimum formwork or to repair or reinforce existing in-situ concrete elements.

For some years now one of the main areas of application for shotcreting has been in tunnelling where it is used to safeguard against flaking of the roof by providing a support which resists the rock pressure. The importance of the shotcreting process for tunnelling is demonstrated by the fact that this technique was employed exclusively for the two new routes of the German Federal Railways which together total more than 130 km in length.

The shotcreting method has been improved continuously during its more than eighty years of evolution.
Innovations in the field of machinery and concrete technology have helped shotcrete to reach technical and qualitative perfection and made its use economically competitive. If we look at the working conditions prevailing during the use of shotcrete the question, however, arises whether this method meets today's requirements as far as the protection of employees against accident and safeguarding of their health is concerned.

2.2 POTENTIAL HAZARDS

The basic principle common to all shotcreting methods is the acceleration of the concrete components - aggregate, cement and water - in a nozzle by means of compressed air. The material is propelled through the air for a short distance (about 1 to 2 m) before striking the rock, formwork or an existing structural element. The fresh concrete is compacted on impact. Additives known as accelerators are usually added in order to improve bonding and initial strength which is necessary primarily when spraying on vertical walls and spraying overhead.

There are essentially two work areas in shotcreting which require especially critical examination: These are firstly the workplaces at the shotcreting machine where in the traditional process dry mixture is transloaded, mixed with additive and put into the conveyor machine. Investigations of the breathing air have shown that the possibility cannot be ruled out that the limit values for dust and particularly fine silicogenous dust will be exceeded (fig. 1).

From the shotcreting machine the mixture is conveyed in pipes and hoses to the placement point. At the end of the hose is a nozzle which is generally held by hand and pointed at the placement point.

The workplace of the nozzle operator is exposed to several hazards. Here too, high concentrations of fine dust occur and holding and directing the heavy nozzle/hose combination involves strenuous physical exertion which is further aggravated by the pump surges. When working with shotcrete in tunnelling the nozzle operator has to stand in the vicinity of the freshly exposed rock before it is secured. The risk of rock cave-ins cannot be eliminated even with careful control and observation.

The nozzle operator is also at risk from ricochet, primarily when shotcreting overhead but also when placing the shotcrete on the wall. When the concrete strikes at high velocity, individual aggregate particles and sometimes also larger lumps of concrete ricochet back and can hit and injure the operator. The high level of noise at the shotcreting nozzle and the hazards arising from the fact that the nozzle operator frequently has to use unstable surfaces or piles of heaped earth as a work platform, thus exposing himself to further risks, should be mentioned to provide a complete picture of working conditions during shotcreting.

Cement and above all the shotcrete additive are highly alkaline in an aqueous solution. The risk of skin burns, allergies and injury to the respiratory organs cannot be ruled out.

2.3 RESEARCH PROJECTS IN THE FIELD OF SHOTCRETING WORK

As shotcreting became more widely used, these shortcomings with regard to the protection of employees as well as problems relating to the quality and cost-effectiveness of the process increasingly became the subject of discussion. The strength of the concrete after placement is influenced to a large extent by the proportion of water and additive in the mix. In the traditional dry shotcreting method this proportioning is performed more or less "by feel" by the operators at the shotcreting machine and the nozzle. Pumping pressure, spray angle between the nozzle and application surface, spraying distance and the motion of the nozzle during application of layers are crucially important for quality but equally important as regards rebound. Rebound refers to that part of the sprayed shotcrete which by the nature of the process fails to adhere at the application point and falls to the ground as waste. If a nozzle operator working in dust and noise has to concentrate all the time on not being hit by rebounding material or slipping off a highly unsuitable work platform, he will scarcely be able at the same time to ensure that he holds the nozzle at the optimum distance, angle etc.

Partly for safety reasons, but also to improve the quality and cost-effectiveness of shotcrete applications it was therefore necessary to develop solutions in which work was automated as far as possible.

The now completed research project "Improvement of workplaces in tunnelling by mechanizing the dry shotcreting process" produced important findings which have already been published and have been applied in practice. Following on from these findings, a further research project was started in 1987 in which the use of shotcreting robots to optimize the shotcreting process is being investigated.

2.4 STATE OF DEVELOPMENT

Up until a few years ago the market was dominated by the dry shotcreting process in which dust is released in all conveying and transloading operations. The period since then has seen an increase in the development of machines which allow "factory-premixed" normal concrete to be used for shotcreting. The result of this is that the composition of the concrete is preprogrammed on a mixing machine and mixing "by feel" is avoided. Naturally the amount of dust released in this method is considerably reduced. However, contrary to original expectations, fine dust also occurs in wet shotcreting in the vicinity of the nozzle although, depending on the method, the dust concentration is substantially reduced compared with dry shotcreting.

Another source of dust now as in the past is accelerator additive in powder form, a highly alkaline substance which was for a long time added directly at the shotcreting machine by hand with a trowel. Proportioning devices have now been developed which allow this powder to be added in precise quantities according to preset formulations and above all without producing dust.

To facilitate the use of additives and at the suggestion of industrial safety inspectors, liquid additives have been tried. These require considerably less complicated proportioning equipment than powdery agents.

2.5 MECHANIZED NOZZLE OPERATION

All these developments have contributed to making workplaces in shotcreting safer. They were not, however, suitable for solving all existing problems satisfactorily. In the first place the nozzle operator is still exposed to particular hazards and burdens. It was to reduce these that shotcreting equipment was developed as long ago as the beginning of the 1960s in which the nozzle was no longer operated manually but by remote-controlled spray manipulators. Shotcreting arms operated by cable or by hydraulic means were mounted on lorry chassis, thus allowing the machine operator to direct the nozzle while standing on a platform in the section of the tunnel which had already been secured (fig. 2). This solution did not gain acceptance for many years, however, at least not in German-speaking regions. The reasons for this were primarily inadequacies in the equipment and the considerably higher cost compared with conventional solutions.

With the construction of the new routes for the German Federal Railways from the mid-1980s onwards came an increase in the use of remote-controlled systems in Germany as well. With these systems, shotcreting nozzles mounted on excavators or special carrier devices can be controlled from the ground via a portable remote control or from a cabin which moves with the supporting structure. The nozzle operator has only light physical work to perform and dangers arising from ricochet or rock cave-ins are significantly reduced. The ability to operate more powerful and heavier shotcreting machines continuously with this equipment also means that considerably higher performances can be achieved with spray manipulators than with manual shotcreting.

These modern systems also require the operator to stand close to the placement point since he has to constantly check and correct the spray direction and the nozzle distance. Consequently he is still in an area which is exposed to dust pollution. This and the efforts to further improve the quality of the shotcrete were the motives behind the development of automatic systems for nozzle operation.

2.6 AUTOMATIC NOZZLE OPERATION

The Department of Construction Engineering and Construction Management at the Ruhr University in Bochum under Prof. B. Maidl and the Tiefbau-Berufsgenossenschaft in collaboration with the Study Company for Underground Traffic Systems, Cologne, began a research project into this in 1987 with the backing of the Federal Ministry for Research and Technology. A comprehensive series of tests on the shotcreting test stand at the Ruhr University in Bochum - the subject of another paper to be read at this symposium - has now been followed by the first successful application under site conditions of the shotcreting robot developed (fig. 3).

From the point of view of the safety of employees the findings made about the fine dust concentration were of particular interest. Above all the motion of the shotcreting nozzle has a considerable influence on the fine dust concentration. Circular movement of the spray nozzle reduces the fine dust concentration by up to 15% compared with holding it rigidly. Varying the distance of the nozzle from the placement point resulted in lower fine dust concentrations as the nozzle distance increased. Since the concrete compressive strength which can be attained depends very greatly on this nozzle distance, it is generally necessary to keep to a distance of about 1.5 m at which value a compromise is reached between dust reduction and concrete quality.

The tests have also indicated that fine dust concentration depends essentially on the expansion of the shotcrete jet and the intensity of the indicated flow. The fine dust concentration C_F is therefore shown in figs. 4 a+b as a function of the radial acceleration of the shotcrete jet a_r and of the nozzle distance a_D. Dust reductions of up to 40 mg/m^3 were detectable when the nozzle was operated at optimum efficiency. This is equivalent to a halving of the maximum dust concentration detected.

All trials with the shotcreting robot carried out to date have been made with an industrial robot modified for this application. They have provided valuable information for the development of a machine which will have to be specially designed to meet the needs of the construction industry. But even the use of a robot which was originally designed for other purposes has shown that robots in tunnelling no longer belong to the realm of science fiction. We hope that the initial success of this project will provide the opportunity and incentive for further investigations in this field.

3. SUMMARY AND OUTLOOK

The example of shotcreting has been used to demonstrate that improvements in the areas of "quality", "economy" and "protection of employees" can be developed in parallel in this special field of construction engineering. This joint approach will facilitate our task of further developing work processes which will benefit employees.

Shotcreting is only one of many areas of construction in which automatic systems can, and from the point of view of the protection of employees must be employed. I would like to mention the following areas while making no claims to completeness:

- the construction of underground pipelines using the microtunnelling technique,
- repair of existing pipeline networks by remote-controlled inspection and repair machines without deploying personnel in the pipe,
- remote-controlled or automated operations in contaminated areas, e.g. disposing of asbestos or at waste dumps,
- processes for demolishing irradiated parts of shut-down nuclear facilities or
- using robots to replace divers or instead of working in compressed air.

Initial trials of all these processes in practical applications have been successful although development has not been finalized in any cases. The common endeavour of all those involved in construction, in other words the client, the research institutions, machine manufacturers and construction companies must be to follow up these initial solutions in the interests of employees and to apply them more intensively. We at the Berufsgenossenschaft pledge our support in this task.

4. REFERENCES

- Patent specification 1232182 /Date of application 1st March 1961, AB Skanska Cementgjuteriet, Stockholm
- Maidl, B u.a.: Spritzbetonarbeiten im Berg- und Tunnelbau, Essen: Verlag Glückauf, 1987
- Maidl, B. u.a.: Industrierobotereinsatz in der Spritzbetonforschung; BMT 1 (February 1989), pp. 5 - 8
- Maidl, B. u.a.: Erster Einsatz eines Spritzroboters in der Praxis (unveröffentlichtes Manuskript)
- Maidl, B: Spritzbetonroboter im Tunnelbau; VDI-Bericht Nr. 800: VDI-Verlag, 1990
- Poppy, W.: Warum braucht die Bauwirtschaft Mikroelektronik und Automatisierung ?: VDI-Jahrbuch 1990; Düsseldorf: VDI Verlag 1990.

Quartz content (% by weight)	German TLV (mg/m^3)	dust specification
$Q < 1$	6.0	General dust limit (fine dust limit)
$1 \leq Q \leq 3.75$	4.0	Fine dust containing quartz
$Q > 3.75$	0.15	Fine quartz dust

Fig. 1: German Threshold Limit Values (MAK-Werte) for dust

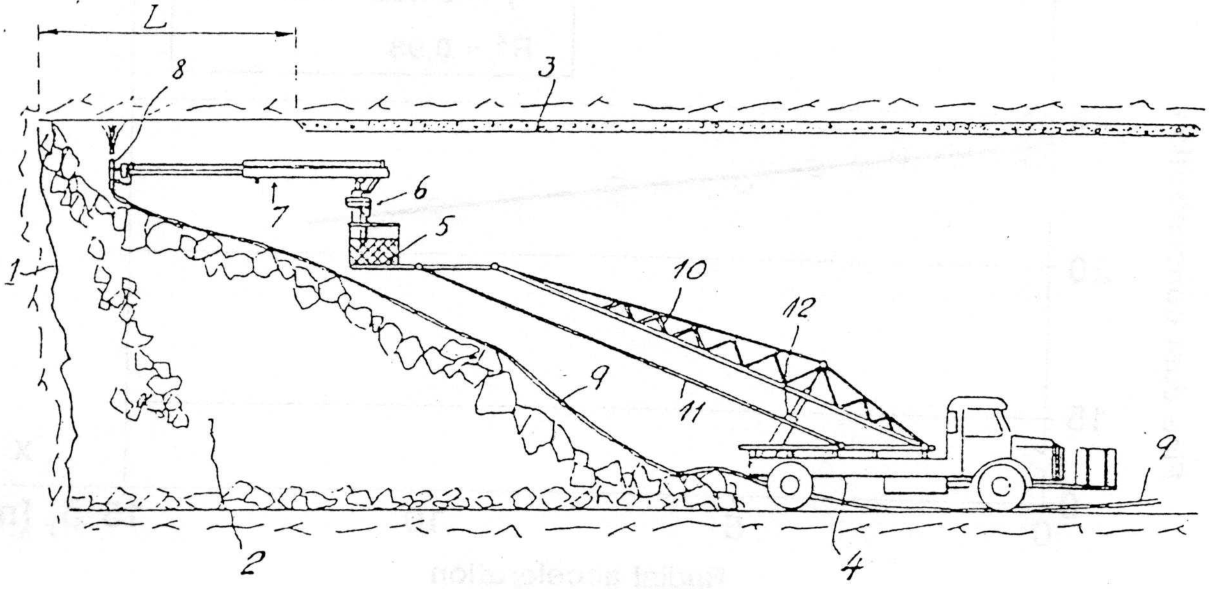

Fig. 2: Shotcreting arm mounted on a truck chassis (1961)
(4-carrier vehicle, 5-platforme, 8-nozzle)

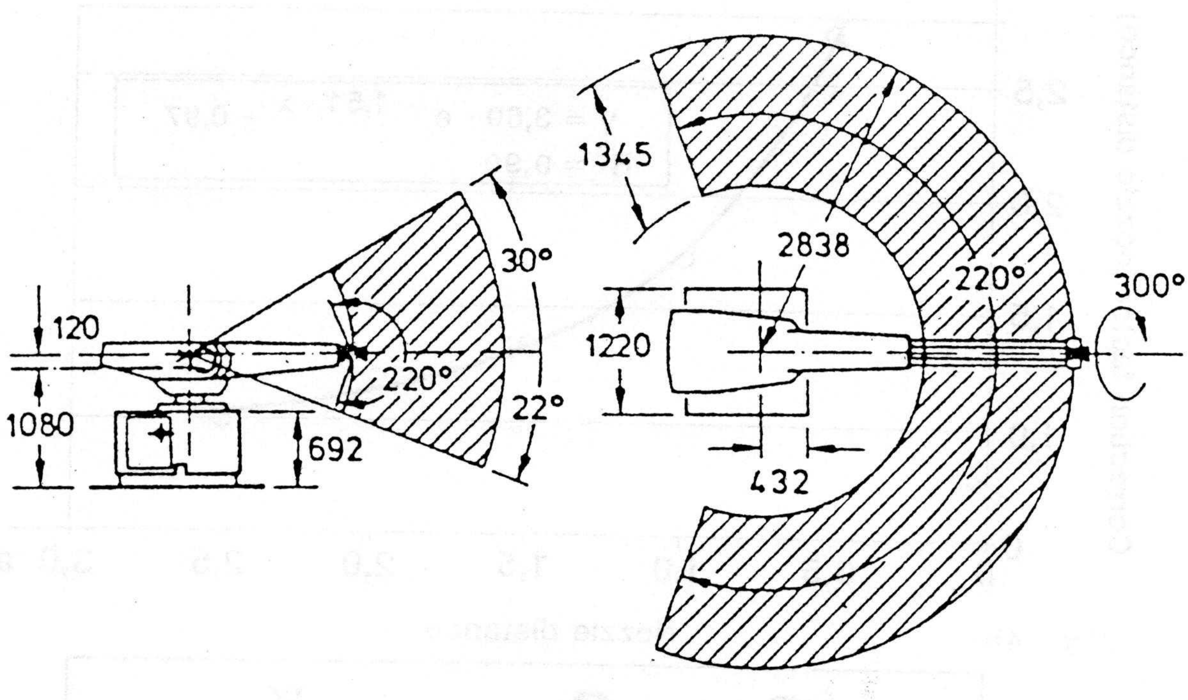

Fig. 3: Industrial robot Unimat 2105 G

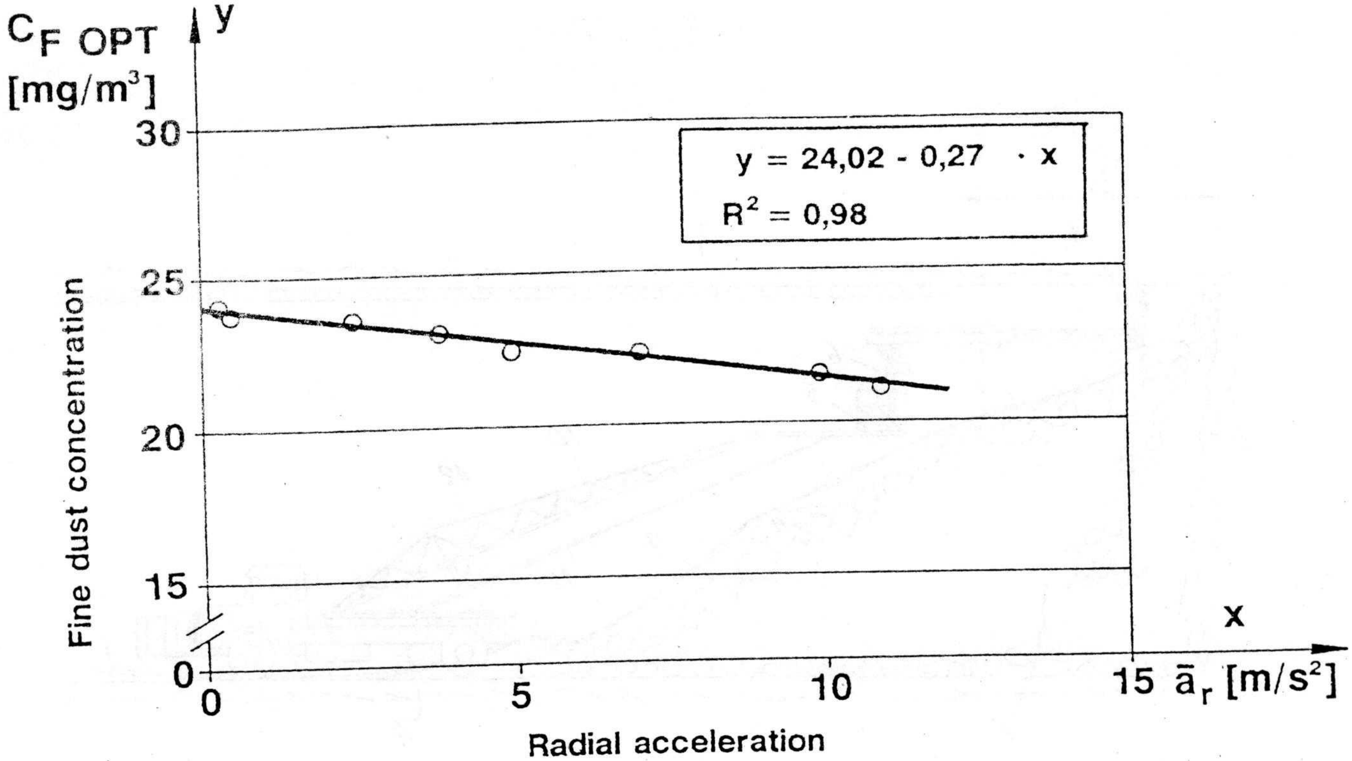

Fig. 4a

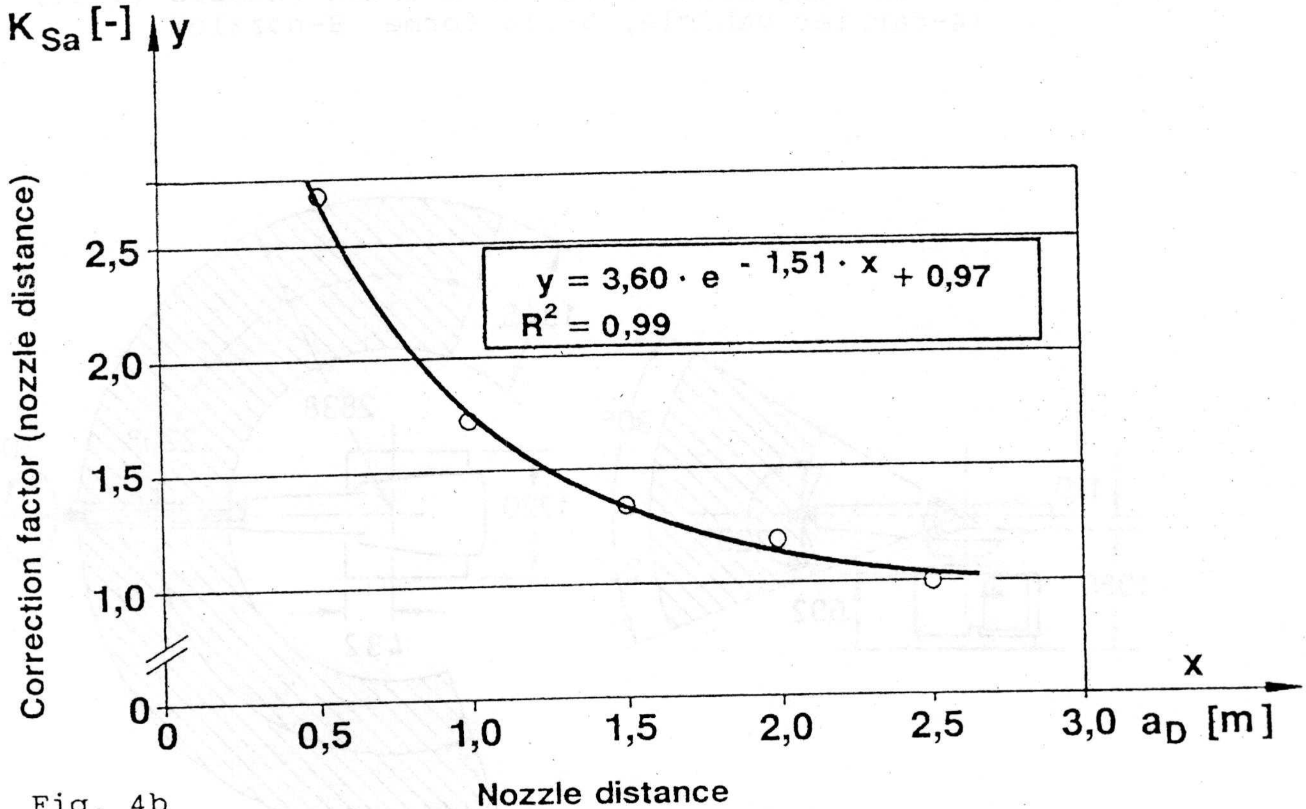

Fig. 4b

$$C_F = C_{F\,OPT} \cdot K_{Sa}$$

Fig. 4: Influence of nozzle operation on the fine dust concentration