MODERN FABRIC FILTER TECHNOLOGY FOR CLEANING GASES FROM FERRO-ALLOY FURNACES

By S. Strangert*
(presented by Mr. Strangert)

SYNOPSIS

The story of fabric filtration of ferro-alloy fumes illustrates the general development of common types of filters and fabrics since the 1960's.

Beside the traditional bag house type filters, pulse jet cleaned filters are now employed, requiring between a half and a third of the filter area for a given gas flow when compared to bag house filters. This has been achieved through improvements in the filter design - method and control of cleaning, gas distribution in the filter - as well as by application of recently developed Nomex and glass fabrics.

For a typical case of ferro-silicon fume filtration, installation and operating costs are about the same for the two types of filter over a ten year period. The choice between the two is discussed further with regard to fan selection, space requirement, and maintenance aspects.

BACKGROUND

When filter fabrics from manmade fibres gained a more wide spread use in the 1960's, cleaning of gas emitted from ferro-alloy furnaces became one of the first applications for fabric filtration at a large scale. Alternative technologies available - wet scrubbing and electrical precipitation - had demonstrated certain drawbacks which ended up in cost figures in favour of fabric filtration in some demanding ferro-alloy operations.

It goes without saying that development of fabric filtration technology has been closely, but not exclusively, connected to evolution or break-through in the filter fabric technology. The design of a fabric filter must always start from its prime component, the filter element. This fact should come through in the following also if the discussion will be based on state of the art and future trends rather than on history.

The range of ferro-alloy processes which will be dealt with is limited to the production of the various ferro-silicon alloys up to Si-metal, and to ferro-chrome of different grades.

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Filtration concepts

By design and operating mode, for filter media in use could be characterized either as surface or as depth filtering.

This basic distinction is dictating the entire design and operation of the corresponding types of filters, and the following discussion will mainly deal with a comparison of the performance of the two types in ferro-alloy fume filtration.

The first type of fabric collects the particles on the surface in a relatively dense deposit well separated from the medium which serves as a substrate from which the dust cake is removed mainly by scaling. The fabric could be either a supported membrane, a weave or needle felt. If needle felt is applied, particle collection in this case has to be restricted to the surface of the fibrous structure by suitable surface properties and low filtration velocity. At cleaning the filter section must be taken off stream. The cleaning, carried out either through reverse flow, which relies on shear forces created by bag deformation, or shaking where moderate mass forces overcome cake-to-fabric adhesion must be well distributed over the filtering area. Non-uniform cleaning patterns would give corresponding variation in filter resistance and consequently local penetration; particle penetration is strongly dependent on filtering velocity since diffusion is a major collection mechanism.

When the second type of filter and filter medium is applied, the depth filtration concept is fully utilized. Particles adhere to the individual fibres through the depth of the medium to form a dentritic structure. This mode of filtration in fact relies on the possibility to maintain the high porosity of this fibre-like structure. If that is not achieved the medium - the needled, mostly scrim supported felt - will instead act as a reinforcement to the ever increasing dust deposit resulting in high pressure drop, high local penetration and mechanical damage of the material.

The filter elements, outside filtering bags on a supporting cage, are therefore cleaning by an inside jet pulse, accelerating the bags to give a snap-back accelération of a few hundred g, enough to overcome particle to fibre adhesion. Cleaning of a part of the bags in a filter section can be done while the remaining part is still filtering.

To sum up, combinations of these concepts have today crystallized into the two main groups of filter often referred to as low and high ratio filters respectively. Table 1 gives the main features of the two groups including range of typical operating data. The figures 1 through 3 show some filter installations at silicon metal, ferro-silicon and ferro-chrome plants.

Filter media - limitations, requirements and possibilities

Selection of durable filter media for this in some respects difficult application must take chemical and textile considerations into account, based on the following process conditions.

- Particulate. Little agglomeration before collection, sub-micron size, static change build up.

- Gas temperature. Range from 120^{o}C on low side (open hooding, low furnace load), through 180^{o}C (open hooding, FeSi, normal operation) up to 280^{o}C or more (Si metal production or after cooling of gases from semi-closed furnaces).

- Gas composition. Various concentrations of water vapour, sulphur oxides, fluorides.

  Possible fibres constituting applicable fabrics and which have been tried over the years are polyester, polyacrylic, aromatic polyamide and glass. Other available fibres are limited in temperature or chemical resistance, or in economics.

- Polyacrylic offers good resistance against temporary acidic conditions but requires back-up gas cooling, must be carefully heat stabilized and protected from large mechanical stress to avoid creep and stretch.

- Polyester could operate without gas cooling in some cases but is prone to hydrolysis if certain metals are enriched in the fabric and peaks in sulphuric acid concentration occur in cycling operation.

- Aromatic polyamide, with Nomex as one wellknown trade name, has heat resistance to cater for gases from open FeSi furnaces without additional cooling, but suffers from acid attack unless protected by some additional fibre/fabric treatment.

- Glass which became available for filtration use only after coatings protecting the brittle fibres were developed.

All of these fibres could to-day be processed into woven or needle felt media, suitable for any of the two main types of filters. The high temperature capacity of aromatic polyamide and especially glass has stimulated to considerable work to further improve the treatments of these fibres.

For some time aramide fabrics have been available, which through physical and chemical treatment can operate with such a tough gas composition as 800 - 1000 ppm SO_2 and 10 percent water vapour, and with sulphuric acid dew points up to 110 - 120°C, still with an acceptable service life.

A few media manufacturers have also succeeded to make a durable needle felt from glass fibre, and others are to follow. The success relies on the use of especially fine fibres which can stand the needling operation. After a heavy temperature resistant impregnation is applied, the brittleness of the fibre is overcome and the fabric with a fine porous structure can be used as synthetic needle felt in pulse jet filters although with a somewhat lower filter velocity. This approach is interesting as inorganic fibres are expected to be more price stable than petroleum based synthetic fibres.

Evaluation of various fabric candidates is a time consuming job. Chemical degradation might be simulated, and thus accelerated, in the laboratory. Physical degradation however is best studied in the field, if erroneous scaling up shall be avoided. Continuous follow-up of fabric in use with testing of residual strength and filter resistance in service are useful tools in the screening of possible filter media.

Filter systems - development trends

A traditional ferro-alloy filter system comprises a combined precollector-spark arrestor, or - if the furnace is of the semi-closed type - of some type of gas cooler, a low ratio filter - bag house - equipped with glass fibre or Nomex bags, a fan, ducting, some sort of stack and a dust handling system.

To lower fixed costs in the filter construction the development has led to large size of the filter bags as well as of the filter sections. Because of the high pressure drop over the filter medium - an inherent condition in the process, unless very low filtering velocities are selected - this design approach has very often resulted in the selection of overpressure filters, with the main fan upstream the filter. The pressure differential upstream as well as downstream the fans is limited and the only parts of the filter subject to overpressure are the inlet duct and the dust hoppers.

However, operation of a fan with dust loaded gas is not without problems. To avoid excessive wear and clogging of the fan wheel this must be designed with straight vanes, which leads to low efficiency and increased need for service.

If the common method of reverse flow cleaning is employed, the reverse flow fan has to operate with gas which is heavily dust laden, which creates the same potential problems as for the main fan. These problems are reduced but not eliminated if shaker cleaning - with a special fan for the flow collapsing the bags - is utilized.

Not surprisingly, the clear trend observed in the application of pulse cleaned filters to more and more demanding processes has been a challenge to introduce this filter concept also to ferro-alloy fume filtration. The objectives and facts behind this are among others:

- High ratio filters occupy less ground area and could often be fitted into available space closer to the furnace, with means less ducting.

- High temperature filter media with the required chemical resistance are developed.

- High ratio pulse cleaned filters can without large increase in cost be built for under-pressure operating, which permits high efficiency fans with little needs for maintenance to be located downstream the filter.

- Increased dust load in the gas from semi-closed furnaces does not need to be considered for the fan selection.

- Filter bags can be replaced in a better controlled working environment especially if single sections of the filter shall be serviced.

The problem which had to be faced and solved if the advantages of high ratio filtration were to be demonstrated were principally:

- Blinding of the depth filter medium due to inappropriate cleaning procedure, leading to premature bag replacement.

- Rapid chemical degradation of the filter media.

While the solutions found by media manufacturers within the latter problem area have already been described a few notes should be made on the nature of the first one.

The filter resistance, or pressure drop, over a filter medium increases during the first months of operation by a factor of 50 - 100 from the value in the clean state. Fabric blinding is the common term for a rapid increase in resistance, while a slow pressure development is a normal phenomenon. The nearly stabilized value corresponds to a saturation of fine particles in the fabric. Change in the particle accumulation occurs mainly when the particle structure is disturbed at cleaning.

If the filtration velocity through a filter bag after it is cleaned is not controlled to stay below a permitted level, this accumulation of particles is accelerated. The unbalance in flow between bags in cleaning and filtration state is best controlled if filter cleaning is initiated when a certain dust deposit rather than a certain pressure drop level is reached. In this way cleaning is not started by sudden peaks in gas flow or temperature. On the other hand excessive pressure drop occurring when the filter velocity increases stepwise after a long period of dust accumulation at a low filter load can be avoided - such steps could otherwise lead to unstable operation of the filter.

In a more elaborated cleaning control system, overcleaning from too high pulse jet pressure can be avoided by reducing the pulse jet supply pressure at low filter pressure drop. Further the filter could be cleaned in advance if the control system is programmed to foresee certain process stages with heavy dust emission. Another feature, easily incorporated in such a microcomputer based cleaning control system is control of the fan speed to reduce fan power at low furnace loads.

Equally important in order to prevent bag blinding is to control the dust flow inside the filter compartment. The gas flow pattern must therefore be correspondingly arranged to reduce redeposition of dust which has once been removed at bag cleaning on-line. Also a suitable sequence of bag cleaning is practiced so that dust is not transferred between adjacent bags.

If the feature mentioned - cleaning control, cleaning sequence and flow distribution - are fully observed and an optimized pulse cleaning system is applied, a considerable filter area can be installed in each filter section. This reduces the number of cleaning valves, dampers for section isolation, etc., all beneficial for the investment cost.

When the two current principal types of filters for ferro-alloy fume filtration - the larger low ratio baghouse and the compact, high ratio pulse cleaned filter - are compared, the first type represents a design where little complication is obtained at the expense of some drawbacks regarding maintenance. The second type has the potential of rapid operating control and controlled working conditions during maintenance at the cost of a more complex design. The cost and maintenance aspects shall be more closely studied in the next section.

Costs and maintenance

A comparison of costs for installation, energy supply and filter bag replacement for typical low and high ratio filters reflecting the state of the art is presented in summary in table 2.

Typical values for filtration of fume from an open medium grade ferrosilicon furnace have been selected. The low ratio filter is assumed to operate with reverse flow cleaned glass fibre bags and to be of the pressure type. The high ratio filter for operation under suction is equipped with acid resistant Nomex bags - the gas temperature is limited to 190 - 200°C - which are cleaned by jet pulsing.

The installation cost includes the filter house, filter bags, bag cleaning auxiliaries and erection costs. The cost figures have been referred to the installation cost for the low ratio filter with an index cost of 100.

The following general conclusions can be made for the specific calculated case. However, used as a cost sensitivity analysis it is applicable to most ferro-silicon and ferro-chrome filtration cases:

- Investment cost is about 10 percent lower for the high ratio alternative.
- Total costs for energy absorbed by the main fan and the cleaning fan and compressor resp. is lower for the high ratio filter system although the cleaning energy supply is higher in this case.
- Annual bag replacement cost is assessed to be about three times higher for the high ratio alternative than for the low ratio filter, for the fabric selection preassumed.
- The total of first and annual energy and bag replacement costs will equalize after ca. 5 - 7 years of operation (if capital costs are not considered).

As bag replacement cost is a critical figure in the budget shown it is worthwhile to have a closer look at this item.

Filter bags fail for a number of reasons. If bag blinding is disregarded in this connection, mechanical failure is caused by abrasional wear from fabric flexing, at local high velocity - high dust load concentrations, random faults from the manufacturing of the fabric and bags, chemically initiated degradation of the fabric, etc.

All these phenomena are of course of a statistical nature, and the failure rate may therefore be well described with some statistical frequency function. The operating time until a certain percentage of the bags have failed can be estimated in advance. When a bag failure occurs the most rational measure is to shut off the bag by plugging, etc.; this procedure can be used until a predetermined fraction of the filter area is blocked, and the actual failure rate is too high for maintenance to catch up. The bag life should then be defined as the time elapsed until the failure rate has reached the level mentioned. A figure of 10 percent is often used.

To practise this replacement strategy it is essential that bag blocking could be carried out easily. The filter is scanned for faulty bag by shutting off the sections one by one while observing the opacity reading - one leaking bag normally increases the emission by some 5 - 10 mg/m^3 n. In low ratio filters the open compartment is shut off and possibly allowed to cool down before entry. In the high ratio filter case the compartment is shut off, the top lid lifted off and the failed bag plugged immediately.

Both procedures are reasonably convenient, with a bonus for better working atmosphere in the high ratio case.

<u>Summary</u>

To-day types of fabric filters can clean ferro-alloy fumes to a residual dust load well below 10 mg/m^3 n, which fulfills current emission limits with margin.

Two main established types, the low ratio filter for overpressure operation and the high ratio filter with the fan in down-stream position, will absorb about the same total installation and operating cost over a ten year period.

Further development of filter media, especially of the depth filtering type, will probably further decrease energy and bag replacement costs for both alternatives.

In some applications the high ratio filter, with reduced space requirement, can give a more compact installation with less ducting. With the ongoing trend towards energy conservation through closing of the furnace hooding, and installation of heat recovery equipment, the location of the main fan on the clean side is a premium for the high ratio filter relative to the traditional low ratio type.

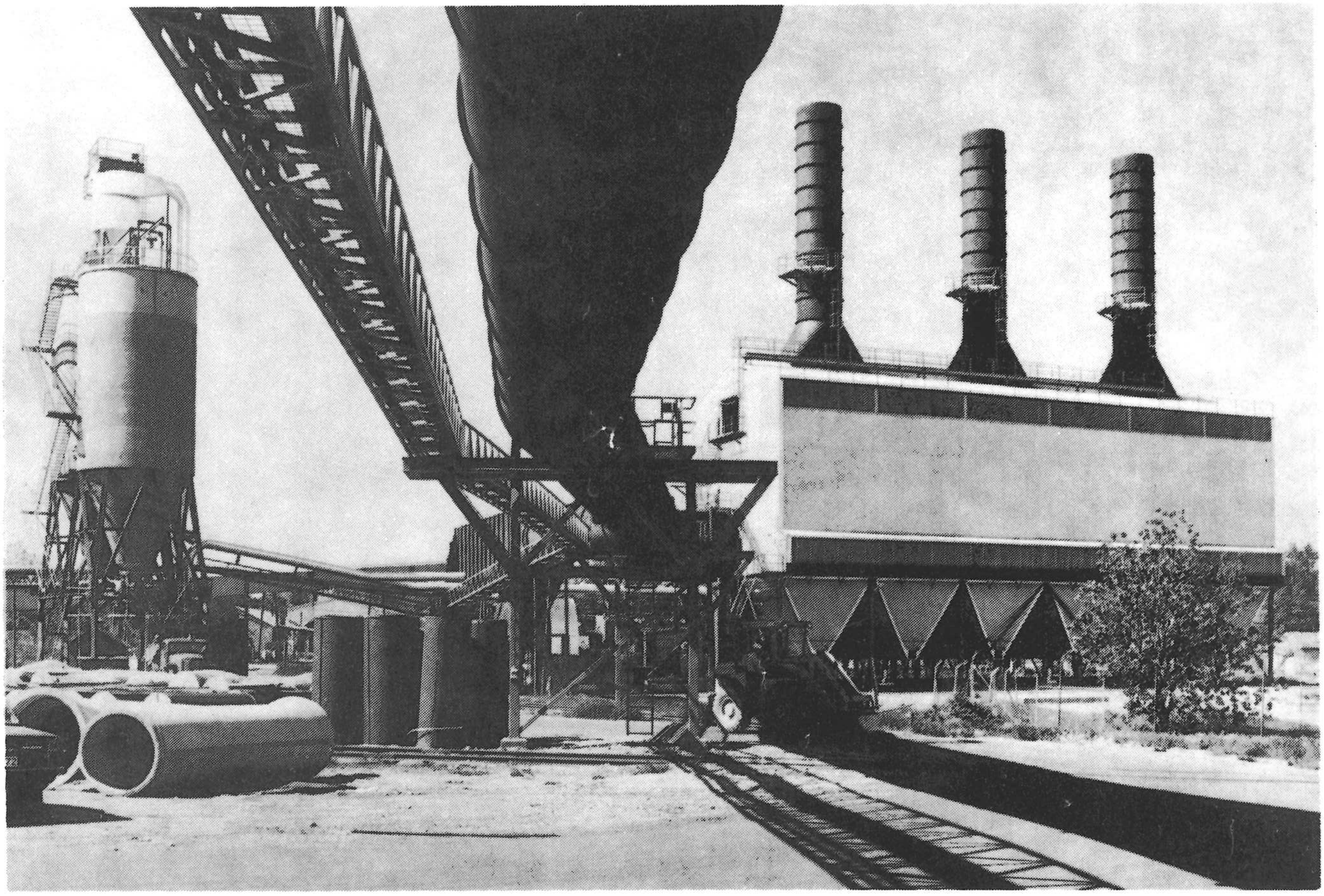

Fig. 1

Flakt installation of a low ratio fabric filter for 330,000 m^3/h of gas from a 13 MW silicon metal furnace at Kema Nord, Ljungaverk, Sweden.

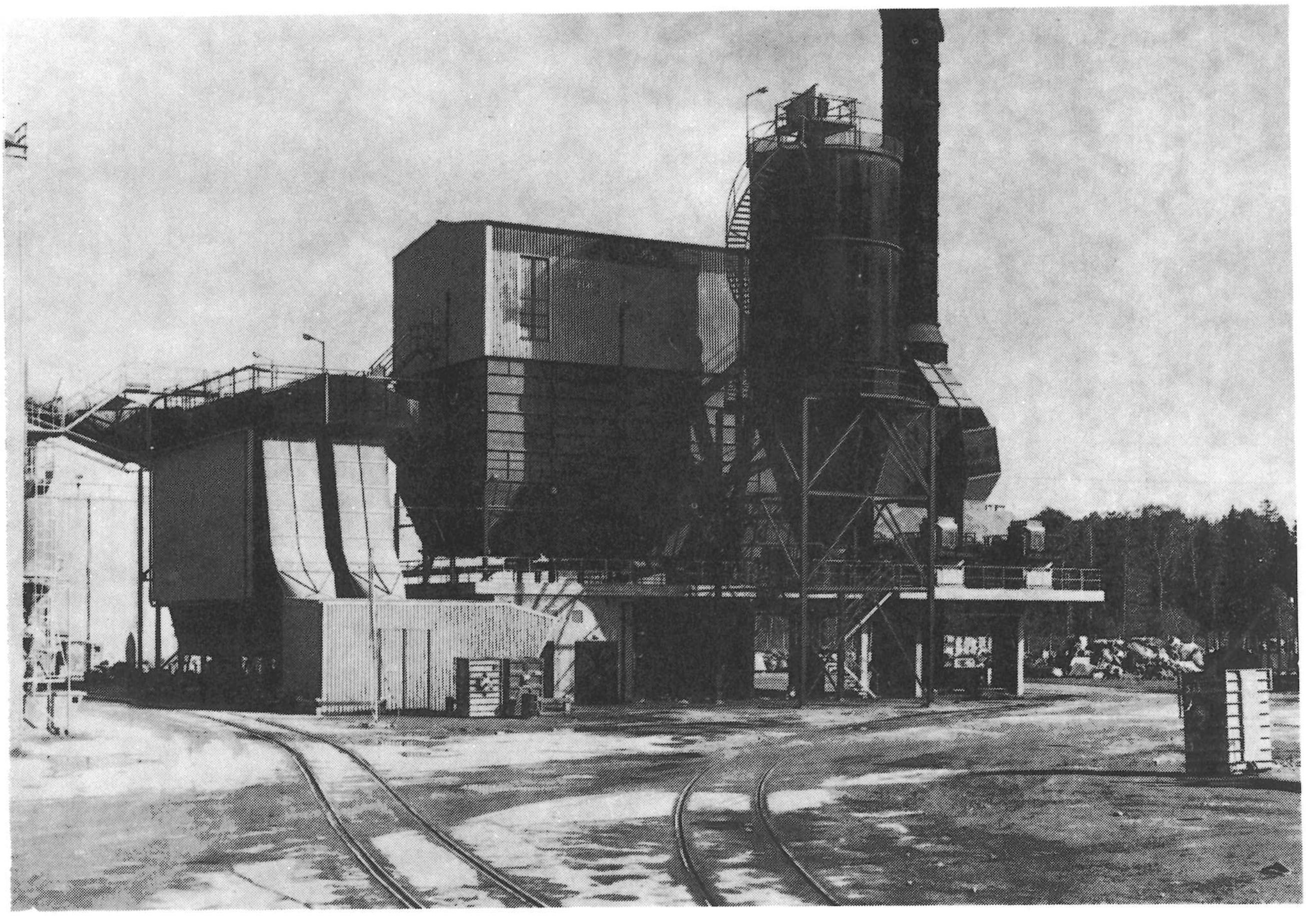

Fig. 2

Fabric filter plant for 425,000 m^3/h of gas from a 25 MW open ferrochrome furnace, comprising a forced draught cooler, a high ratio pulse cleaned filter and dust handling equipment, supplied to Ferrolegeringar AB, Trollhättan, Sweden, by Flakt.

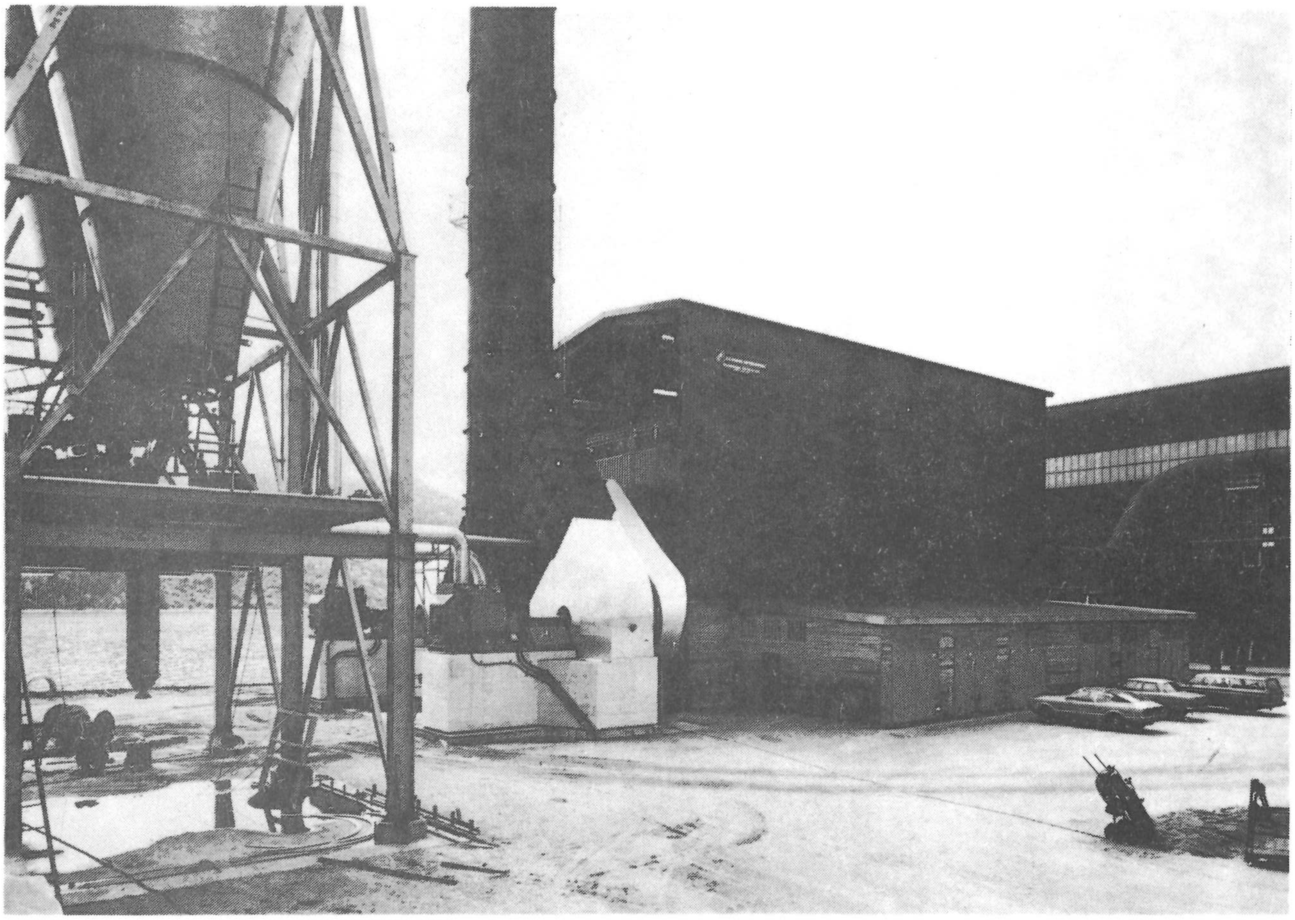

Fig. 3

A Flakt high ratio filter plant cleaning 500,000 m^3/h of ferrosilicon fume at Tinfos Jernverk A/S, Notodden, Norway.

DISCUSSION

Mr. A.G. Arnesen*

Allow me a few comments before I phrase my question, please. I think I go along with Mr. Schmitt very much that investment cost is only one part of the truth. The operation and the maintenance cost is the second part and the third part, which might be the most important of it all is that after all, we want to operate a furnace, we have regulations to comply with and if you have to stop your furnace because of the filter, then you have a very expensive filter. We have our bag house installation in our own plants in Norway and many of you will know that in Norway you are allowed to operate a maximum of 4% of the time without the bag house in operation. We have seen our own statistics and in the last year for the two plants we have at Fiskaa the downtime on the two filters was each of 0.8%. So we only utilize a small fraction of the 4%. I think we would very much like to see similar figures for the high ratio filters before we can make a fair comparison because, otherwise, I feel that we are more or less in a situation of perhaps some new developing African countries: on one side comparing the old European Colonial World with its sins in the past, with the promised heaven of the Socialist system which will be realized in the future, perhaps. So my question is: Do you feel that the bag house installation is a more proven system than the high ratio filter system?

Mr. S. Strangert:

Well, in the sense that we have a considerably longer experience to back on, I would agree. Availability: I have been informed that the downtime due to bag failures that has occurred with high ratio filters has not interfered with the furnace operations so far. This comes back to the fact that bag replacement is a rapid operation in high ratio filters and also that there has been a reasonable possibility to plan this maintenance. One could, of course, extend the concept of high ratio filters by using the cassette replacement system without any major increase in the cost of the filter. But I think the figures I mentioned or rather the bag failure rates I showed on one of the slides indicate that also if the average life differs for the two filter concepts, we still have a predictable situation with the high ratio filter. When it comes to replacement costs again, the costs for replacement labour, not only the material costs, were included in the comparison figures I presented.

Mr. A.G. Arnesen

I thank you for the answer. Looking at the columns that you have there on the blackboard now, you see that the sensitivity in the operating price to the bag failure is very high. You have calculated with a bag life of 2.5 years. Now, I do not know whether anyone has realized such a bag life in any installation so far. Could you comment on that please?

Mr. S. Strangert:

No. This is because we are in an extended development phase because no-one has come up with a method to accelerate, under lab conditions, all the mechanisms that deteriorate the filter fabric. We can perhaps accelerate the mechanical

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wear but not all the chemical factors that will affect the fabric. So, we more or less have to rely on field testing and full scale testing. That means that we have attained a fabric life of just below two years and we can make predictions for the remaining time up to the 2.5 years that I indicated. The figures are based on the development that we are currently undertaking in co-operation with the industry which is aiming at improving the weak points of the depth filter media. For example, we have recognised that the fabric scrim is very important. I think this process presents some of the most demanding conditions that we ever encountered and we do go to extremely high initial tensiles strength of the fabric. We have seen the effect of improving features such as initial strength in other applications and we are quite confident in the prediction of the expected performance. So, actually, we are aiming further than 2.5 years. Another aspect, by the way, will also change the comparison in favour of high ratio filters, namely the lower filter resistance which is, as you have pointed out, quite important when we are looking at annual energy costs.

Mr. E. Hällgren*

You are using compressed air for the cleaning pulses. That creates a very hard shock on the textile material at every cleaning, that is every third minute, which, of course, causes wear. The bags are under vacuum and I know another filter manufacturer who just releases this vacuum, saying that he uses the atmospheric pressure, or rather the difference between the atmospheric pressure and the vacuum inside the bags, for the cleaning of them. He does not need any compressor and he gets much milder shocks to the bags. Do you have comments on this? Do you mean that the cleaning efficiency becomes too small?

Mr. S. Strangert:

Yes, I think that you almost gave the answer yourself. We are relying on the very quick retardation of the filter fabric which, in a purely mechanical way, throws off the dust cake. But actually the mass forces involved in this retardation of the fabric are quite small, so the tension in the fabric is still just a fraction of any other strength figure that we compare with, just in the order of 1% of the tensile strength of the fabric. Another aspect is that we probably have more problems with the abrasive wear. If wear occurs this happens when the bag returns to its collapsed, or its filtering position. This is due to the actual flexing of the fabric and the fact that the fabric is reinforced by the impregnation of particles that creates, contrary to woven media, a stress gradient throughout the fabric. If the surface fibres start to break, cracks form in the bending zone along the rods of the cages and once such a crack has been formed it acts as its own stress concentration. The measure to counter this is to maintain the flexibility of the fabric by limiting the impregnation of the particles and by maintaining the flexibility of the fibres themselves by any of the treatments I mentioned. The retardation of the fabric is in the order of a few hundred times the acceleration due to gravitation and we would reluctantly reduce that figure or we would face a high, increased filter resistance.

Mr. C.N. Harman**

I would like to ask Mr. Strangert to elaborate a little more on the unsuitability of the electrostatic precipitator because we heard from Mr. Goss that

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there are two electrostatic precipitators working in USA quite satisfactorily and my request is particularly in connection with high carbon ferro-chrome operation on semi-covered furnace.

Mr. S. Strangert:

Being a fabric filter man, I do not think I can be too specific on the subject, but it is more a matter of an economical comparison than any principal obstacle to the application of precipitators.

Mr. C.N. Harman

Because you mentioned that the particles have a high resistance and they also carry a static charge, so, would that be derogatory while using an electrostatic precipitator?

Mr. S. Strangert:

It is one of the extremes in terms of dust properties occurring that would be handled by precipitators, but it has successfully been accomplished.

Mr. C.N. Harman

Since in the case of the bag filter, also we are using a precooler and proper conditioning of the gases is done. Maybe some kind of conditioning could be done before the electrostatic precipitator as well, to make the particulate matter more amenable for electrostatic precipitation?

Mr. S. Strangert:

Yes, that is a common practice and I should say also that this discussion has, perhaps not outspokenly, been concentrated on open or semi-closed furnaces. When we are moving over to more closed furnaces or totally enclosed furnaces then the whole discussion will change.

Mr. E. Hällgren*

As you are a bag house man, Mr. Strangert, I can console you by telling you that I happen to know the plans are to replace those two electrostatic precipitators in the US by bag houses.

Prof. O. Rentz**

Also to give a comment on the comparison of electrostatic precipitators and bag houses I would like to add that actually - by number and not by gas volume treated - in the German ferro-alloy industry we have about 60% electrostatic precipitators and the rest are bag houses. My impression is that we should not make the comparison between the two precipitators superficially or even blind as we did it in the past. Just from industrial experiments which we carried out last year with high resistivity fumes electrostatic precipitation with ratios of SiO_2 in the fumes up to 80% even with conventional electro-

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static precipitators we came down to about 20 MG/m^3 in the cleaned gas (FeSiCr). This shows that in principle it is possible, but what we have to do is to look much more closely at the properties of the fumes, at the properties of the waste gas, at the furnace behaviour, and so on.