Pollution control and energy recovery in the ferro alloy industry

Oluf Chr. Bockman
Einar Eriksen
Aage Lømo*

ABSTRACT

PART—I Pollution Control and Energy Recovery in the Ferro Alloy Industry

The paper describes the gas and smoke cleaning plant for closed and open furnaces. New high temperature filters for dry cleaning of carbon monoxide gases from closed furnaces have been developed and the operation of a full size filter at Bremanger Smelteverk is discussed.

The paper also describes the various types of filters that are in use today. Baghouse filters using reverse air and with bags made of glass fibre have been discussed in detail. Altogether 14 filters designed by Elkem are in operation at various places in the world.

PART—II Energy recovery in the Ferro Alloy Industry

The interest for energy recovery in the ferro alloy industry is increasing rapidly. The energy recovery system for semi-closed furnace developed at M/s. Elkem is described. Trials for energy recovery from a closed Fe-Si furnace at Bremanger Smelteverk is also discussed.

PART—I

Gas and smoke cleaning plant for closed and open furnaces

With regard to pollution problems in the ferro alloy industry we have to distinguish between cleaning problems for open and for closed type furnaces. That is, cleaning of burnt non-explosive, non-toxic gases from the open furnaces and CO-rich, toxic and explosive gases from the closed furnaces.

Gas cleaning plants for closed furnaces have been built for many years. Rotary scrubbers of the Theissen and Buffalo types were quite common up to some 14-16 years ago. A substantial disadvantage with these installations were their high water requirements, which would amount to some 3-400 m^3 for a smelting furnace of about 20 MW.

In a modern gas cleaning installation employed today namely the high efficiency venturi scrubber—the water requirement for cleaning

* Authors are with the M/s. Elkem a/s, Norway

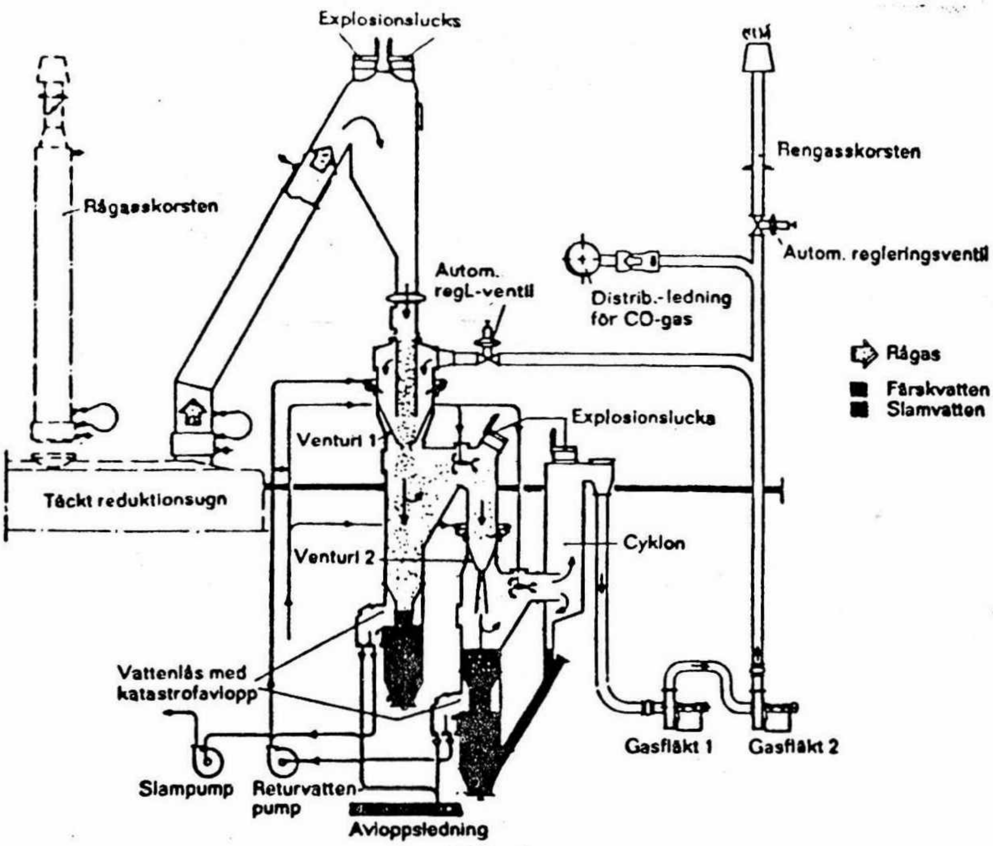


FIG. 1

the same amount of gas is about 50 m^3/h, i.e. less than 20% of the water consumption for plants with rotary scrubbers.

There are two types of venturi scrubbers. built by SF in Sweden and the Finnish company Ahlstrφm, through their subsidiary Varkaus Bruk.

The SF venturi gas cleaning plant as shown in Fig. - 1 consists of two almost identical venturi stages, each comprising an inlet duct, a mixing chamber and a diffusor. The first stage is used as a cooler, humidifier and precollector, while the second stage is the main collecting unit. With a total pressure drop across the venturis of about 13 kPa and a raw gas dust load not exceeding 150-200 g/Nm^3, a dust content in clean gas of less than 50 mg/Nm^3 can be expected.

The cleaning efficiency of the SF plant depends on maintaining a relatively constant gas flow through the venturi throat, that is the pressure drop must be kept constant. This is achieved by recirculating a variable amount of gas to the venturi throat in accordance with the variable load and gas production in the smelting furnace. A regulating valve in the shunt line is governed by the pressure variations in the smelting furnace.

The Finnish system shown in figure 2 is based on a different principle, in as much as the gas flow is powered by pumps and water jets instead of fans.

The performance of the two gas cleaning systems is quite equal, however, the water consumption of the Finnish venturi may be somewhat higher. Although the cleaning process in the above described systems is quite simple and virtually without technical problems, the operation leaves us with a waste product—the scrubbing water and sludge—which cannot be discharged in nature without special treatment.

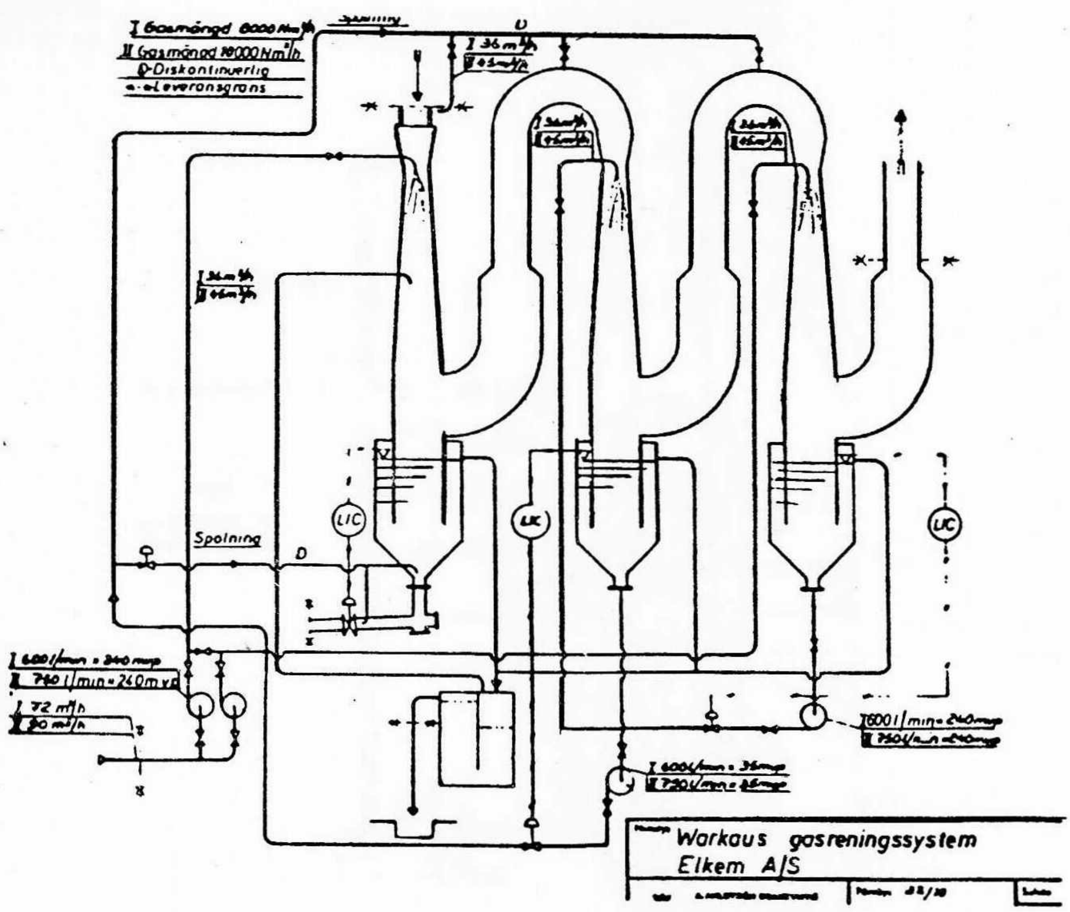


FIG. 2

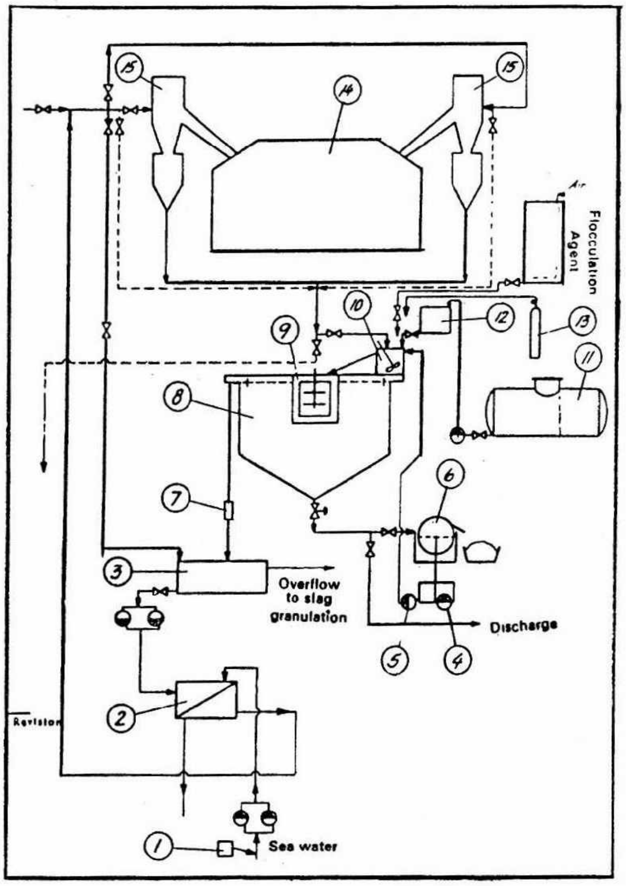
Treatment of gas scrubbing water

The effluent liquids from gas scrubbing plants attract the attention of the authorities, due to their complex chemistry and harmful effects on nature, human beings and animal life. Strict regulations are set up in many countries, in some countries no effluents whatever, are permitted to be discharged due to scarcity of drinking water.

The gas scrubbing water will contain dissolved elements including heavy metals at different concentrations and poisonous cyanides depending upon smelting process in question. Scrubbing water from a FeMn furnace will for instance contain mostly dissolved Mn. In addition to the dissolved materials the water will contain variable proportions of suspended matters. The acidity of the water, its pH-value, will vary with the reduction process and the ratio of CO/CO_2

A chemical treatment of the scrubbing water with precipitation of the dissolved material and sedimentation of the suspended matters will produce a sludge that will contain all the materials mentioned above. The scrubbing water can either be recirculated in the gas cleaning plant, or it can be discharged as waste or a combination of the two. The treatment of the gas scrubbing water compatible with direct discharge, will require a substantial consumption of chemical reagents, besides being expensive with regard to water consumption. The cost of the chemical reagents will in most cases make an alternative totally unacceptable.

Figure 3 shows a water treatment installation based upon recirculation of the water with sedimentation tank for removal of matters susceptible to sedimentation and with subsequent vacuum filter for separation of the sludge from the liquid. The cooling is being done by heat exchanger using sea water as cooling agent.



1-Chlorination 2-Heat exchanger 3-Surge tank
4-Vacum pump 5-Filtrate pump 6-Vacuum filter
7-Polarizer 8-Settling tank 9-Flocculation tank
10-Mixer 11-Sodium hybroxide supply tank 12-Day tank
13-Chlorine gas bottle 14-Reduction furnace
15-Gas cleaning plant

FIG. 3

It is quite obvious that gas cleaning plants using venturi scrubbers and water treatment plant for cleaning and detoxification of the waste water is not a cheap solution. Neither with regard to capital cost nor with regard to operating cost.

Furthermore the wet cleaning system has several drawbacks which will become more significant in the future :

—The water vapour in the scrubber gas entails heat losses after combustion.

—Non-recovered cooling of high temperature energy in the gas.

—Utilization of particle discharge is more intricate in the form of sludge.

All these facts led to the development of a high temperature filter (HT-filter) which could clean the gases from closed furnaces with a dry method, i.e. without using water.

This development started in January 1976 and a pilot filter test was run on unburnt gas from FeMn, SiMn and FeSi processes with several filter materials. In June 1979 a full scale filter was connected to the closed 9 MW FeSi furnace at Elkem a/s, Bremanger Smelteverk in Norway. The testing of filter materials and components has continued up till now, and the filter system has proved safe and reliable.

Description of the filter system

A principle sketch of the system is outlined in Fig. 4 and 5.

Raw Gas System

The furnace gas is piped to the HT-filter via the gas offtake, one cyclone and raw gas fan. The purpose of the cyclone is to cool the hot gas before entering the raw gas fan and to reduce the actual gas volume before entering the filter. It also separates any coarse particles to avoid excessive wear on the fan impeller. The raw gas fan transports the gas and increases the pressure throughout the system to avoid underpressure to prevent air leaks into the filter system. Excess overpressure should also be avoided due to possible gas leaks to the furnace building. It must be kept in mind that the process gas from a closed furnace is both explosive and very poisonous. A by-pass line connects the raw and clean gas side of the

ELKEM HIGH TEMPERATURE FILTER

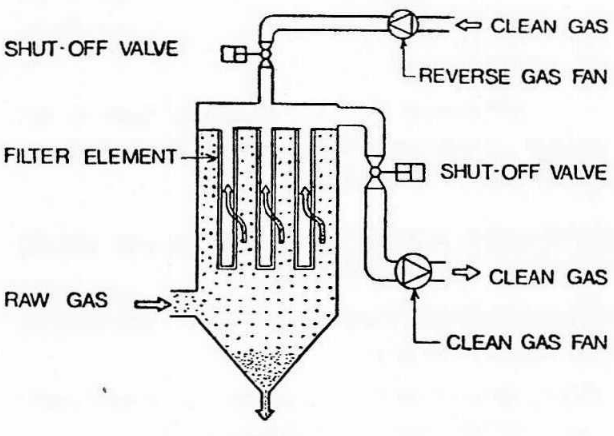


FIG. 4. SCHEMATIC DRAWING OF HT–FILTER

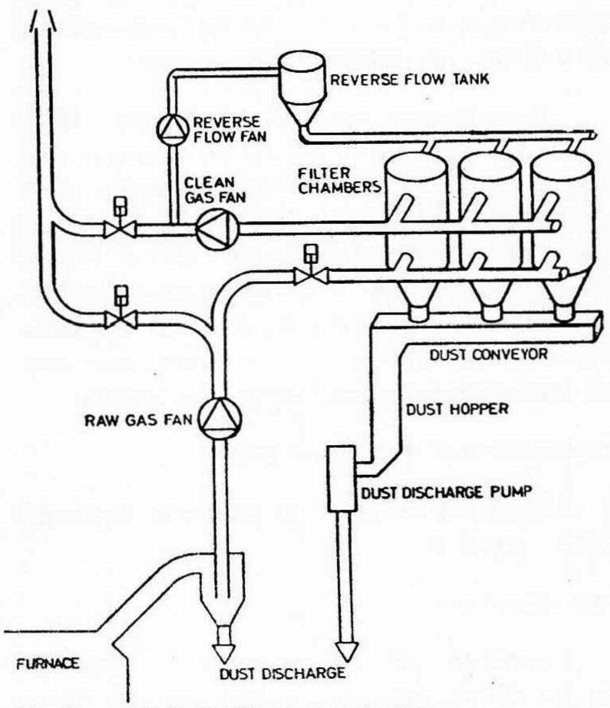


FIG. 5. HIGH TEMPERATURE FILTER

filter system. It is a substitute or, if desirable, supplement to the raw gas stack.

Filter Chambers

Each filter chamber contains about 80 filter elements. The filter material best suited for the process has so far proved to be Inconel in the form of fiber cloth of sintered metal.

Clean Gas System

The clean gas fan creates the necessary pressure drop across the filter material. The furnace pressure is controlled by the valve after the clean gas fan. The valve is a combined regulating and isolating type which, together with the inlet valve, isolates the system from the furnace gas when desired.

Reverse Flow System

Clean gas is used for cleaning the filter elements. Three gas fans pressurize a reverse flow tank for pulse cleaning of the elements.

Dust Transportation Systems

The separated dust is fed by gravity into a chain conveyor which transports the dust to the hopper. The dust discharge pump, initiated by level indicators in the hopper, pushes the dust out of the system. The discharge pump is leak proof in such a way that no gas escapes and no air enters the system.

Dust Treatment

Before dust deposition, undesired elements in the dust have to be destroyed. A simple destruction process is under development by Elkem. Silica dust from the FeSi-process is an increasingly valuable material to other industries. Methods for treatment of the discharge dust from the HT-filter to a high quality product is therefore under development.

Cleaning of smoke from open furnaces

While the technology for wet cleaning of CO-rich gases from closed furnaces has been well known for the last 30 years, the technology for cleaning of smoke from open furnaces with a reasonable success has only been known for the last 10-12 years.

Early in the fifties we tested a bag filter, designed by ourselves, for the cleaning of silica fumes. We did not at that time attain a convincing solution. In 1966 a dry electrostatic precipitator was put into operation at Fiskaa Verk, cleaning the fumes from a 9 MW furnace producing silicon metal. Due to extensive corrosion problems this method had to be given up.

At the same plant a bag house filter was purchased in 1971, cleaning the fumes from a 12 MW furnace. The performance of this filter was not satisfactory, and major parts were completely rebuilt. Mechanical details were improved, and the bag cleaning operation was converted from shaking to reverse flow. Since then the filter operation has been satisfactory.

Based on the experience already achieved at Fiskaa Verk—not only with the filtering process itself, but also with dust handling system and since we were now faced with the problem of installing filter units in all our own ferro silicon plants within the next few years, the decision was taken to design the filter ourselves. The next filter at Fiskaa Verk cleaning fumes from a 20 MW FeSi furnace was put on stream early in 1976. Before that we had successfully managed to design and construct a bag house filter which was started just before Christmas 1974 for an Italian customer. At present we have altogether supplied 14 large bag house filters, of which 5 to our own plants. 5 new plants are on order.

Before dimensioning a filter for a customer certain information is required, as for instance : See Fig. 6 (a, b and c).

1. Type of smoke hood, i.e. semiclosed, low hood or conventional old type with flexible cables underneath smoke hood roof. The last one requires a specific gas volume of at least 15 Nm^3/kwh. Low hood with cables above the smoke hood roof about 10-12 Nm^3/kWh. Semiclosed hood about 6-8 Nm^3/kWh and semiclosed hood combined with energy recovery about 3 Nm^3/kWh.

2. Raw material composition and in particular the type of the reducing agent for instance ratio of coal/coke, wood chips etc.

FIG. 6-A

A. OPEN FURNACE
B. FILTER

V-10-15 m_N^3/kWh

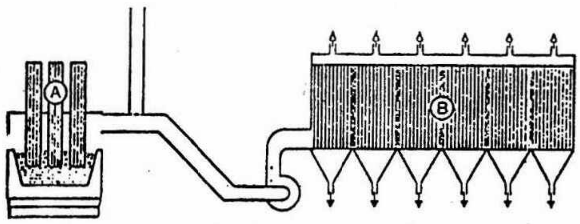


FIG. 6-B

A. SEMICLOSED FURNACE
B. FILTER
C. COOLER

V-6-8 m_N^3/kWh

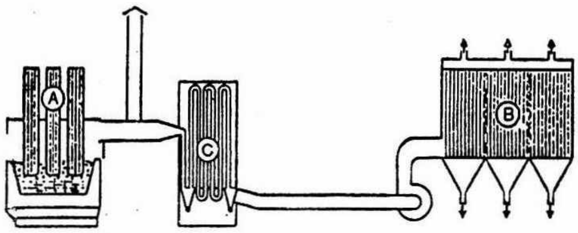
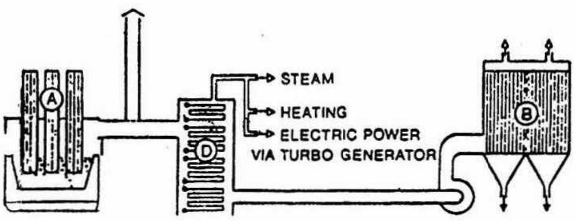


FIG. 6-C

A. SEMICLOSED FURNACE
B. FILTER
D. WAST HEAT BOILER

V-3-5 m_N^3/kWh



We have developed a formula for heat content in the gas based on heat balance calculation where certain correction is made for heat losses by radiation and convection from gas to air and watercooled furnace equipment. The correction has been checked against good measurements on a 12 MW silicon metal furnace. See Fig. 7.

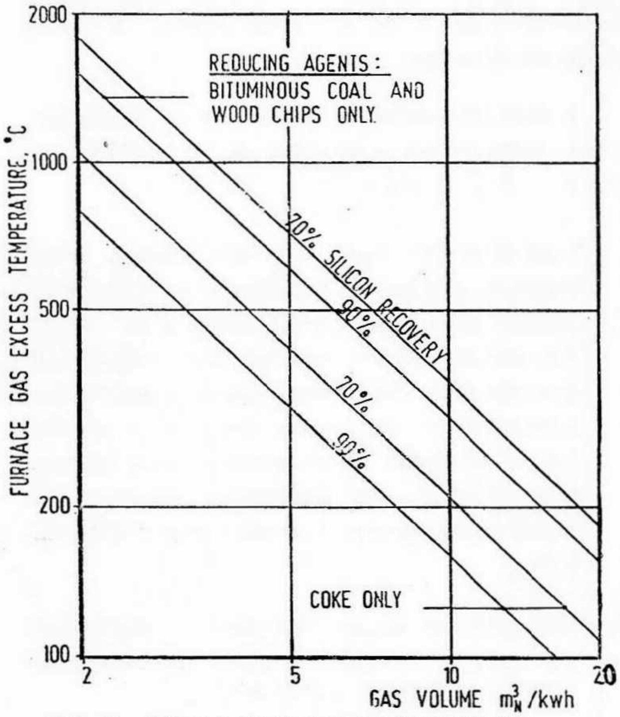


FIG. 7. CALCULATED GAS TEMPERATURE

The gas temperature increases as silicon recovery decreases, and as content of voltatile matter or reducing agents is increased. In modern furnace operation quite a proportion of coal and wood chips is used, to the effect that volatile matter contributes 15-40% to the heat combustion.

The type of smoke hood and the specific gas volume in Nm^3/kWh which can be drawn off through the hood, has also a great influence on the gas temperature.

The size of the filter and the area of the filtering media will depend on the type of cleaning mechanism applied to remove the dust from the filter media.

There are three different methods commonly used today namely : Reverse air, shaking and pulse jet. See Fig. 8.

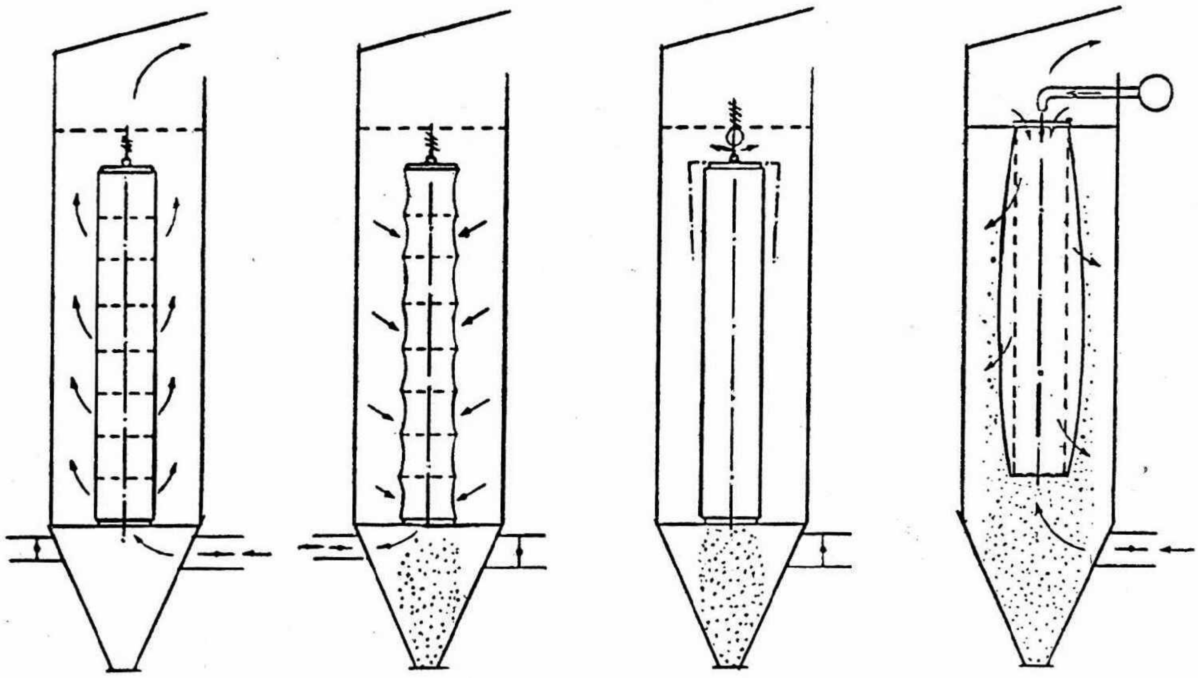
The pulse jet method is used in the high ratio filters or in filters having a rather high filtering velocity, for instance about 100 m^3/h per m^2 filter media usually expressed as filtering velocity in m/h. Normal bag size is about 3 meters length and 10 cm diameter. Some manufacturers are using bags up to 5 meters length and 20 cm dia. The pulse jet filters are all working with an underpressure, i.e. with the fans on the clean gas side. Filter media is normally Nomex with max. operating temperature below 200°C.

Filters using shaking as cleaning method can either be pressure type filter or filter working with underpressure. Normal bag size 6 meter length 20 cm diameter. Bag material normally Nomex. Filtering velocity about 40-50 m/h depending on the frequency of the shaking.

The reverse air system is used in the large open bag houses which are always working as pressure type filters, i.e. with the fans on the dirty gas side. Due to the gentle handling of the bag material during reverse air, glass fibre bags can be used. The advantage with this material is the high temperature resistance with working temperature up to 260-270°C. Normal bag size applied for bag houses in the ferro alloy industry is 9-10 meters length and about 30 cm dia.

Normal filtering velocity for glass fibre bags when cleaning FeSi-furnace using reverse air system is 30-40 m/h. However, if same bag house is using Nomex instead of glass fibre bags, the filtering velocity can be increased to 40-50 m/h.

While are referring to filtering velocity and quoting certain figures, one should bear in mind that filtering velocity alone, without at the same time giving the corresponding pressure drop across the fabric, is meaningless. Therefore the correct way to express the capacity or



Reverse air cleaning   Shaking   Pulse jet cleaning

FIG. 8

performance of a filter is to quote filter resistance (American : Filter drag) expressed in

$$\frac{\text{mm WG}}{\text{m/h}}$$

For instance pressure drop 200 mm WG, equal to 2 kPa, filtering velocity 40 m/h.

$$\text{The filter resistance} = \frac{200}{40} = 5.$$

Main requirements for a good filter

For the filter operation the most important requirement is reliability and high operating time with easy access for inspection and maintenance. Of special importance, defective bags should easily be detected and blanked off or replaced. For efficient operation of the filter, these are mandatory requirements. In addition, cost of investment and operation should be reasonable, especially consumption of energy. Space requirements may be important. Also low noise level, especially from the fans, is most desirable.

Taking these points into consideration, a filter has been designed to handle a gas volume of 300,000 Nm^3/h with a gas flow of 15 Nm^3/kWh for a 20 MW furnace with old type smoke hood, and installed at Fiskaa Verk (Fig. 9). The filter however, can be divided longitudinally into two separate filters of half the size to suit adaptation of the filter to new condition if future rebuilding of the furnace is considered.

Layout

The coarse particles mainly coke and a small amount of silica dust, altogether about 5%, are separated out in a battery of cyclones acting as precollectors. Two fans between the precollector and the filter, supply the gas to the main duct of the filter. Through inlet valves to each of the 14 compartments the gas enters the hoppers and further on to the bags for filtration. The bags are elastically suspended between hopper and a grated floor in the top of

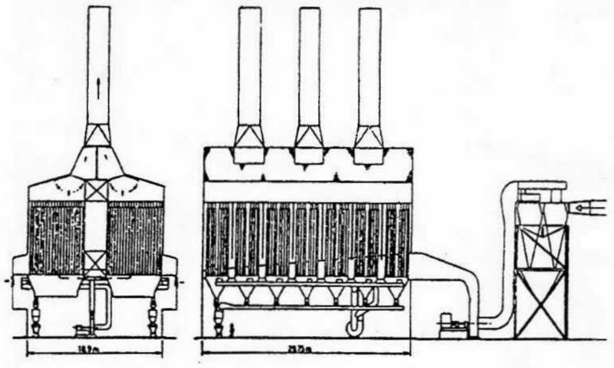


FIG. 9 : ES BAGHOUSE AT FISKAA VERK

the filter. The dust is deposited inside the bags. The cleaned gas passes through the bags and rises by natural draught up through the three stacks. (Roof ventilators along the ridge of the roof may also be used.)

For cleaning the bags, one compartment at a time is taken off stream by closing the inlet valve. By a special fan, the reverse air is drawn from the compartment and discharged to the main duct. With the bags partly collapsed the filter cakes are released and fall down into the hopper. The dust is transported by a screw conveyor to the one end of the hopper, where it is taken through a rotary feeder down to a chain conveyor. At the end of the chain conveyor the dust is pneumatically transported to a storage bin. The bags are made of glass fibre cloth, they are 9.1 m long and approx. 300 mm in diameter. Seven equally spaced rings of stainless steel are sewed into each bag. The rings shall prevent the bags from collapsing under reverse flow conditions. Each compartment has 160 bags arranged in 2 x 4 rows of 20 bags in each row. On both sides and in the centre walkways give access to all bags within two bag reach.

At the level of the hoppers the filter building walls have ventilation openings. Fresh air from these openings passes up through the grating floor surrounding the hoppers and is mixed with the filtered gas and leaves through the stacks.

Between compartments partition walls extend from the roof down to a level 2 m above the greting floor between the hoppers. This arrangement gives easy access for inspection of the bags. When a compartment is taken out of operation, for instance for bag replacements, gas temperature in this compartment will drop and natural draught is reduced. To prevent gas from neighbouring compartments to enter the compartment out of operation, this compartment may be completely separated at the top by a hinged flap. To each compartment a door from the tunnel at level of upper grating floor gives easy access to this floor. This door may be used as fresh air inlet to a compartment out of operation. In this way good working conditions are established for inspection and maintenance in a compartment out of operation, even when the other compartments are on stream.

A central control room contains the instruments, alarms, sequence controls and other equipment necessary for automatic or manual operation of the filter. From this control room the pelletizing plant is also operated. Gas temperature and bag pressure are continuously recorded.

Fan control

The fans have to be controlled in order to adjust the fan operation to the furnace need for ventilation, and in order to protect the fan motors from overload. Three possible ways of controlling the fans are presently used :

1. Controlling the fans by inlet guide vanes. This is a simple and rugged method, fairly inexpensive. At Fiskaa Verk this alternative is chosen.

2. Fan speed controlling by using hydraulic coupling between motor and fan.

3. Variable speed motor. Usually a slip ring motor controlled in cascade is used.

Combined energy efficiencies for motor and controlling method are shown in Fig. 10. Guide vane controlling and speed control by hydraulic couplings show low efficiencies at reduced gas volume flow, and large losses may occur. The variable speed motor in question, on the contrary, shows high efficiency at all speeds. Such a motor is expensive, however, and in each case it is a question of balancing investment against operating cost.

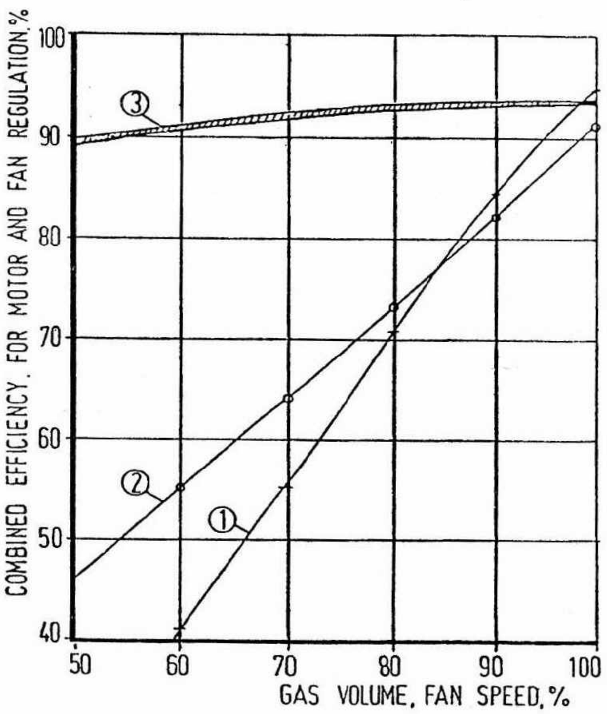


FIG. 10. DIFFERENT METHODS FOR FAN CONTROL, TOTAL EFFICIENCY

1—GUIDE VANES
2—HYDRAULIC SPEED REDUCTION
3—VARIABLE SPEED ELECTRIC MOTOR

Controlling principle may be to keep constant motor load. In this case, however, a cold furnace will get a better ventilation than a hot furnace. Introducing the temperature of the gas in the control loop, to the effect that motor load is reduced when gas temperature drops, will save energy and give less strain to equipment. Especially when using variable speed motor this way of controlling is favourable.

Experiences

Reliability of operation may best be illustrated by stating that downtime caused by faults in the filter itself is about one per cent.

The filter has an open structure which facilitates inspection and maintenance work. Well ventilated, the filter atmosphere is acceptable at inspection points. All bags are easily inspected during operation of the filter. Defective bags are easily detected and blanked off. When a certain number of defective bags have been disconnected, the compartment is isolated and bags replaced by new ones, while the other compartments are still operating. (In Norway this is a requirement by The State Pollution Control Authority.) When replacing bags, you do not get in touch the dirty side of the bags, which is inside of the bags.

The filter has been in operation for 7 years, and so far only about 30% of the bags are replaced. Our experience froms everal plants indicates an average bag lifetime of about 6 years. The fans operate at the dirty gas side of the filter, but this has not caused any trouble. It is reported from other installations, however, that coarse particles in the gas stream have caused fan wheel wear. This is not the case with our filters, probably because of the efficient precollectors. The filter may seem voluminous. Compared with high ratio filters, however, it is felt that the following considerations are valid.

A high ratio filter is bound to use Nomex or very expensive bags with teflon base, with the limitations this impose. A fair comparison would then be against a bag house also equipped with Nomex bags. The higher filtration velocity possible in a bag house when using Nomex instead of glass fibre, will reduce the size of the bag house considerably.

The large volume of a bag house is in part caused by the great height of the building. In fact, the two types of filter do not differ so much in demand for ground area.

Nevertheless, so far we have preferred to use glass fibre bags, because of greater temperature flexibility and because of uncertainties of sulphur attack on Nomex. In addition glass fibre bags are substantially less expensive. These fans produce some noise. Speed controlled fans are less noisy, a fact in favour of this control method. The noise may be reduced, however, by using silencers specially developed for this purpose by our consultants on noise problems.

Micro silica

The dust collected in the smoke cleaning plant was until 1980 considered to be more or less wasted material. Except for some minor quantities used for powdering of fertilizer grains most of the silica dust was pelletized and dumped or used as landfill. However, extensive research and development have opened new area of application for this by-product from ferro silicon and silicon metal production.

Today a company Elkem Chemicals with main office in Kristiansand and branch offices in USA and England, employing altogether 60-70 persons, is marketing the silica dust under the name of Elkem Micro Silica.

The research has demonstrated that the microfine particles ($\sim$0.1 micron) of micro silica possess physical and chemical characteristics which have great property enhancing effects on a vast range of concrete, refractory and polymer products.

PART—II

Energy recovery in the ferro alloy industry

The interest for energy recovery system is increasing rapidly in the ferro alloy industry. The main reason is that electrical energy is becoming more expensive and availabe power more limited. Consequently recovered energy is becoming more competitive. Regulations and incentives given by local authorities may also accelerate the development. It should be emphasized that the situation varies from one country to another and often from plant to plant. Fig. 11

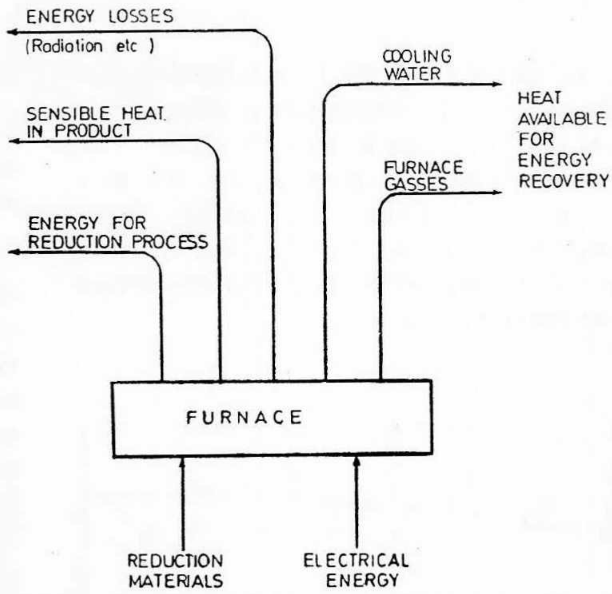


FIG. 11. SIMPLIFIED ENERGY BALANCE DIAGRAM

shows a simplified energy balance diagram for a ferro alloy furnace. Electrical power and reduction materials represent the process energy input. The metal is tapped at an elevated temperature. In practice it is difficult to utilize the metal sensible heat. Heat is lost from the furnace to the surroundings. Energy is lost in the furnace gas and in the cooling water. but a considerable part of this energy may be recovered. The available heat for energy recovery will mainly depend upon the process in question. The form in which the recovered energy may be utilized is as steam, hot water, electrical power or combinations of these. The unburned calorific gas from a closed furnace may be used directly as a fuel or for chemical purposes. It is natural to consider some aspects of energy recovery for closed and open furnaces separately.

We have previously seen how we can increase the temperature leaving the smoke hood by limiting the dilution air entering the smoke hood to about 3 Nm^3/kWh. The gas temperature from the furnace will normally be 700-900°C. Limitations in allowable temperature on furnace equipment and in hood design puts for the time being a stop to a further reduction of the gas volume from the furnace. This type of hood is equipped with large doors to facilitate stoking. It is necessary to have a certain minimum dilution air quantity through the openings to prevent gas from escaping. If the temperature is increased too much, there is a certain possibility that the dust may sinter on the heat transferring surface.

The reduction materials will normally contain sulphur. A sulphur content of 2% by weight of fixed carbon will result in a SO_2 concentration of approx. 400 ppm. Hence, if the waste gas temperature is lowered too much, the acid dew point in the gas will be reached causing corrosion on the tubes in the economizer at the steam generator outlet. The outlet temperature should therefore normally be about 200-230°C.

By reducing the specific volume to 3 Nm^3/kWh the size of the bag filter will be only 25% in size of a filter for a low hood furnace, and the power consumption for the filter plant will be reduced to approx. one third.

The energy content in the gas from the furnace may be stepped up by selection of raw materials with a high content of volatiles. On the other hand the choice of reduction materials should not have a negative effect on the production result as the main purpose is to produce metals, not power. As a result a combination of simplicity and cycle efficiency to give an optimum total solution must be found. This solution will, however, vary from plant to plant. An endeavour to utilize all energy in low temperature water and waste gas means a more complicated plant layout and operation. Fig. 12 shows the amount of energy available for energy recovery when producing 75% FeSi Coal constitute 40% by weight of the reduction materials. Wood chips are used. The silicon recovery is taken as 87.5%. The energy content in the gas is in this case approx. 5% higher than the electrical energy input. The heat of

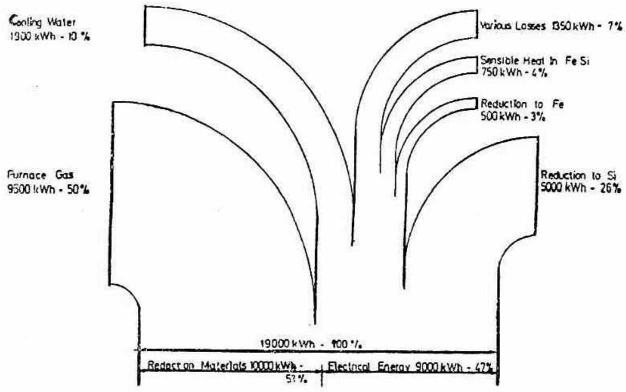


FIG. 12 SANKEY DIAGRAM FOR 75% FeSi FURNACE (kWh values per ton metal)

combustion from the volatiles will contribute with approx. one quarter of the energy content in the gas. This indicates the influence of the reduction materials on the energy in the gas.

The energy from an open furnace may be recovered as steam, hot water, electrical energy or as a combination of these. The choice of form is influenced by various factors All alternatives, however, imply the use of a steam generator. If the steam produced can be utilized as such, the efficiency of the energy recovery will be high. However, most likely there will be no need for this huge quantity of steam within the smelting plant itself. Therefore this alternative is feasible only if an industry requiring steam for its processes is located in a reasonable distance from the smelting plant.

As in most cases it is difficult to find a market for steam and hot water, production of electrical power in a turbo generator will be the only realistic and natural alternative. An energy recovery plant of this type is shown on Fig. 13. The steam from the steam generator expands in a turbine which runs the power producing generator expands in a turbine whice runs the power producing generator. The steam is then condensed in a heat exchanger, and the condensate is pumped to the deaerator tank from which it is returned through the feed pumps to the

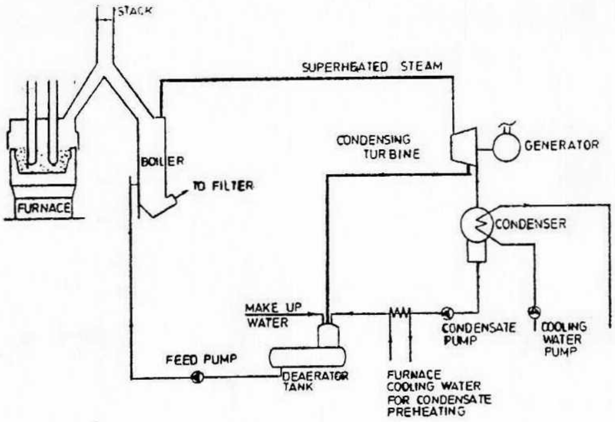


FIG. 13 ENERGY RECOVERY CYCLE WITH CONDENSING TURBINE

steam generator. Make up water is added to the system in the dearator tank.

Fig. 14 indicates the quantity of energy which can be recovered in case of a 30 MW, 75% FeSi furnace. The furnace gas in the energy balance diagram already shown in Fig. 12 is used as basis. The gas volume of 3 Nm^3/kWh is passed through a steam generator. The thermal efficiency is approx. 80%. The main loss is in the gas leaving the steam generator with the already mentioned temperature level of 200-230°C. Approx. 30% of the steam energy input to the turbine is converted to electrical power in the generator. In this case the recovered electrical energy represents approx. 25% of the electrical energy supplied to the furnace. In general this relationship will vary within an approximate range of 22-27% depending upon the type of reduction materials in the charge.

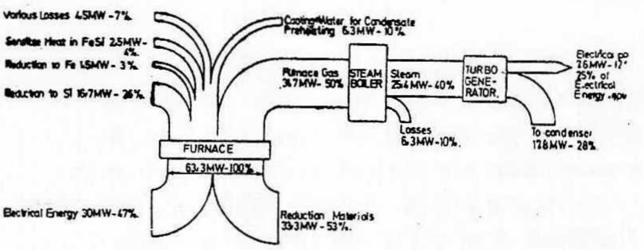


FIG. 14 ENERGY RECOVERY FOR A 30MW 75% FeSi FURNACE

The total efficiency of thermal electrical power plants is low compared to hydroelectrical plants. The degree of expansion through the turbine will influence upon its efficiency. The expansion depends upon the turbine outlet conditions which in practice are the condenser absolute pressure and temperature. These parameters should therefore be kept as low as possible. With a water cooled condenser having for instance a cooling water temperature of 20° C it should be possible to have a vacuum with an absolute pressure of approx. 0.075 bar with a resulting condensate temperature of 40°C. Air cooled condensers may alternatively be used for example due to lack of water. They will normally result in a higher condenser pressure. The turbine described above is called a condensing turbine.

Simultaneous utilization of electrical power and steam for heating or process purpose will result in a considerably higher total efficiency. In this case a back pressure turbine is installed as shown in Fig. 15. The expansion through the turbine is restricted, and the steam is leaving with a higher pressure and temperature than from a condensing turbine. This means a reduction in electrical power output. On the other hand it is possible to take advantage of the heat of evaporation in the steam.

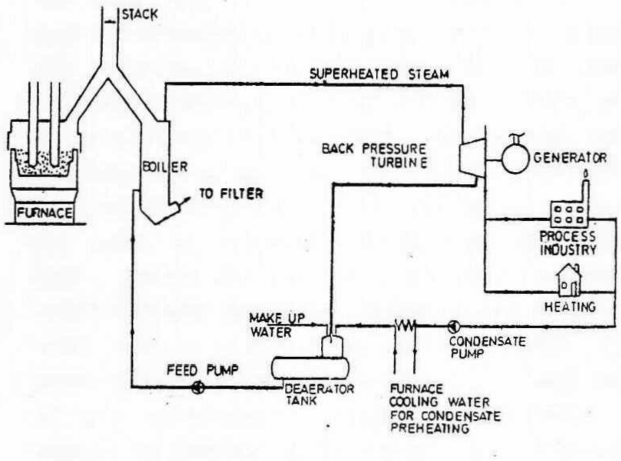


FIG. 15 ENERGY RECOVERY CYCLE WITH BACK PRESSURE TURBINE

The main concern when designing the steam generator, is to avoid dust clogging to the heat transferring surface The dust concentration in the gas from a 75% FeSi furnace is within wide ranges. However, when operating with 85% silicon recovery, the average concentration is approx. 10 g/Nm³. The dust particles which are extremely fine in size, stick very easily to exposed surfaces. Even a thin layer of this dust will have a fatal effect due to its insulating characteristics.

The design pressure and temperature of the superheated steam from the steam generator should be chosen in close cooperation with the turbine manufacturer to give the optimum solution. The steam generator delivered to France is for example designed for 36 bar, and the steam is superheated to 435°C. An increase in pressure and temperature gives a higher efficiency of the energy recovery cycle. The turbine efficiency is, however, slightly reduced if the pressure is too high. Higher pressure does also mean that the steam generator becomes more expensive and the water quality specification more strict.

A typical steam generator for an open ferro alloy furnace is shown in Fig. 16. It is in general identical to the one in operation in France, the main difference being that the latter is divided in two vertical passes in series instead of one due to its size The gas is passing vertically down the steam generator through the first part of the evaporator, the superheater, the second part of the evaporator and the economizer before leaving. The walls around the evaporators and superheater consist of welded tube panels with natural water circulation and are part of the evaporating surface. The heat content in the gas leaving the furnace is fluctuating due to charging, stoking etc. The reason for dividing the evaporator in two parts is to absorb the peaks of the heat in the first part of the evaporator before the gas is entering the superheater. This makes it more convenient to control the temperature of the superheated steam to a constant value.

The feed water pump delivers the water

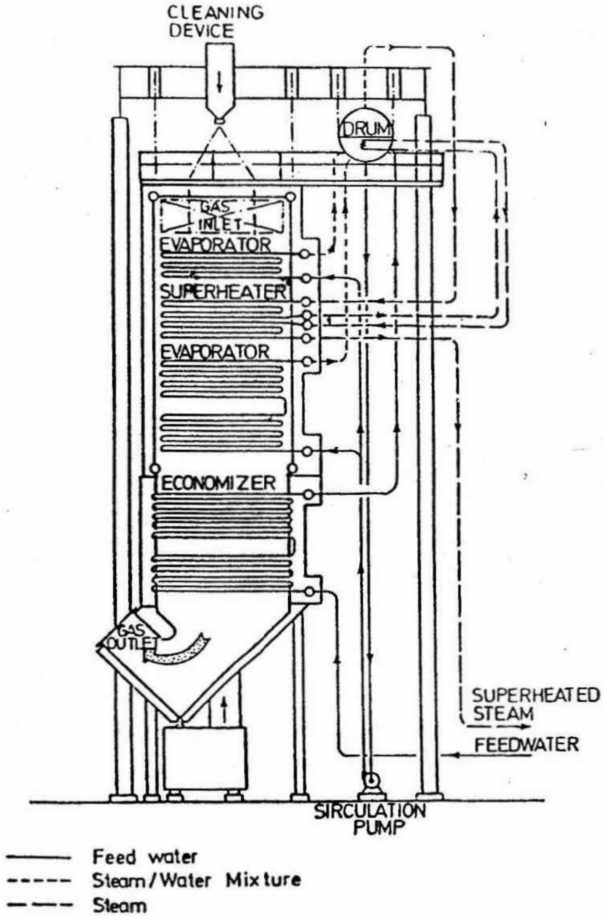


FIG. 16 TYPICAL HEAT RECOVERY STEAM GENERATOR FOR FeSi-PLANT

through the economizer to the drum. The water entering the boiler is preheated to avoid corrosion in the economizer where it is further heated. The evaporator circuits have forced circulation. The circulation pump delivers hot water from the drum through the evaporators where part of the water gets evaporated. The mixture of steam and hot water is returned to the drum. The superheater consist of two tube bundles, the primary and secondary superheater. The steam temperature is controlled by passing a fraction of the steam via a heat exchanger placed inside the drum before entering the secondary superheater.

Different cleaning systems to avoid dust settling on the tubes were tested out before the actual installation in France. In the system adopted small steel shots are conveyed to the steam generator top and fed into a device spreading them over the whole cross sectional area. The shots on their way down the steam generator hit the tubes and successfully prevent dust from clogging. The tubes should not be finned.

As mentioned a relatively large amount of heat is transferred to the water in the furnace hood cooling circuit. Hot water is used to avoid corrosion on the tube external surface. The heat removed in the hood is used to preheat the condensate before entering the deaerator tank. Alternatively the hood may be designed to be an integrated part of the boiler evaporat ing surface.

In this instance, the circulation pump will also distribute hot water from the drum to the hood. The plant in France is based on this principle. The choice of system must be decided upon in each case. With the hood as an evaporator, steam must be bleeded directly from the turbine to the deaerator tank to preheat the condensate. The purpose of preheating in the tank which is also a buffer reservoir, is to drive off oxygen from the water. It is esential to avoid leakages in the system through which air can be introduced.

The available raw water may contain suspended and dissolved materials. It must therefore be treated before it is added to the heat recovery plant as make up water. The type of water treatment required depends upon the analysis of the water. The main object is to prevent corrosion and scale formation inside the tubes. It is necessary to remove oxygen and carbon dioxide from the water and to control its pH-value if corrosion is to be avoided. The scale formation will normally consist of chemical compounds containing calcium, magnesium and silicon. The scale has a heat insulating effect. The tendency of scale formation is largest in the part of the surface where the heat effect is highest and the evaporation is most vigorous. This would result in excessive steel temperature and tube rupture.

If there is a general shortage of electrical power greater than the amount that can be regained, additional firing with oil or gas may be a solution. The same applies if the price for power is high or if it is a requirement to find the optimum thermodynamic solution. The gas leaving the steam generator may for instance be used as preheated combustion air in a separate oil or gas fired steam generator. However, such an installation will have a much more complex design. It should be remembered that even the simplest energy recovery plant for production of electrical power will involve a new and unknown technology and work situation.

The gas from a closed furnace may be used in different ways. Due to its calorific value and low dust content when cleaned, some works are using it as fuel for various heating purposes. In some cases it is sold for use in chemical processes. Alternatively it may be burned in a gas fired steam generator. The steam could then be used for production of electrical power as previously described.

For a certain ferro alloy reduction process the steam generator efficiency will be higher for a closed furnace than for a semi-closed furnace due to the reduced gas volume and consequently the higher temperature. The amount of false air can be reduced to the quantity required for combustion.

For the FeSi and Si-metal processes theoretical considerations and operating data from the closed test furnace indicate that the energy content in the gas from a closed furnace is slightly lower than for a semi-closed furnace. This is, however, outbalanced by the higher steam generator efficiency, and the total amount of recovered energy.

Steam boiler for uncleaned off-gases

To use the uncleaned gas as fuel in a boiler special care must be taken due to the high dust concentration. A functional test started in 1979 of a small hot-oil boiler with an energy input of 830 kW. The results from this pilot boiler indicated that it was possible to burn the uncleaned gas without clogging of dust on the boiler heating surfaces. The test showed that special care had to be taken in the design of the gas transport system, the burner and of the boiler combustion chamber. In 1980 our company established a cooperation agreement with Gφtaverken Angteknik AB, Division Maskinverken (GVA) in Sweden for waste heat boilers for semi-open ferroalloy furnaces. Together with GVA our company made a new design for a natural circulating water tube boiler specially designed for the purpose of burning uncleaned CO-gas from the closed 75% FeSi furnace at ELKEM a/s, Bremanger Smelteverk.

Boiler design

A schematic drawing of the boiler system burning uncleaned gas from the closed furnace is shown in Fig. 17. The uncleaned gas is transported from the furnace stack through a specially designed, isolated pipeline, 80 meters long, to the boiler gas burner. The transport system is equipped with its own raw gas stack serving as a safety relief of the gas in case of an unexpected shut down of the boiler. Since the transport system handles uncleaned gas with inherent explosion hazards, a safety system in collaboration was developed with the National Inspectorate for Explosive and Flambles. To ignite the mixture of uncleaned gas and air, the boiler is equipped with smaller igniter using propane gas as fuel. The propane as burner has an input effect of about 220 kW. The gas burner is placed at the top of the combustion chamber. The bottom of the combustion chamber is equipped with a continuous screw conveyor removing the precipitated dust. The superheater and economizer surfaces are placed in last passage of the boiler. The heating surfaces are cleaned by means of shoot-cleaning.

To reduce the costs of the boiler the exit gas temperature is very high as shown in table. The standard Bag House filter design temperature is lower than boiler exit temperature. Therefore, the exhaust gas had to be diluted to reach acceptable temperature conditions.

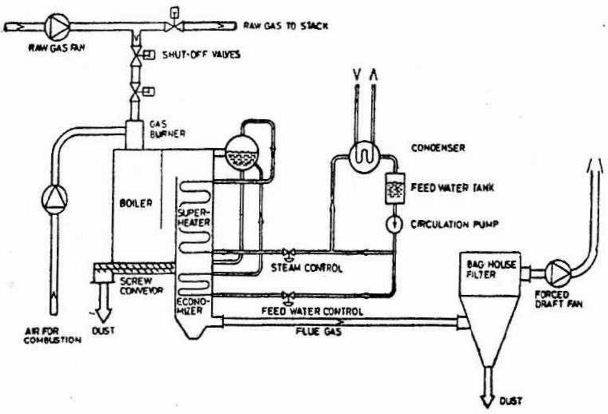


FIG. 17 SCHEMATIC FLOW-SHEET OF BOILER FOR UNCLEANED GAS

The superheated steam produced by the boiler is reduced in pressure and temperature before entering the condenser. The condensate is pumped back to the boiler by a circulation pump.

The aim of the project :

- To observe the behaviour of dust in the transport system, the gas burner, in the combustion chamber and on the heating surfaces.
- To measure the efficiency of the boiler during different operating conditions.
- To measure and analyse the dust and gas leaving the boiler.

Experience and results from the operation

The first test of the boiler using uncleaned gas as fuel was carried out during the period November-December 1981. The results of this test showed that the special care which has been taken in the design of the boiler was a success. The test was carried out with different inputs and different excess air ratio. Table shows the results from three different operations of the boiler. In the last campaign the shoot-cleaning device was not used, and this resulted in a lower degree of superheat as seen in table :

TABLE

Results from three different operation conditions for the boiler using uncleaned gas as fuel.

Operation No	1	2	3
Gas flow (mn^3/h)	850	1000	1250
Gas temp. (° C)	180	187	219
Excess air (mn^3/h)	2675	3400	3750
Excess air ratio (%)	41	52	35
Fuel-gas temp. (° C)	340	375	380
Steam flow (tons/h)	3.0	3.6	4.3
Steam pressure (bar)	18	17.5	17.5
Steam temp. (° C)	370	390	370
Feedwater temp. (° C)	98	99	103
Boiler efficiency (%)	81	78	81

The efficiency of the boiler was higher than expected due to less dust layer on the heating surfaces. As shown in table the boiler efficiency was 78% to 81%, depending on the excess air ratio, even though the exhaust gas temperature was about 380°C. With an exhaust gas temperature of normally 180°C, the boiler efficiency will increase to 89%. During the test period samples of the dust were drawn in order to determine chemical analysis and physical properties.

Analysis of the dust for carbon showed that the content was decreased to an average of 2.5%. The volume weight of the dust was increased to an average of 300 grams per liter, compared with an average of 70 grams per liter for the dust from the furnace. As the dust passes through the boiler, the specific surface reduces to 1/10. Analysis for polycyclic aromatic hydrocarbons (PAH) shows that the content is reduced to less than 100 ppm. Due to the high temperature in the combustion chamber some of the amorphous dust changes to crystalline dust. Most of the crystalline dust was unloaden at the bottom of the combustion chamber of the boiler.

References :

Piene, Kristian and Pedersen, Thor "A More Energy Efficient Ferro Silicon Process". Presented at INFACON 83, the 3rd International Ferro-Alloys Congress, Tokyo, May 8-11, 1983.

Discussions

R. Y. Sane, Paramount Sinters Pvt. Ltd., Nagpur

Q. What is the effect of carbon monoxide at elevated temperature on the filter tubes made of INCONEL ?

A. We have had no bad experience while using INCONEL tubes. But we have hardly been above 400°C at the tubes.

Q. Do you suggest the use of Electrostatic precipitator for gas cleaning in Ferro-alloy industry ?

A No, we have had bad experiences with electrostatic precipitator for our Ferrosilicon/ Silicon metals furnaces at Fiskaa Verk.

M. Subramanian, FACOR, Shreeramnagar

Q. While direct burning of uncleaned gas, do you find any change in the size and shape of dust after burning and collected in Bag houses ?

A. We have noticed a tendency to become crystalline in the case of dusts that are left in the combustion chamber.

Q. What maximum dust load can be used for uncleaned gas ?

A. We have no exact figure for the maximum dust load of the uncleaned gas but we had no problem with dust content upto 200 g/Nm^3.

C. N. Harman, FACOR, Shreeramnagar

Q. Could you give an approximate idea of the capital cost and cost per kWH of energy produced in the French plant and the proposed Indian plant ?

A. It is difficult to give a figure on capital cost. The cost of energy produced would be approximately 14-15 paise per kWH.

Q. What are the chances of explosion due to air leakage in case of covered furnace gases being taken through the filter ? Any safeguard to eliminate such happenings since such explosion would cause extensive damage to the filter ? We have had experiences of safety flanges of rubber provided in the old rotary scrubbers blowing out.

A. The filter consist of several relatively small units to minimize the effect of any possible explosion.

G. Rangarajan, Maharashtra Electrosmelt Ltd., Chandrapur

Q. With reference to one of your slides showing recovery of heat from the raw gas of a closed FeSi furnace, what is the temperature of the off gas ?

A. The temperature of the off gases varies from 300 to 700°C.

Q. What is the quantity of solids in g/Nm^3 ?

A. The quantity of solids in the off gases is around 50 to 60 g/Nm^3.

Q. Can similar experiments be used efficiently in FeMn furnaces ?

A. Yes, they can be used for FeMn furnaces also.

Q. Referring to the slide showing a view of bag house where a person can enter for inspection/repair of bags, how do you take care of the problem about the hazards of CO gas ?

A. One has to ensure that there is no CO content in the area where the man is going.