Progress of Emission Control System in Electric Arc Furnace Melt-shops

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Recently, in order to improve the environment surrounding steel-mill sites, electric arc furnace steel-making melt-shops have been constructed to capture and contain the gases, dusts and other emissions generated within the workshop-buildings. This measure, however, has lead to the deterioration of the working atmosphere for the operators, and even with the installation of large-capacity dust collectors, sufficient results are not necessarily obtained. Problems have also developed in the direct evacuation systems, since the ductwork of the systems is often damaged by the high-caloric exhaust gas and corrosive components in the gas. In this discussion, the technologies developed by NKK to cope with these problems are examined.

1. Introduction

Electric arc furnaces use iron scrap as a major iron component in the manufacture of steel primarily used in construction industry. In most advanced countries EAFs produce 30–35% of total steel production. The composition of scrap, which is substantially an industrial waste, constantly changes and cannot be accurately defined, as it contains up to 2% of such combustibles as oil, plastics, and paint. Since many meltshops are installed in urban areas where scrap is easily obtained, air pollution contained in off-gas emissions from an EAF melting furnace can sometimes becomes a serious problem. In Japan in the last 20 years, air pollution problems emanating from melt-shops have been resolved by fully enclosing the melt-shops and installing a large capacity secondary emission control system. However this has led to other concerns such as the environmental deterioration of the in-plant workspace and an increase in electric power consumption required by larger fans. Additionally, dioxin contained in baghouse off-gas has become controlled under recent regulations. And its density in the workspace atmosphere may be regulated in the near future. This problem cannot be solved by simply increasing the flow rate capacity of the dedusting system, therefore NKK has been systematically changing the criteria for design and operation through investigation of the relationships between the off-gas emission pattern, in-house gas stream, operational sequence of the dedusting system, and floating dust loading of the workspace atmosphere.

The design concept of a direct evacuation system, which induces process gas to cool down and dedust, has changed dramatically, as the demand for higher power-input and additional oxygen/fuel injection has increased which has created a higher calorie furnace off-gas. As a result of this, NKK has revised its design standard based on an off-gas pattern developed from the process simulation and measured data in order to establish a more durable, simplistic system, with a low operational cost. Since damage to water-cooled ductwork by corrosive gas components is frequent in every meltshop, and maintenance cost and down time

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can be considerable, NKK has investigated and developed measures to reduce these problems.

2. Conventional dedusting system in an EAF melt-shops

Fig. 1 is a conventional dedusting system for a typical EAF melt-shops with a 100 tons EAF. The total dedusting system consists of (i) a direct evacuation system and (ii) a secondary emission control system. The former is used to induce outside air into the high-calorie off-gas from the furnace to assist with combusting the uncombustibles, primary dedusting, and temperature reduction of the hot gases before it is sent to the dedusting equipment. The hot gas temperature is cooled down to approximately 350°C through a long (100–150 m) water-cooled duct and then mixed into the secondary emission control system via a direct evacuation blower. Gas flow rate is about 2000–2500 m^3_N/min for 100 tons EAF.

The latter one, the secondary emission control system, is used to ventilate the total EAF melt-shops. Gas flow rate is about 20000 m^3_N/min after being mixed with the former hot gas. A main canopy is installed above the furnace in order to collect transient hot gas which is generated during the scrap charge. There are several additional canopies for auxiliary dedusting thus permitting gas temperature at the baghouse to be less than 100°C.

There are cases where the direct evacuation gas is not mixed with the secondary emission control system and a baghouse is installed separately. However, in this case gas temperature at the separated baghouse may sometimes exceed 200°C and the elimination of dioxin by condensation becomes more difficult. For this reason the confluence type design is becoming the more acceptable standard.

3. New technology and design criteria for secondary emission control system

3.1 Conventional concept

Since it is not easy to define a floating dust load quantitatively, the inheritant capacity capability of the dedusting system has been recognized as the fan and baghouse capacity. This capacity is determined based

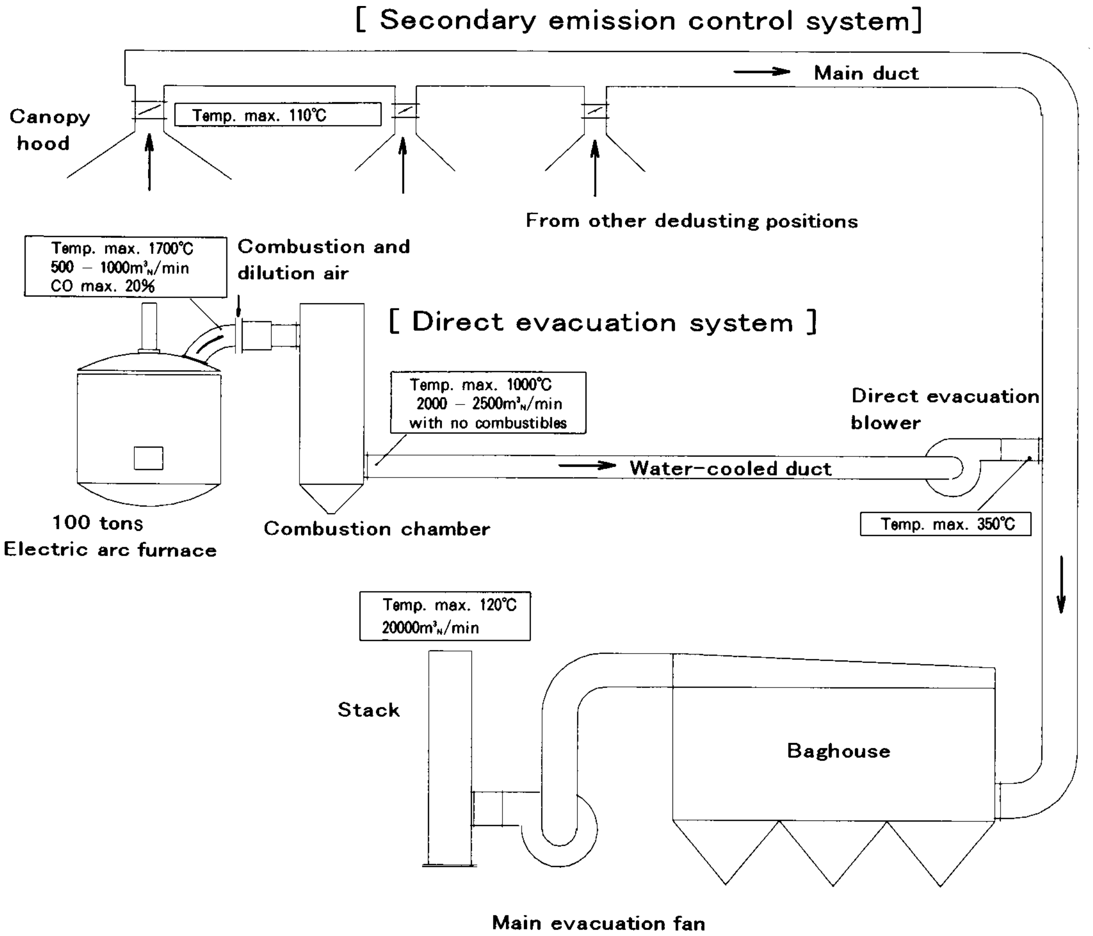

Fig. 1 Typical 100 tons EAF melt-shops dedusting system

on the number of ventilation cycle times. When the inner volume of the meltshop building is 120000 m^3 and flow capacity is 20000 m^3/min, the number of ventilation cycle times is defined as 10 times/hour (20000 $\times$ 60/120000=10). Satisfactory cycle times is, from our experience, approximately 20. It is desirable from the standpoint of investment and operation costs to reduce this number.

As for the flow pattern analysis in the meltshop building, two-dimensional, isothermal, and static potential flow analysis has been generally used. However, when determining the total affect on the dedusting system it is necessary to include the hot gases and dust generated during scrap charging and the influence of other heat sources such as ladle heaters and continuous casting machines.

3.2 Floating dust loading

Floating dust load in the workplace atmosphere is an essential factor to consider when evaluating the performance of a dedusting system, and was not previously considered quantitatively in the melt-shops planning stage. In more recent cases these figures are sometimes required (4 mg/m^3, for example). However, such items as dust particle size, measuring location, measuring method, peak/average definition were not specified. These factors are also indispensable in order to guarantee the required value.

Approved iron-oxide dust loading in the workplace, by the Industrial Safety and Health Act, is 5 mg/m^3. The particle size to be measured shall be smaller than 7.07 μ m, which is considered to be the size capable of reaching the human lung[1]. Gas speed into the measuring probe shall be settled to suck these particles. There are two types of method to measure the floating dust loading, (i) mass loading type and (ii) relative loading type. When measuring by the mass loading type, the dusty gas is continuously sucked through a filter paper for several hours. Dust loading is then calculated by the increase in filter weight and the gas volume passed through it. The measured value then is determined to be the average based on measured time. The relative loading measurement uses the scattering-light principle. Dusty gas is introduced into a dark box and receives laser light. The dust loading is calculated by the strength of the scattering-light. Dust loading fluctuation can be observed by this method. As the level of the scattering differs, depending on the materials, measurement to define the conversion factor shall be done using the mass loading type in parallel for each type of dust.

Since the Industrial Safety and Health Act prescribes the acceptable average value during the working time, the exposed dust loading can be measured by portable equipment carried by an operator. This small and portable relative dust loading monitor can measure the change of dust loading every several seconds. NKK has noticed the applicability of this equipment and investigated the relationship between the dust loading in the workplace and the furnace operation. **Photo 1** shows the measuring device used for this case (PDM-1010 by Shibata Kagaku Kikai).

Photo 1 Digital dust indicator

Monitors are mounted on tripods and placed on the working floor. After a several hours of measurement they are collected and the stored data are transferred to a personal computer. **Fig. 2** is an example of this measurement (1997 Oct., M-Steel K-Melt-shops). NKK is using the following locations in order to compare the data among the melt-shops:

A : working floor, in front of the operating room

B : working floor, near the tapping site

C : others (crane deck in this case)

The relationships between the dust loading and furnace operation observed from **Fig. 2** are as follows:

(1) Large amount of dusty hot gas generated during the scrap charge makes a strong ascending stream caused by buoyancy. This stream ascends with the air around the furnace and the dust loadings at points A and B are reduced in this period.

(2) The main canopy hood above the furnace does not capture all of this hot gas simply because after reaching the canopy and the ceiling these hot gases descends along the wall and remains at the level of point C. This tendency also is demonstrated in the dynamic stream analysis explained in the next chapter.

(3) Dust loading reaches its peak at points A and B immediately following the commencement of carbon injection process which this period the off-gas temperature from the furnace makes very high in turn causes the direct evacuation system to exceed its capacity.

NKK has surveyed these measurements at 10 melt-shops and has investigated the relationships between floating dust loading, furnace operation, and the specification and operation of the dedusting system. This information has been effectively used for operation pattern setting, equipment improvement planning, and the correction data for the dynamic stream analysis.

3.3 Dynamic stream analysis in the melt-shops house

An electric arc furnace is a typical batch melter with repeated cycling of operations that include a roof opening, scrap charge, roof closing, melting, refining, tapping, and repair in about an hour. The hot dusty gas generated from the furnace causes a strong heat convection. Isothermal, static, and potential flow analysis cannot describe the actual stream in the melt-shops building. NKK has applied a three-dimensional unsteady flow analysis using a high-power computer to a melt-shops in-house flow analysis and obtained good results. The following is an example of T-steelmill I-factory.

Applied method
: finite volume method

Software
: SREAM V.2.4

Housing size
: L 117 m × W 55 m × H 57 m

Mesh division
: 86 × 48 × 41 meshes
(169248 elements)

Time division
: 0.1 second

Calculation time
: from –60 to +600 seconds
Zero equals the scrap charge time, and the roof open/close and crane movements are considered during this time.

Boundary conditions
: Building roof and wall are thermally insulated.
Furnace surface is 100℃.
When roof is opened, the furnace upper surface becomes very hot.

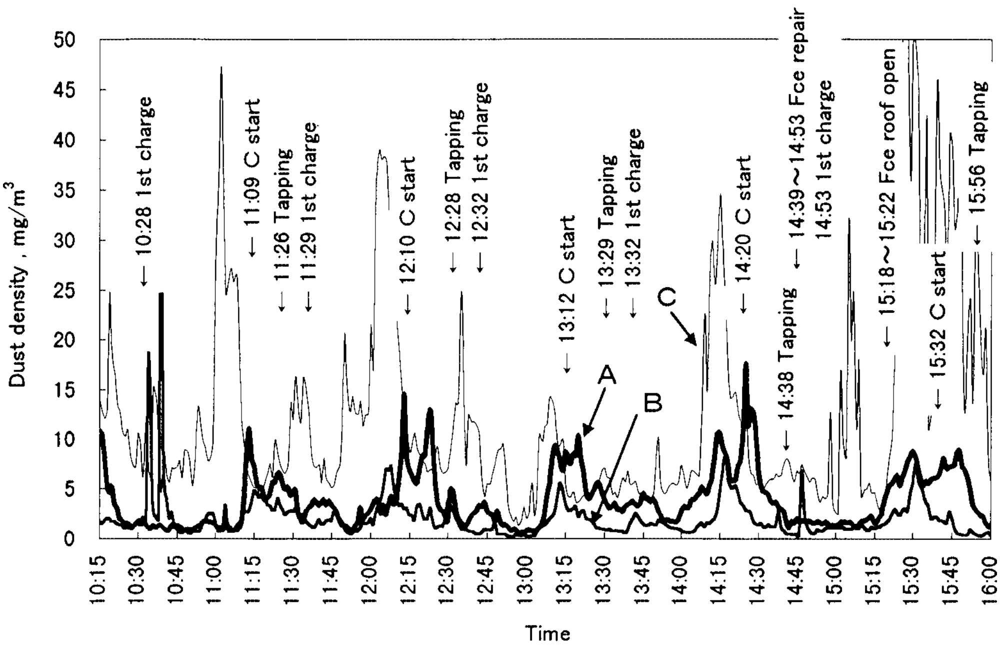

Fig. 2 Change of floating dust loading

Such heat sources as ladle heater and continuous casting machine exist.

Suction flow rates through canopy hoods change according to the settled pattern.

Measured data are used for hot gas temperature, flow rate, and dust loading which is generated during scrap charge.

Diffusion and settling velocity of dust are calculated based on a supposition that the dust size is smaller than 7.07 μ m.

Calculation outputs are temperature, dust loading, and the gas velocity vector of each cycle time and location defined. **Fig. 3** and **Fig. 4** are examples which show dust loading distribution 480 seconds after the scrap charge. **Fig. 3** is the case for existing equipment where the decrease in dust loading takes a fairly long time. **Fig. 4** is the result of the case study of improvement, where the isolation wall for CC yard is installed, ventilation air inlet positions are properly arranged, and the air flow rate through a canopy hood is increased. The decrease in dust loading with the improvement is remarkable. NKK has executed so far four engineering works for improvement based on this stream analysis. The effect of the work is that the floating dust loading has decreased to 20–40% of the original data.

3.4 New design concept for secondary emission control system

Based on the measured data investigation, stream analysis, and in-plant observation, the following concept has become the new criteria to be used when plan-

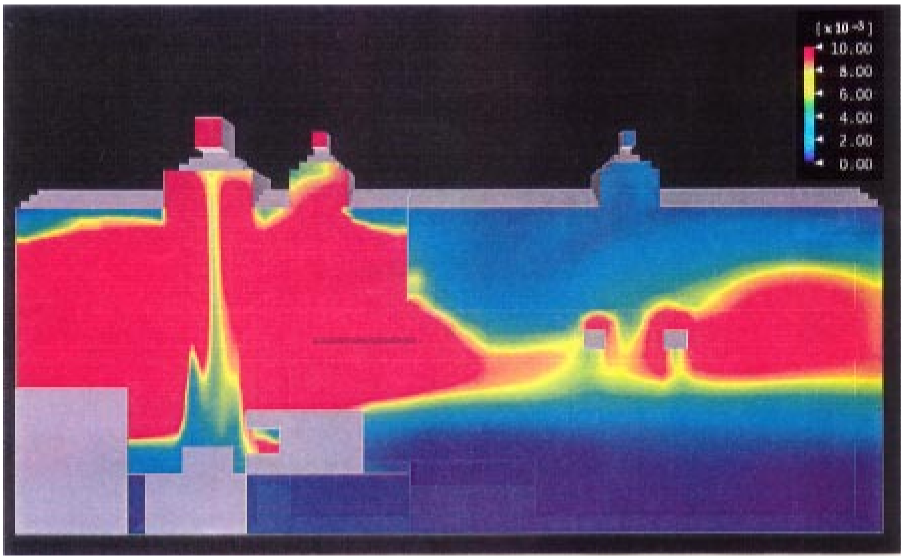

Fig. 3 Floating dust loading before modification

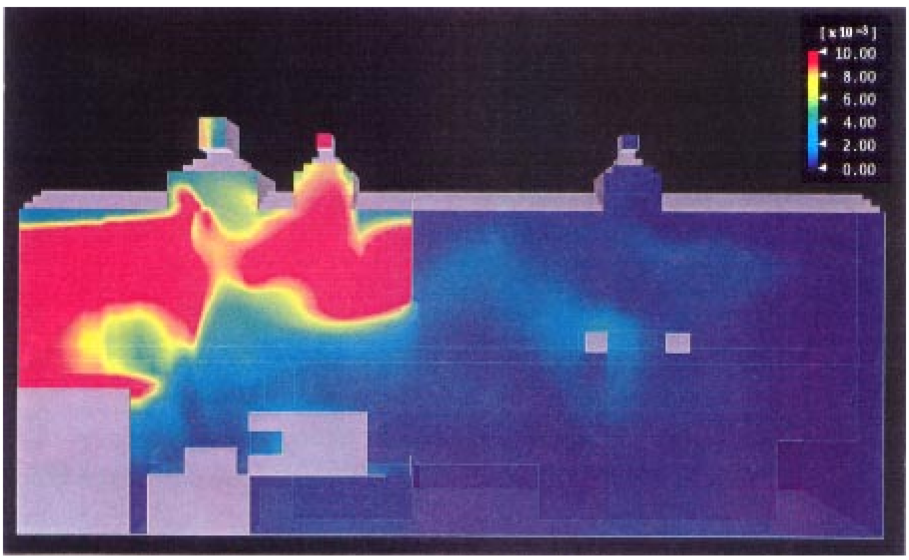

Fig. 4 Floating dust loading after modification

ning the initial design or the improvement of a secondary emission control system.

(1) Since induced air velocity varies inversely proportional to the square of the distance from the source to the canopy hood and a strong ascending stream around the furnace is caused mainly by heat convection, a hood such as that located above a charging crane is not an effective design because of its distance from the source.

(2) A canopy hood should be centralized without separating. Induced air through building openings should be directed to the furnace and be emitted through a main canopy with the aid of the ascending stream caused by heat convection. Location of the openings at various areas of the building should be designed to eliminate stagnation points. A wasteful stream short cuts from an opening to the canopy without passing through a dusting source should be reduced to minimum.

(3) The EAF enclosed building should be as small as possible for good ventilation. It will become a doghouse system as an ultimate style.

(4) The structure of a charging crane should be considered so as not to obstruct the ascending stream from the furnace.

(5) Heat sources in a melt-shops should be reduced or isolated from dusting sources[2]. The heat generated at ladle heaters and the continuous casting area cause a strong ascending stream which enters the canopy preferentially, thus pushing the dusty air from the furnace aside. Ladle cover works effectively in order to avoid this inconvenience. Also a regenerative burner system, which can lower the exhaust gas temperature drastically, is effective when used for ladle preheating. Continuous casting area should be isolated from the EAF area with curtain walls or fixed walls to permit ascending air in the CC area, which is not dusty, to be emitted outside without dedusting.

4. New technology and design criteria for direct evacuation system

4.1 Conventional concept

Furnace off-gas has such characteristics as high temperature, high uncombustibles, and dense dust loading, which vary frequently within a wide range. Large quantities of air is induced at the elbow position to combust the uncombutibles in the off-gas and to lower the temperature by dilution.

Historically conventional designs do not normally provide a control system which considers an off-gas generation pattern that can regulate the induced air into the system. Because the temperature of the off-gas is reduced by inducing additional air at the elbow and by using long water-cooled ductwork, cost consideration can be given to the design of expensive ductwork and the cost of the electrical energy consumption required to circulate and treat the water. This generally equates to 30–50% of the electric power consumed by the dedusting system fans. Consideration can also be given to a reduction in cost to repair and maintain the ductwork and its related downtime which is caused by elevated temperature erosion and acid corrosion.

4.2 Furnace off-gas

The first step in the design of a direct evacuation system is to specify the furnace off-gas temperature, flow rate, and composition. NKK has established a process simulation to describe each time-step furnace phenomena with an input operation pattern[3]. This system can calculate the furnace off-gas specification at each time step. Design configuration will be determined by using these figures with some margin. The furnace heat balance indicates that the majority of heat loss is contained in the exhaust gas. In other words, the lower the furnace efficiency, the higher the off-gas calorie content, thus the heat load to the direct evacuation system increases. **Fig. 5** is an examples of actual off-gas data of temperature and composition at the elbow. The problem of this furnace was not only the low thermal efficiency caused by the high calorie off-gas but also high gas temperature at the baghouse[4].

Since the off-gas generation pattern varies depending on the operation pattern and types of ancillary equipment such as burners and lances, it is not easy to establish the most suitable dedusting system. NKK has, however, standardized the design criteria based on process simulation, measured data, and experience from many furnace installations.

4.3 Damage of water-cooled ducting

Damages of water-cooled ductwork with high gas temperature content is caused mainly by thermal stresses. This problem has been solved by increasing the water flow rate and using a tube-type duct design instead of a plate-type. A problem which frequently occurs is inner wall corrosion in the low temperature portion. From a detailed examination it was observed that the level of the corrosion was the greatest at or near the cooling water inlet point and when the shell surface was coated with a dust layer. The corrosive gas components were measured in order to investigate

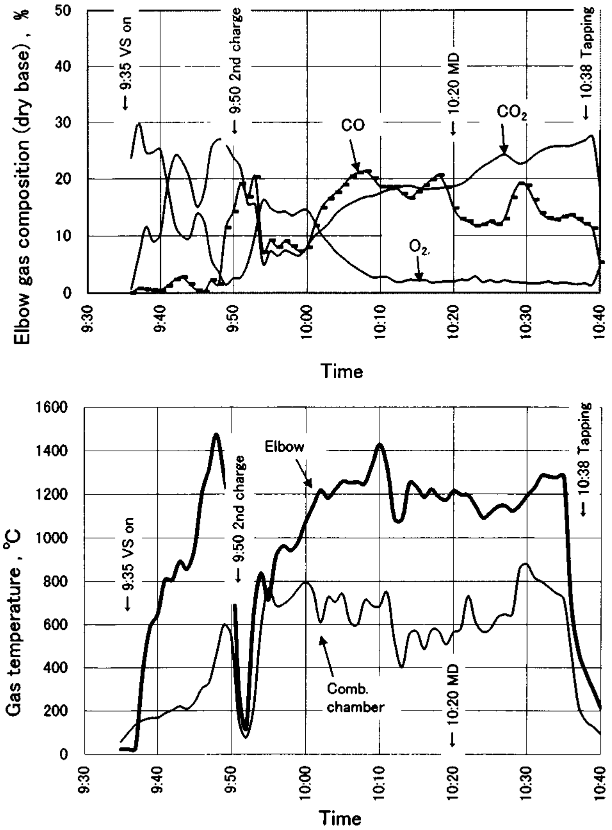

Fig. 5 Furnace off-gas data

the phenomena and the following data was revealed:

(1) As for the acid elements, sulphur dioxide and nitrogen oxides were at a level of several ppm. Hydrochloric gas, however, showed a very high concentration (close to 1000 ppm) during the early stage of the melting period.

(2) Moisture is constant at 8–9%, but was reduced to approximately 2% when electrode spray cooling is eliminated.

It is presumed from this data that low temperature corrosion took place which was caused primarily by hydrochloric acid that was formed by hydrochloric gas being absorbed by the condensed water on the shell surface during low temperature period. When H_2O in the gas at 8% dew point is about 42℃, and when H_2O is 9% it is about 45℃. As inlet temperature of the cooling water is about 35℃, the shell surface temperature under the dust layer will easily become lower than the dew point, thus resulting in water condensation. **Fig. 6** shows the equilibrium between HCl in the gas and the HCl in water (Data from NKK Research Center). Assuming HCl in the gas as 1000 ppm (0.1%) and H_2O as 9%, hydrochloric acid concentration is approximately 16%.

Fig. 7 shows the corrosion speed of carbon steel in hydrochloric acid[5]. Converting the speed in 16% acid

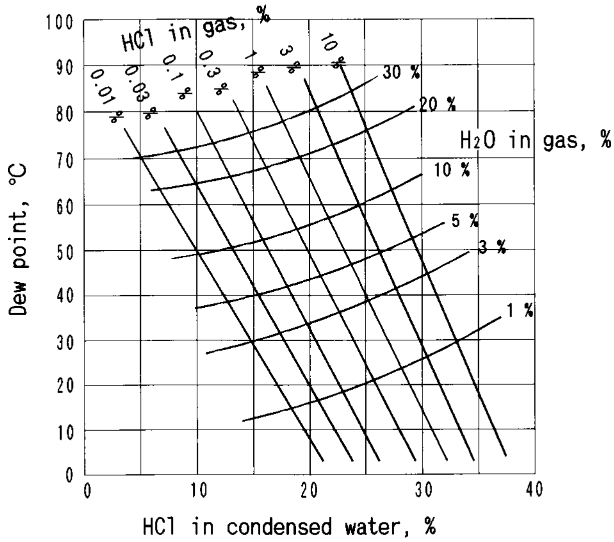

Fig. 6 HCl equilibrium in gas and condensed water

to thickness reduction, it is estimated as 0.00025 mm/h, and 1.8 mm/year if the exposed time is 7200 h/year. There is no economical and anti-abrasion material available to cope with this problem. As for process changes that could be made to reduce this corrosion, there are possibilities such as reducing the chlorine in scrap and additives, reducing the electrode spray-cooling water, and using warm water for the cooling ductwork.

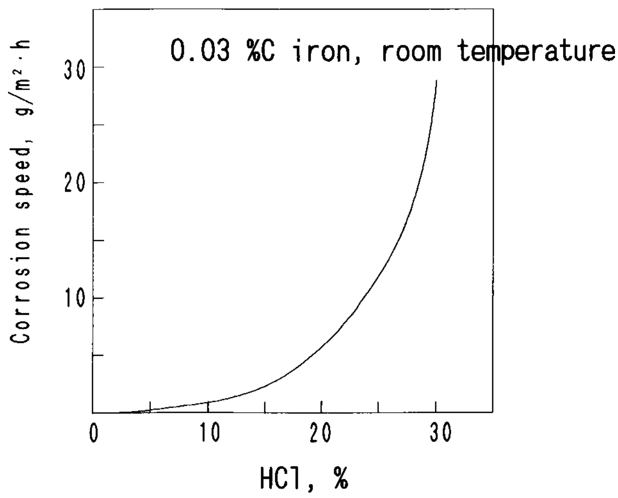

Fig. 7 Corrosion speed of steel in hydrochloric acid

4.4 New design concept for direct evacuation system

Based on experience, process analysis, and cost estimation, the following concept has become the new criteria to be used when planning the initial design or the improvement of an existing direct evacuation system.

(1) Excess air infiltration into the furnace and ductwork should be reduced to the lowest level possible in order to reduce the loading to the system.

(2) Though water-cooled ductwork operate efficiently in the high temperature portion, it requires a large heat transfer area when gas temperature becomes less than 500℃. NKK has tried a direct spray cooling system to make the facility compact and has achieved good results.

(3) It is possible to eliminate a very expensive direct evacuation blower and to connect the direct evacuation line to the main header. The direct evacuation blower is expensive for its high temperature use and anti-abrasion construction. Even though the header pressure must be lowered to about –2500 Pa, which is generally –1500 Pa in case this type of blower exists, the increase in operation cost is less than the decrease in initial cost[2]. NKK has adopted this system for K-steelmill in Taiwan which resulted in the expected effect.

(4) Water-cooled ducting should be designed to be easily maintained when damaged. Interference with surrounding equipment while exchanging a duct should be avoided.

5. Conclusion

With the increasing capacity of dedusting systems in electric arc furnace melt-shops, recent investment cost for dedusting system exceeds the cost for EAF itself. This large scale system, however, cannot show its ability completely without proper basic planning and intelligent operation. Recent requests to NKK for consultation concerning EAF operation and equipment modification are mainly related to dedusting system problems and governmental air quality regulations rather than energy saving or production increase. NKK has supplied dedusting systems to over 30 meltshops and thereby has accumulated a great deal of experience and know-how. Based on this technology we believe we are contributing to environmental improvement inside and outside of meltshops.

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