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Second Interregional Symposium
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Moscow, USSR, 19 September – 9 October 1968

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WASTE GAS CLEANING SYSTEMS FOR LARGE CAPACITY BASIC OXYGEN FURNACE PLANT [1]

by

A.D. Rowe, H.K. Jaworski and B.A. Bassett
United Kingdom

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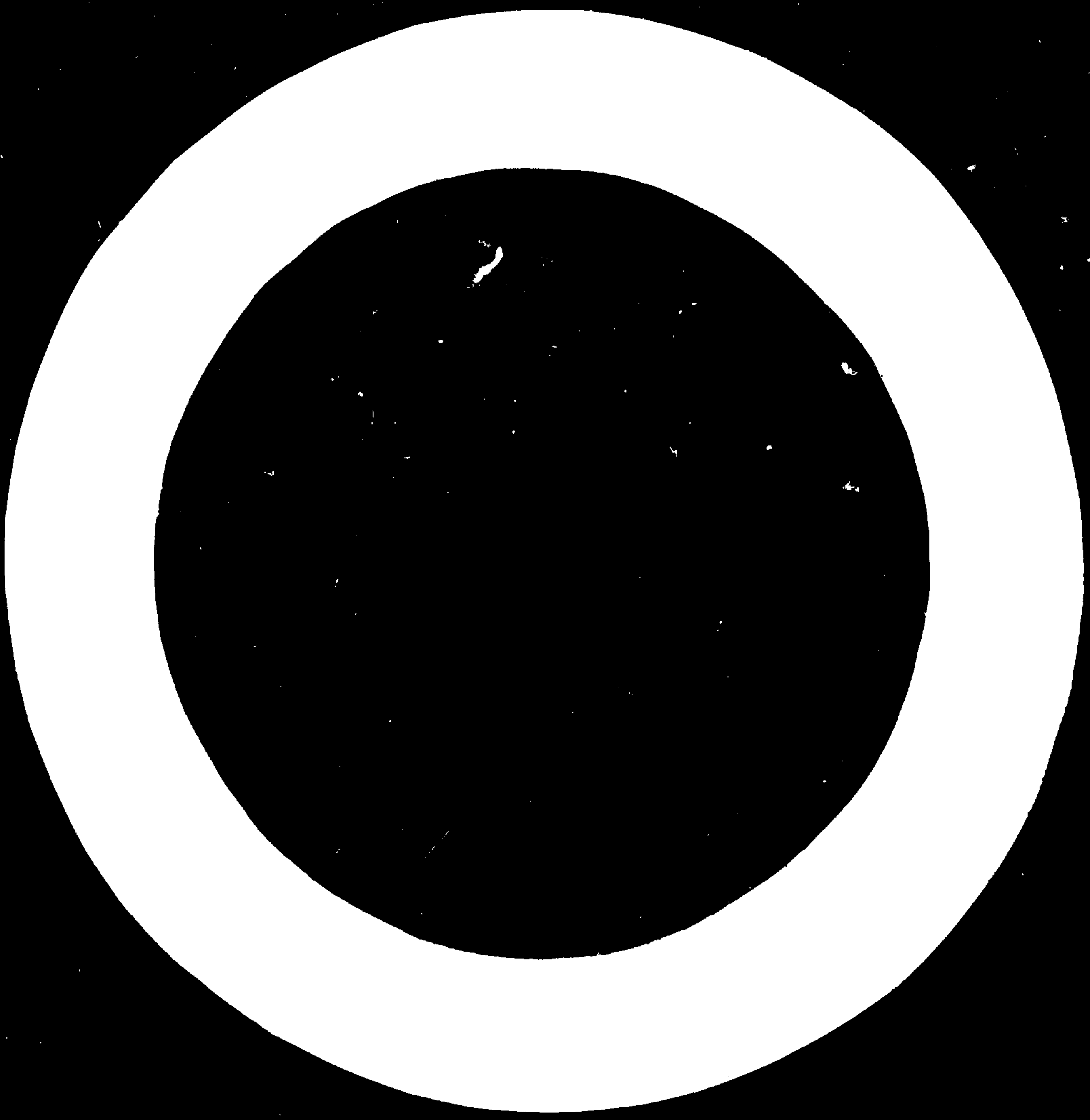

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SUMMARY

This paper compares the main alternative waste gas cleaning systems available for installation in large capacity basic oxygen furnace plants. In the past, the choice facing the steelmaker at the plant design stage, has been limited to one of two well tried systems, whereby the furnace waste gases are burnt in a plentiful supply of combustion air and cleaned in either electrostatic precipitators or wet scrubbing plants. This choice has now been widened by the introduction of proven unburnt gas collection systems, which appear to have the attractive feature of requiring smaller plant. A comparison is therefore made of the comprehensive capital and operating costs for three selected gas cleaning systems suitable for 300 tons capacity basic oxygen furnaces.

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* This is a summary of a paper issued under the same title as ID/WG.14/53.

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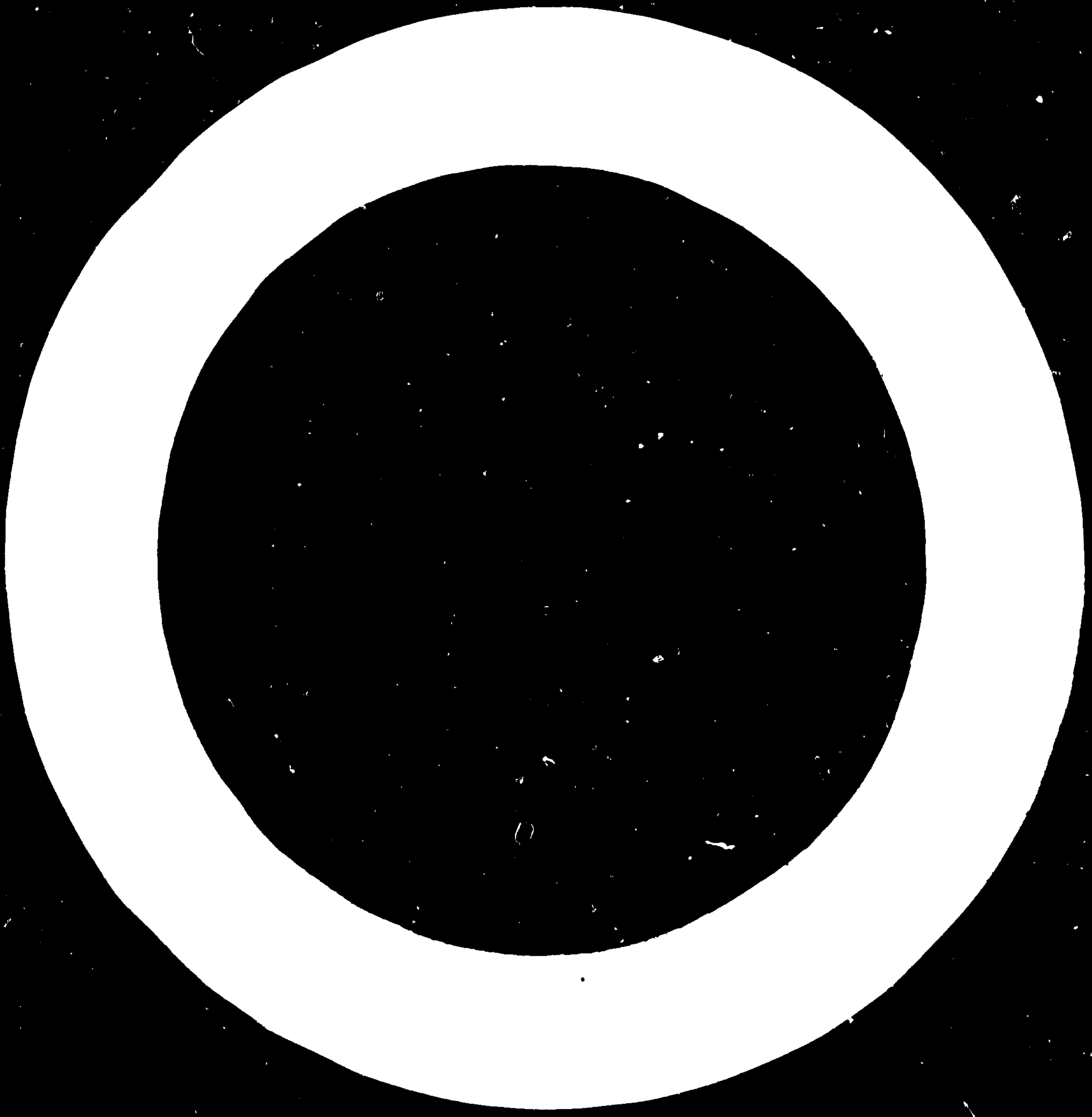

Each system has shown itself to be both technically feasible and economically viable in the field of oxygen steelmaking and in various modified forms account for the majority of basic oxygen furnace plants currently planned or in operation.

The three waste gas cleaning systems selected for comparison are:-

1. Dry plate electrostatic precipitator equipped with a pressurised hood system.
2. A variable throat wet scrubber plant equipped with a pressurised hood system.
3. The Yawata O.G. unburnt gas collection system.

It is recognised that waste gas cleaning systems other than those selected in this comparison have been put into successful operation.

Two schemes are considered for the each of the above systems.

1. Scheme A - Two B.O.F.'s installed, one operating.
2. Scheme B - Three B.O.F.'s installed, two operating.

The paper first establishes the basic design data and discusses the determination of gas cleaning plant capacity in terms of waste gas flow rate and rate of carbon removal. Relationships are given for the mean and peak rates of carbon removal and for the peak gas flow rates for the full combustion systems.

Whatever process is selected for the gas cleaning plant the gases must first be collected, cooled and conditioned. Utilisation of heat by waste heat boilers using auxiliary firing and steam accumulators is discussed and the pressurised hood system, comprising a radiation section only of membrane construction, is selected as the best technical and engineering solution to the problem of collecting the waste gases from the converter mouth. The main features of the membrane hood are outlined. A pressurised steam raising hood cooling system is selected and its advantages compared to a pressurised water cooling system are detailed.

The excess air requirement for waste gas combustion is discussed and excess air quantities of 150% and 75% have been selected for the precipitator and wet scrubber schemes respectively. In comparing hoods required for excess air quantities of 150% and 75% it is found that the latter results in a larger hood for the same gas exit temperature.

The hood and furnace geometry and the relative position of the hood with respect to the furnace mouth is one important aspect of gas cleaning plant design which is very often overlooked. This aspect is discussed and relationships are developed for determining the areas between hood and furnace.

Two types of electrostatic precipitator are considered, namely, wet plate and dry plate. Due mainly to the disposal problems of the iron oxide slurry with the wet plate precipitator, the dry plate precipitator is selected on the basis of resulting lower capital cost. The precipitator plant proposed is briefly described.

The wet scrubbing plant comprising a venturi quencher and variable throat venturi scrubber is described.

The Yawata O.G. Recovery system is discussed with particular emphasis on the use of nitrogen for purging the system. It is pointed out that a full O.G. system is required for each furnace installed and also that the use of a secondary ventilation system is considered normal with the O.G. system. A complete list of existing and new O.G. plants is given.

Reference is made to dust pelletising, and the distinctive characteristics of the process dusts arising from both the burnt and unburnt systems are tabularised.

Comparative displays are given for the capital and operating costs for the three gas cleaning systems.

The wet scrubber system has the lowest capital costs for both the two and three furnace plants, although in the latter case the capital cost of the O.G. system is similar.

The precipitator system has substantially lower operating costs than alternative systems. However, recent developments in O.G. technology indicate that nitrogen may no longer be required and in this event the operating costs would be similar to the precipitator system.

Increased capital costs are given for the additional equipment required in order to utilise the available credits in the form of steam or O.G. gas. The resulting operating credits are given and compared.

A comparison of the systems using combined capital and operating costs is not given since assessments are dependent upon local conditions relating to taxation, investment grants etc.

Finally the paper considers the question of process yield which is claimed to be an advantage for the O.G. system. The actual tapping yields for the No. 1 and No. 2 L.D. plants at Tobata operating with open and closed hoods respectively are compared graphically. The results indicate an increased yield for the closed hood system of 1% and the significance of this result is discussed.

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1. INTRODUCTION

This paper compares the main alternative waste gas cleaning systems available for installation in large capacity basic oxygen furnace plants. In the past, the choice facing the steelmaker at the plant design stage, has been limited to one of two well tried systems, whereby the furnace waste gases are burnt in a plentiful supply of combustion air and cleaned in either electrostatic precipitators or wet scrubbing plants. This choice has now been widened by the introduction of proven unburnt gas collection systems, which appear to have the attractive feature of requiring smaller plant. A comparison is therefore made of the comprehensive capital and operating costs for three selected gas cleaning systems suitable for 300 tons capacity basic oxygen furnaces. Each system has shown itself to be both technically feasible and economically viable in the field of oxygen steelmaking and in various modified forms account for the majority of basic oxygen furnace plants currently planned or in operation.

The three waste gas cleaning systems selected for comparison are :-

1. Dry plate electrostatic precipitator equipped with a pressurised hood system.

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3. The Yawata O.G. unburnt gas collection system.

It is recognised that waste gas cleaning systems other than those selected in this comparison have been put into successful operation.[1.2.3.]

2. THE B.O.F. WASTE GASES

The refining of basic iron in a B.O.F. using 99.5% pure oxygen results in large quantities of hot dust laden gases emanating from the furnace mouth. The refining oxygen generates, during the peak of the decarburisation period, more than twice its own volume ofa gaseous mixture of carbon monoxide and carbon dioxide.

The substantial quantity of heat contained in these waste gases amounts to approximately 22.5 million B.T.U. per minute during the oxygen blowing period for the 300 ton B.O.F. plant under consideration. At the same time, up to 1,5% of the total charge weight is entrained in the waste gases as minute particles of iron oxide fume, which would result in approximately 50,000 tons per annum of dust deposited in the atmosphere for each B.O.F. operated. Local health authorities require that these dust laden gases are suitably cleaned before discharge to atmosphere.

3. DESIGN DATA

The basic design data has been established for :-

1. Scheme A - Two B.O.F's installed, one operating.
2. Scheme B - Three B.O.F's installed, two operating.

Item	Scheme A	Scheme B
Furnace capacity (ingot tons)	300	300
Number of furnaces installed	2	3
Number of furnaces operating	1	2
Operating hours per annum	8,400	8,400
Annual production (ingot tons x 10^6)	3.15	5.25
Average tap-to-tap time per furnace (minutes)	48	57.5
Oxygen blowing rate (ncfm)	32,000	32,000
Blowing time, minimum (minutes)	18	18
average (minutes)	22	22
Maximum outlet dust loading (grains per normal cubic foot of dry gas)	0.05	0.05

4. DETERMINATION OF GAS CLEANING PLANT CAPACITY

4.1. Waste gas flow rate

In order to provide adequate gas cleaning plant capacity, and to ensure effective cleaning of the waste gases, one must, at the design stage, accurately predict the maximum waste gas volume that will be generated in the furnace during the refining period.

Two main factors determine the rate at which gas will flow into the gas cleaning plant, namely :-

1. The rate of carbon removal from the metallic bath.

2. The air allowed for the combustion and dilution of the gases leaving the furnace mouth.

One could initially assume that the maximum rate at which the waste gases flowed from the furnace mouth was entirely dependent upon the oxygen blowing rate at a particular moment. Therefore, for the design maximum oxygen blowing rate of 32,000 ncfm under consideration, one could theoretically expect that the maximum waste gas flow rate from the furnace mouth would be 64,000 ncfm at temperature, based on the assumptions that the blown oxygen oxidised bath carbon only, and that the resulting product of oxidation was simply carbon monoxide. However, in practice it has been found that the waste gas flow rates greatly exceed the maximum gas flow rate computed in this manner. It therefore follows that during the peak of carbon reaction in the furnace additional oxygen to that supplied via the lance is released to the bath, either from the slag FeO, from the charge oxides, or by some inherent mechanism of the oxidation process.

In order to design for adequate gas cleaning plant capacity, one must therefore correctly determine the maximum waste gas flow rate from the furnace, which must be a direct function of the peak rate of carbon removal from the metallic bath.

4.2. Determination of Rate of Carbon Drop

It has been frequently demonstrated in the literature [4] that the oxygen refining process is distinguished by three distinct phases, as illustrated in fig.1.

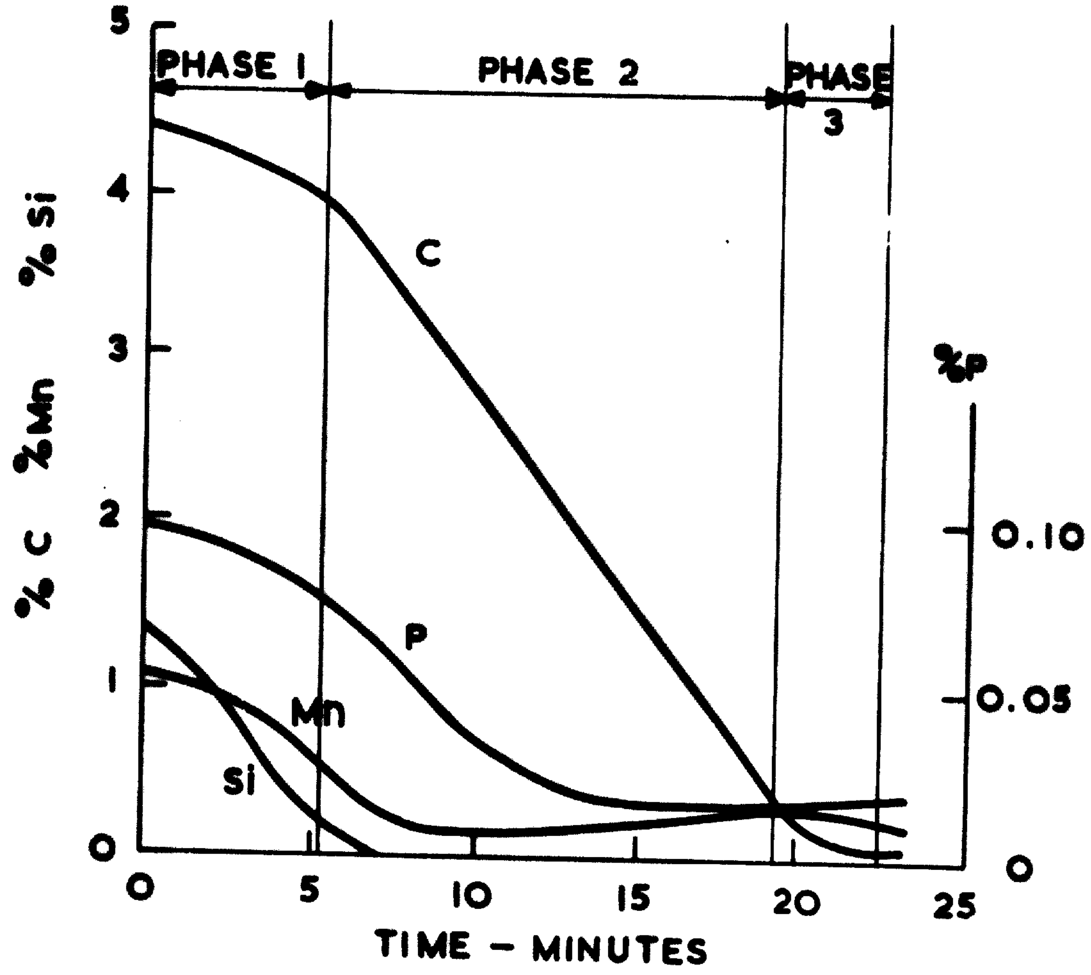


FIGURE 1: GRAPH SHOWING VARYING RATE OF CARBON REMOVAL. THE REACTIONS ARE SELECTIVE AND VARY WITH TIME.

Phase 1 Silicon Blow

During this phase, silicon and manganese are oxidised preferentially to carbon. The rate of carbon drop is low.

Phase 2 Carbon Blow

The available oxygen is utilised mainly for the carbon reaction. In this phase the rate of carbon drop reaches a peak.

Phase 3 Finishing Blow

The aim during this period is to produce blown metal of the desired analysis. During this phase the rate of carbon drop is continuously decreasing.

4.3. Mean Carbon Drop

If one neglected the carbon content of the scrap, and assumed a low residual blown metal carbon content (0.05%), then the mean rate of carbon drop can be estab- from the anticipated blowing period, and expressed in the form :-

$$R_1 = \frac{C}{t} \quad \ldots\ldots\ldots\ldots (1)$$

where R_1 = mean rate of carbon drop

C = % carbon in hot metal

t = blowing time in minutes

From the mean rate of carbon drop, the corresponding mean waste gas flow rate from the furnace can be calculated (see appendix A) from the simplified relationship.

$$V_F \text{ (mean)} = 24.6 \text{ H.C.} \quad \ldots\ldots\ldots\ldots (2)$$

where V_F = mean furnace waste gas flow rate measured in ncfm

H = maximum heat size in ingot tons.

C = % carbon in hot metal

based on :

1. yield of sound ingot taken as 88.5%.
2. maximum hot metal percentage of the metallic charge weight is 80.0%.
3. mean oxygen blowing time taken as 22 minutes.

However, the equipment must be designed to be efficient under maximum loading conditions, which occur during the peak carbon removal period.

4.4. Peak Carbon Drop

With no accurate means available at present of measuring continuously the bath carbon content, the peak rate of carbon drop in the bath cannot be determined directly. In practice, however, it has been calculated from the waste gas analysis, and the waste gas flow rate, and it has been found that the ratio of the peak to mean rate of carbon drop varies between 1.6 and 1.8. Blum[5] has reported that the actual ratio is dictated by the oxygen blowing technique used by the plant operators. Thus, if during the silicon blow (phase 1) the oxygen blowing rate is excessive, the oxygen not taken up by the metalloids will be used to oxidise iron and produce a slag rich in FeO. The excess oxygen in the slag is subsequently released during the carbon blow (phase 2), resulting in excessively high peaks of gas evolution, causing slag ejections from the furnace.

In the present study the hood and gas cleaning plants have been designed for :

$R_2 = 1.8 \times R_1$ .... (3)

where R_2 = peak rate of carbon drop.

The peak waste gas flow rate from the furnace can now be calculated (see appendix A) from the relationship :

V_F (peak) $=$ 44.3 H.C. .... (4)

where V_F (peak) = peak waste gas flow rate measured in ncfm.

4.5. Total Waste Gas Volume :

The waste gas flow rate into the gas cleaning plant on the O.G. unburnt waste gas recovery system will be substantially less than the total gas volume to be cleaned on the full combustion systems.

On the O.G. plant, up to 10 percent of the CO content of the furnace gases will be burnt to CO_2, this combustion being due to the unavoidable ingress of diluent air into the system. The total volume of waste gases to be cleaned in the O.G. plant is therefore only 30 to 40 percent higher than the actual furnace gas flow rate shown in equation 4.

In the case of the full combustion systems the peak gas flow rate into the gas cleaning plant can be determined (see appendix A) from the relationship

$V_T = 0.55 . V_F . (1 + 3.9E)$ .... (5)

where V_T = waste gas flow rate after CO combustion measured in ncfm

E = air excess factor for CO combustion

(N.B. for the exact stoichiometric quantity of air E = 1)

5. WASTE GAS HOOD SELECTION FOR FULL COMBUSTION SYSTEMS

5.1. Whatever process is selected for the gas cleaning plant, the waste gases must first be collected as they issue from the furnace mouth, and be cooled and conditioned prior to their entry into the gas cleaning plant.

The hot waste gases leaving the B.O.F., having a calorific value of approximately 350 Btu per normal cubic foot, attracted the European steelmakers to install heat recovery equipment as an intrinsic part of the waste gas hood system.

Whilst it may appear desirable to recover the waste heat in the process gases in the form of steam, difficulties arise in practice due to the intermittent nature of the oxygen blowing period during the steelmaking process. The production of large quantities of steam on a cyclic basis leads to widely fluctuating load swings with which the steam power plant must cope. Efforts to mitigate the difficulties of cyclic steam production have included the introduction of auxiliary firing equipment and the provision of steam accumulators. Nevertheless, experience has shown that many steelmakers have been discouraged from installing complex waste heat boilers to fulfill this function, which detracts from the prime function of the plant, which is to produce steel rather than steam.

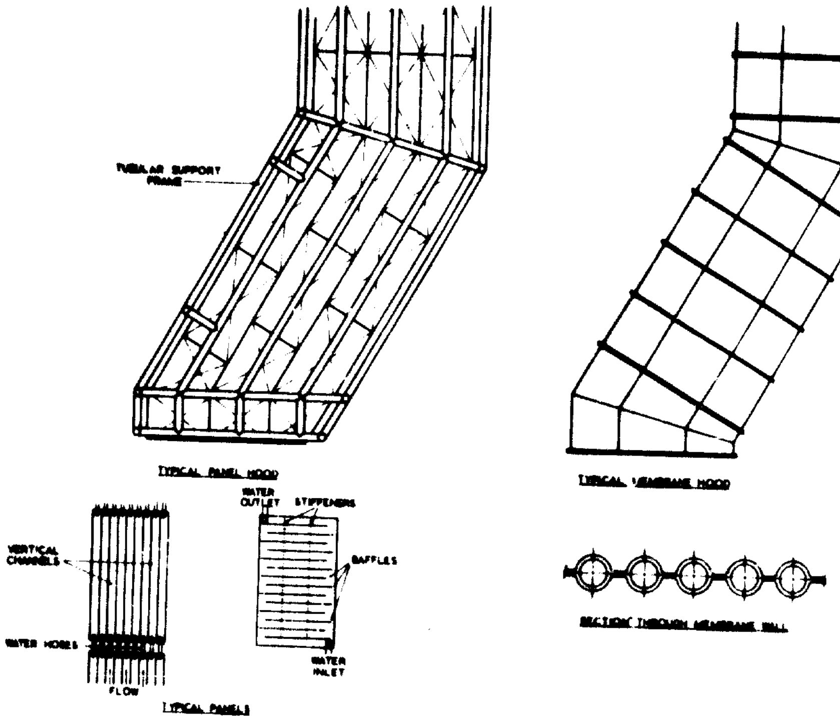


FIGURE 2: CONSTRUCTION OF PANEL AND MEMBRANE HOODS

In the United States and Canada, where steelmakers have an abundant supply of relatively inexpensive indigenous fuel, the additional expense of providing suitable equipment for recovering the energy contained in the hot waste gases was not attractive. Until 1961 almost every basic oxygen furnace installation on the North American continent was equipped with the panel type of water cooled hood, (fig.2) which cools the hot gases without useful recovery of waste heat. Although the energy position has remained virtually unchanged since 1961, it is significant that since this date a large proportion of the new plants commissioned have departed from this practice, and pressurised hood systems are frequently installed.

In this paper a pressurised hood system consisting of a radiation section only, i.e. a half boiler of membrane tube construction, has been selected as the best technical and engineering solution to the problem of collecting the waste gases from the furnace mouth.

5.2. Features of the Membrane Tube Hood

a) This type of construction (fig.2) lends itself to pressurising, allowing increased cooling water temperatures, or the generation of steam.

b) It is less subject to thermal shock than the panel hood, due to the higher operating temperature distribution resulting from the superior water flow distribution throughout the hood.

c) The hood is an air tight fabrication, and no allowance has to be made in the gas cleaning plant design for air leakage into the system. Steelplant ventilation is consequently improved.

d) Less maintenance is required than with the panel hood, resulting in improved furnace availability.

e) A high capital cost compared with the panel hood.

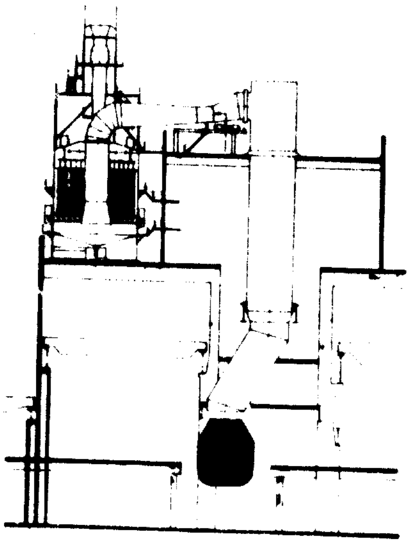


FIGURE 2a SECTION THROUGH THE WET PLATE ELECTROSTATIC PRECIPITATORS AT THE 240 TON B.O.F. PLANT OF MANNESMANN HUTTENWERKE AG. DUISBURG DESIGNED FOR AN AIR FACTOR OF n = 0.7 COURTESY LURGI APPARATEBAU GESELLSCHAFT m.b.H. FRANKFURT

5.3. Hood Cooling System

A closed circuit steam raising hood (not necessarily steam exporting) as opposed to a pressurised water cooled hood has been selected for the following reasons :-

a) Near constant pressure evaporation maintains the tube metal temperatures at approximately saturation temperature throughout the entire hood and thus severe temperature stresses are avoided.

b) A reduced circulating water quantity is required.

c) The future possibility for steam exporting is available.

d) With closed cycle systems operating in temperate countries where freezing conditions can be experienced, some form of anti-freeze arrangement has to be incorporated in a pressurised water system to protect the heat exchangers. With a properly designed closed cycle steam raising system, this feature is not required, with consequent reduction in capital and operating costs.

The selected hood cooling system is shown in Fig.3.

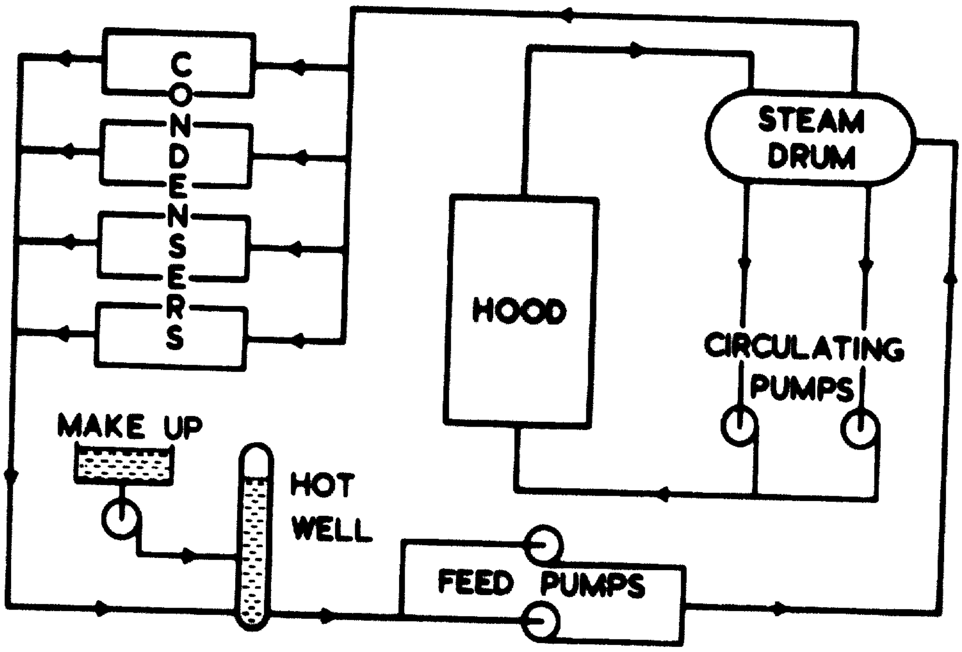


FIGURE 3 : HOOD COOLING SYSTEM

This scheme is the widely adopted recirculating type, in which water is pumped at pressure and the water tubes comprising the hood walls generate saturated steam. A steam drum is positioned between the hood and a battery of condensers which are designed to dissipate to atmosphere the peak absorption by the hood. Once the system has been initially filled the only requirement is for a nominal quantity of make-up water.

A MEMBRANE HOOD SHOWN DURING ERECTION AT A 300 TON B.O.F. PLANT
COURTESY OF BABCOCK & WILCOX LTD.

6. EXCESS AIR REQUIREMENT FOR WASTE GAS COMBUSTION

A hood designed to operate in conjunction with a dry plate electrostatic precipitator would normally require that the furnace gases are burnt with a minimum of 150% excess air, to ensure that no unburnt carbon monoxide enters the precipitator. Alternatively, the hood required to operate in conjunction with a wet scrubbing system could safely be designed to burn the waste gases with the excess air quantity limited to 75% or less. In this comparison, air excess quantities of 150% and 75% have been selected for the precipitator and the wet scrubber schemes respectively.

With the reduction in waste gas volume, one could assume that a smaller and consequently less expensive hood could be supplied to meet the requirement of the wet scrubbing plant. Contrary to this, however, it is found that combusting the furnace gases with the lower quantity of excess air results in higher mean gas temperatures within the hood, and therefore higher heat radiated to the hood walls[6] with consequent effect on the size of the hood ancillary equipment. Furthermore, for the same hood surface area, higher gas exit temperatures are obtained. In comparing the hoods required for excess air levels of 150% and 75%, it is found that the latter results in a larger hood for the same exit gas temperature.

It further becomes evident that in mixing the B.O.F. gases with different quantities of excess air, the relative waste gas volumes to be cleaned differ substantially for each cleaning system. The waste gases leaving the furnace are increased by a factor of 1.4 using the O.G. system, 4.3 using the wet washing system and 5.9 for the electrostatic precipitation scheme. In practice, however, wet scrubbing plants[7] and electrostatic precipitators (see fig.2a) utilising substantially less air are effectively employed on basic oxygen furnace installations.

Finally, it should be noted that the total quantity of dust deposited in the atmosphere is increased using the waste gas cleaning systems exhausting the higher quantities of waste gases to atmosphere. This factor would be significant in plant locations where the local authorities stipulate a maximum dust emission to atmosphere in terms of lbs. per hour, rather than a gas cleanliness in grains per cu. ft.

7. THE HOOD - FURNACE GAP

Hood and furnace geometry, and the relative position of the hood with respect to the furnace is one important aspect of gas cleaning plant design, which is very often overlooked.

If the size of the gas cleaning plant is to be reduced to the desirable minimum, the air entry into the hood must be restricted by reducing the hood - furnace gap, or by providing other means of completely eliminating the air, e.g. as in the unburnt gas recovery system discussed later in this paper.

In a conventional gas cleaning system where carbon monoxide collection is not attempted, the action of the gas jet from the furnace will induce air into the hood. If the gas jet induces less air than the design capacity of the gas cleaning plant then the induced draught fan will tend to produce its own effective negative pressure at the base of the hood. On the other hand the air gap may be too great to offer any significant resistance to air flow caused by the flame injection action. In this instance it is very likely that the gas cleaning plant will not be capable of dealing with the total gas volume passing into the hood. With such a system, a pulsating gas flow into the hood will ensue, and the excess gas which is not exhausted by the fan will escape from the mouth of the hood into the shop atmosphere.

The total quantity of air drawn into the hood (Q) is a function of the available suction at the base of the hood (P) and the cross-sectional area (A) provided for the air flow between the furnace and the hood.

Then $Q = K.A. \sqrt{P}$ .... 1.

In equation 1, $P = P1 + P2$
where $P1 =$ suction induced by the furnace gases
and $P2 =$ suction produced by the I.D. fan.

The furnace gas flow rate (Q1) through furnace mouth opening (Area A1) will induce a suction (P1) across the hood - furnace gap, so that

$Q_1 = K_1.A_1 \sqrt{P_1}$ .... 2.

The required area for air intake into the hood can then be calculated from the relationship.

$$A = \frac{Q}{K \sqrt{P_2 + \left[\frac{Q1}{K_1 . A_1}\right]}}$$

The values of K and K1 can be evaluated from known pressure loss factors for a given hood and furnace geometry.

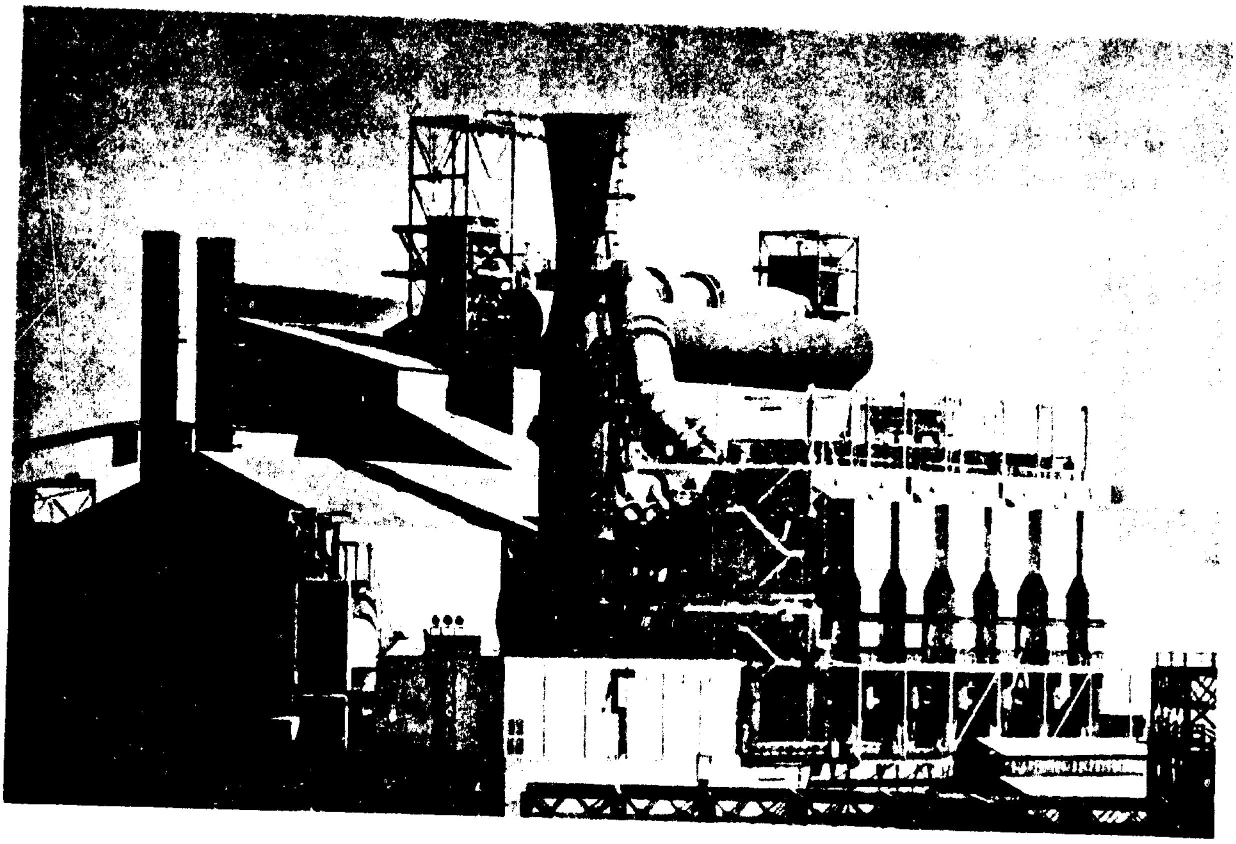
It will be noted that maximum hood - furnace gap is permitted when $P2 = 0$ i.e. the suction due to the fan effect at the base of the hood is nil.

In practice, the total suction produced by the gas cleaning plant fan will be in the order of 7 to 13 inches w.g. for electrostatic precipitators, and 45 to 60 inches for wet scrubbers. It is recommended that Area A be evaluated for $P2 > 0$. i.e. 0.1 to 0.25 inches w.g.

The minimum distance between the hood and the furnace will be dictated by the turning circle of the furnace, after making adequate allowances for slag build-up on the furnace nose.

In practice it will be found that conditions do not remain constant during the entire furnace campaign. Thus the hood - furnace gap may be periodically reduced by skull build-up on the furnace nose; the furnace mouth diameter may be increased due to lining wear, or it may be reduced due to slag and skull build-up.

The designer should take into account all these variables when sizing his hood and the gas cleaning plant.



THE DRY PLATE PRECIPITATORS AT REPUBLIC STEEL CORPORATION'S 220 TON CLEVELAND B.O.F. PLANT. COURTESY OF KOPPERS COMPANY INC.

8. ELECTROSTATIC PRECIPITATOR

Precipitator Selection

Two types of electrostatic precipitator are considered, namely, wet plate and dry plate.

8.1. Wet Plate Precipitator

In comparison with the dry plate system, the wet plate precipitator may be operated at lower inlet gas temperatures (170°F), resulting in a reduced gas volume to be cleaned. Furthermore, the wet plate system is more efficient per unit of collecting area than the dry plate system. The cumulative effect of these two factors would be a smaller precipitator plant.

A wet plate system would therefore appear to be the more economical installation until one considers the disposal problem of the iron oxide slurry. The capital cost of the necessary water clarification and dust recovery plant are sufficiently high to negate the attractions of the wet system, and a dry plate system has therefore been selected on the basis of lower capital cost. However, for gas cleaning plant being installed in an integrated works where there is existing capacity for handling the wet slurry, a wet plate precipitator is an attractive proposition. It should be noted that where the B.O.F. plant incorporates a full waste heat boiler system, wet plate precipitators should not be selected. The auxiliary oil firing used in such boiler systems to supplement the process waste gases, results in considerable corrosion problems when the fumes are cooled to dewpoint conditions.

8.2. Dry Plate Precipitator

The dry plate precipitator selected in this comparison is designed for an inlet waste gas temperature range of 500 - 570°F. This operating temperature has been selected for the following reasons :-

a) The waste gas temperature is well above both the acid and the water dew points (250 - 300°F).

b) The higher temperature dust remains dry longer, making its removal easier.

c) A reduced water consumption.

d) An increased latitude on temperature control.

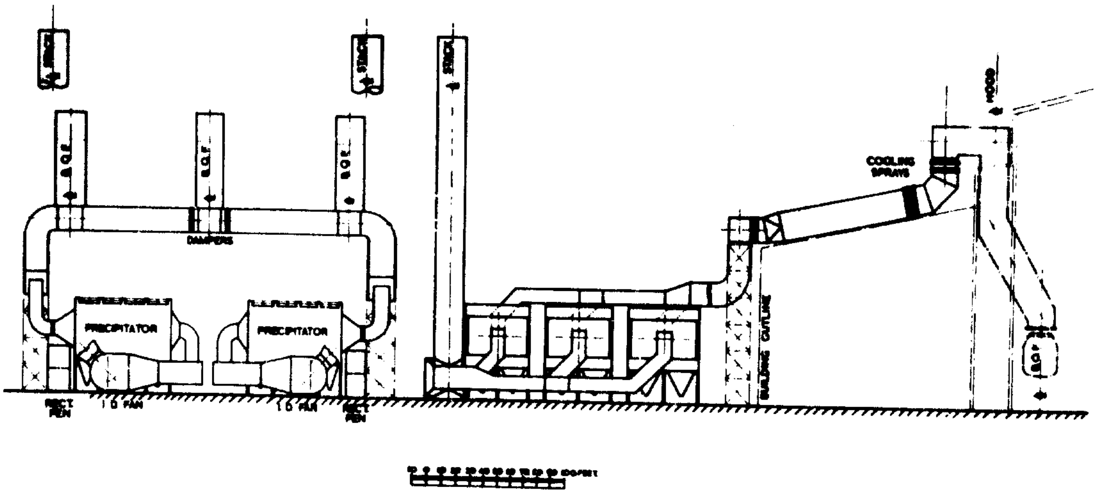


FIGURE 4 : GENERAL ARRANGEMENT OF PRECIPITATOR PLANT

8.3. Description of Plant

The proposed precipitator plant comprises a cooling section, in which the gases leaving the hood are cooled from approximately 1850°F to 500°F and an electrostatic precipitator designed to give an outlet dust burden not exceeding 0.05 grains per normal cubic foot of dry gas. The scheme selected is shown in Fig.4.

The precipitators are free-standing outside the steelplant building and it is necessary to lead the waste gases to them through long lengths of ducting. The dimensions of this ducting are such that the duct itself may be utilised as a cooling and conditioning section. The internal diameter of the gas duct is approximately 20 feet and is suitable refractory lined to withstand the temperatures and duty involved. The cooled gases are led to three electrostatic precipitators per operating furnace through an unlined gas main, and the cleaned gases exhausted to atmosphere via an I.D. fan and stack.

8.4. Water Spray System

The spray system is designed to produce dry bottom conditions in the cooling duct, for which the available contact time of 3½ seconds is considered adequate.

A binary spray control system is incorporated on four spray banks having 18, 36, 72 and 144 nozzles respectively. Each nozzle has a feed line and a controlled spill return line which gives a 10 - 1 flow turn-down ratio. Delivery from each nozzle is 0.2 to 2 gallons per minute at a spray pressure of 300 p.s.i. and efficient atomisation is achieved at any flow rate within this range.

9. WET SCRUBBER GAS CLEANING PLANT

The wet scrubbing plant comprises a venturi quencher and a variable throat venturi scrubber, in which the dirty gases are cleaned to an outlet dust burden not exceeding 0.05 grains per normal cubic foot of dry gas. The layout of the proposed wet scrubbing plant is shown in figure 5.

The gases leaving the hood cooling section at approximately 1850°F pass into the venturi quencher where they are cooled to approximately 175°F. The quenched gases then immediately enter a separating elbow where most of the liquid is separated from the gas stream. One quencher with its associated elbow is provided for each furnace. Two separate refractory lined ducts lead the gases from the elbows into the venturi scrubbers, which remove the remaining fume.

The venturi throats are fitted with automatically adjusting throat sections. The position of these throat dampers is continuously adjusted, such that during the peak of of the oxygen blow the venturi throat is wide open to permit the larger gas volume to pass, whilst at the beginning of the blow the adjusting dampers restrict the throat area. To conserve power during the non-blowing period, a two speed fan motor is provided, which automatically runs at reduced speed during this period. The cleaned gases leaving the scrubbers pass via an extraction fan and stack directly to atmosphere.

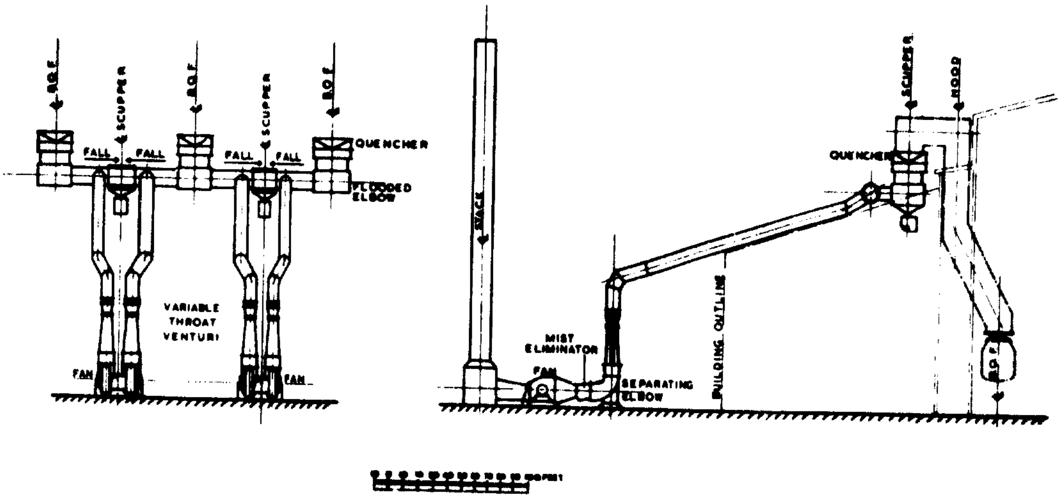
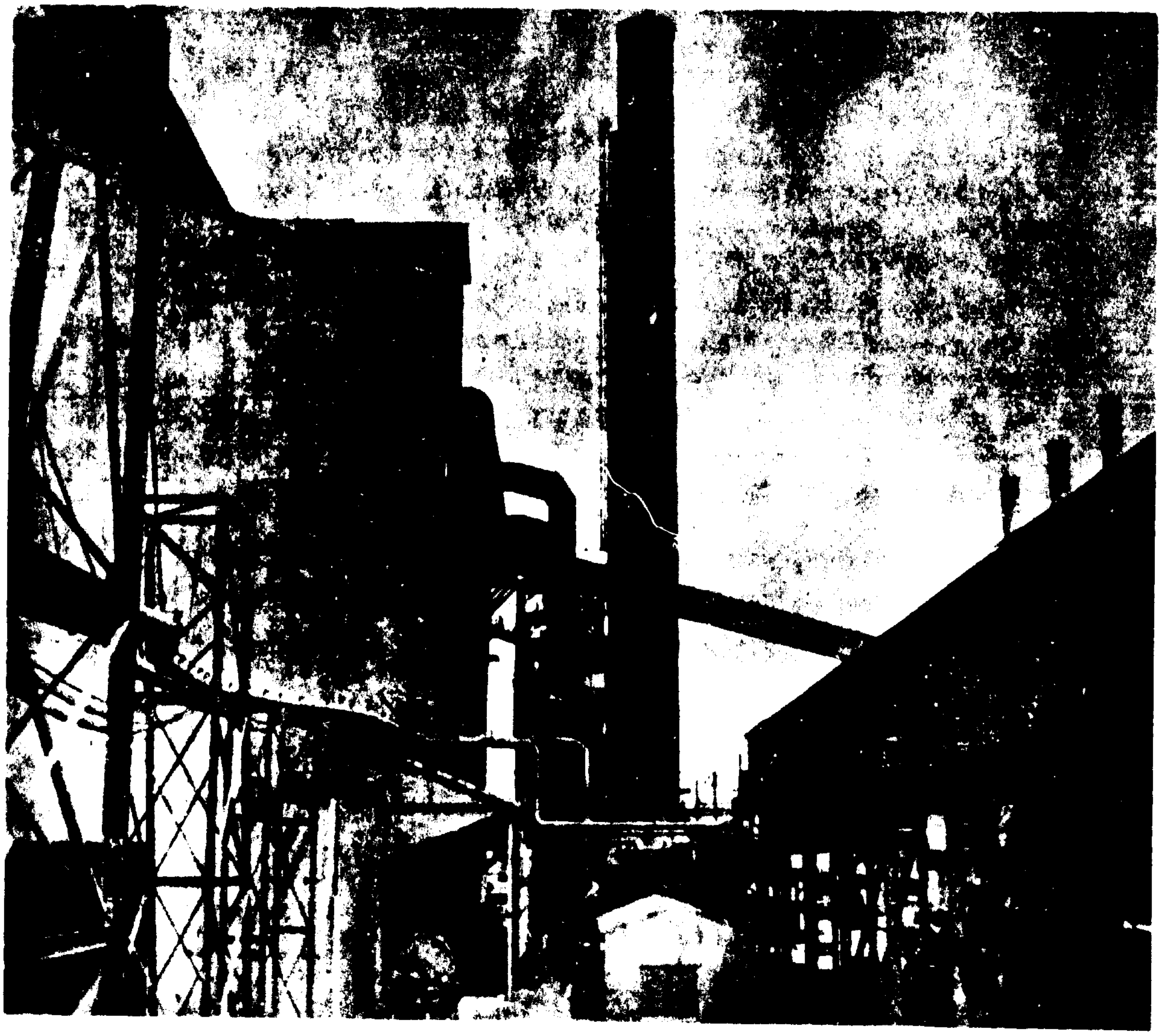


FIGURE 5: GENERAL ARRANGEMENT OF WET SCRUBBER PLANT



THE WET SCRUBBERS AT BETHLEHEM STEEL CORPORATION'S 200 TON SPARROWS POINT B.O.F. PLANT
COURTESY CHEMICO (N.Y.)

10. THE YAWATA OXYGEN GAS (O.G.) RECOVERY PROCESS

10.1. INTRODUCTION

The Yawata O.G. gas recovery process has been established in Japan since 1961, and to date in excess of 35 million ingot tons of steel have been produced from basic oxygen furnaces equipped with this waste gas system. However the process is relatively new to European and American steelmakers, and it therefore merits a fuller description than the previously considered waste gas systems.

The first commercial O.G. plant began operating in 1962 at the Tobata No.2 works of Yawata Iron and Steel Company Ltd. Fifteen basic oxygen furnaces are presently operating in Japan with O.G. equipment, and a further two furnaces will commence operation in 1968 at Yawata's Kimitsu Works. In 1969 the first European plant will be commissioned at the Abbey Works of the Steel Company of Wales, and the first North American plant at the Middletown Works of Armco Steel Corporation. A complete list of O.G. steelplants is given in Appendix B.

A layout of the O.G. gas cooling and cleaning plant suitable for a 300 ton B.O.F. is shown in fig.6 and fig.7. It can be seen that a separate gas cleaning plant is required for each basic oxygen furnace installed.

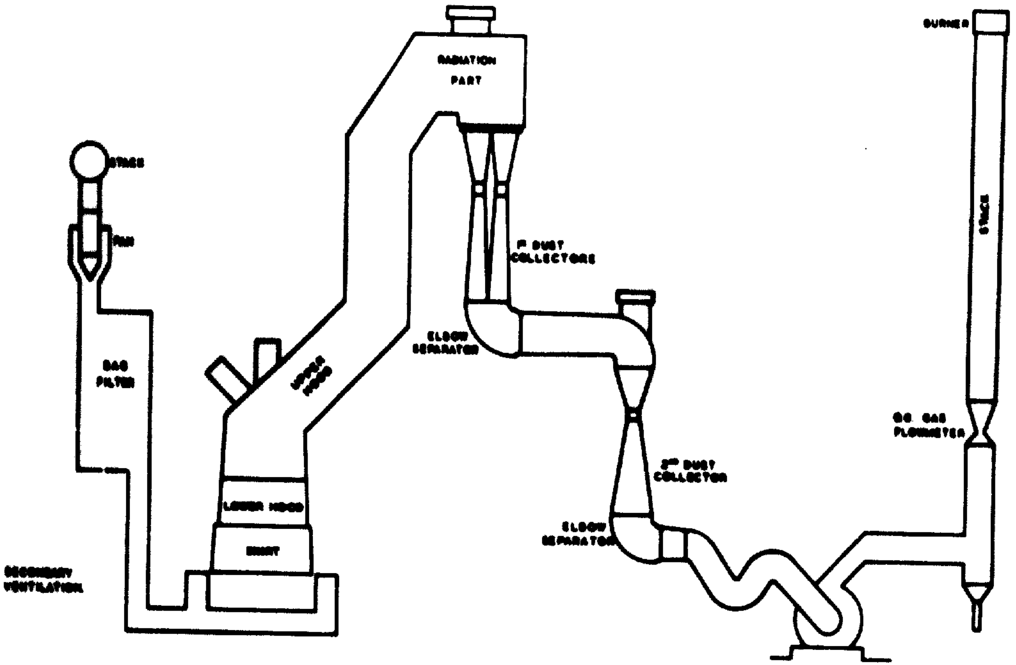


FIGURE 6: SCHEMATIC LAYOUT OF O.G. SYSTEM

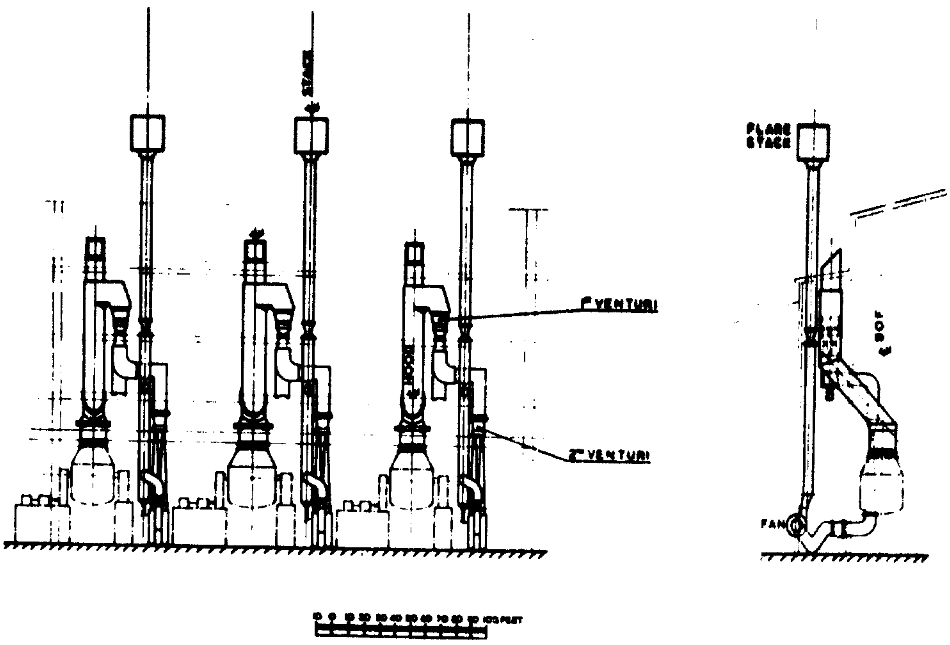


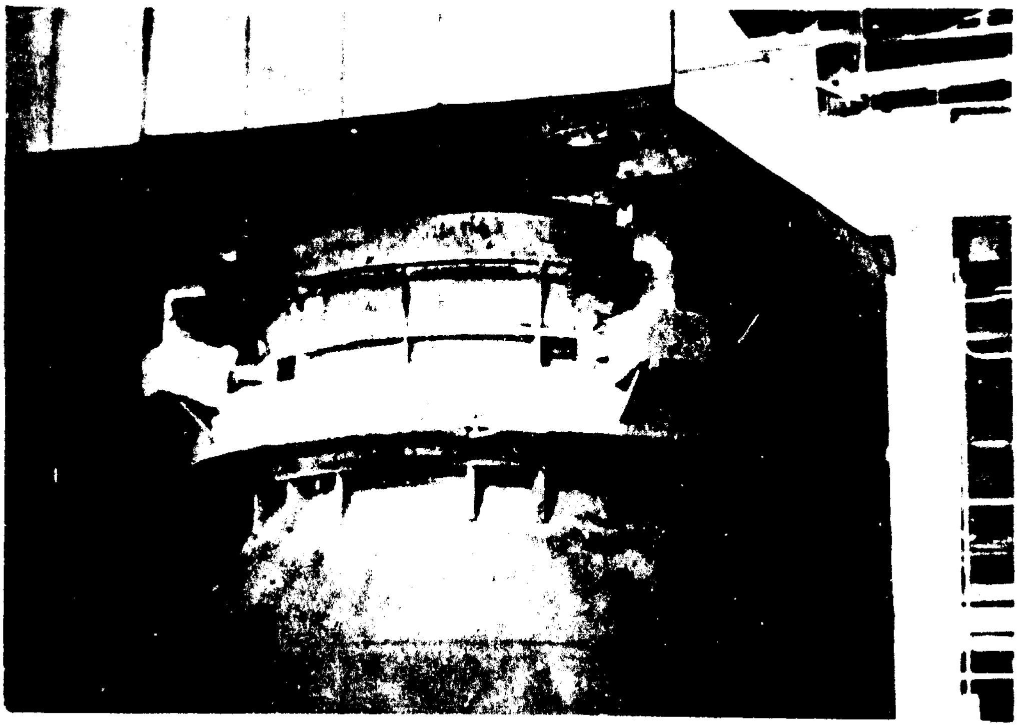
FIGURE 7: GENERAL ARRANGEMENT OF O.G. PLANT

10.2. WasteGas Collection

In order to collect the waste gases in an unburnt condition the gap between the B.O.F. mouth and the waste gas hood is minimised by a moveable skirt. In the original O.G. installation any space remaining between the skirt and the B.O.F. mouth was sealed off by a nitrogen curtain. However, in the present O.G. installations, no nitrogen curtain seal is used. The space between the skirt and the B.O.F. mouth is closed as much as practically possible by lowering the skirt directly onto the furnace nose section. During the oxygen blowing period a slightly negative pressure is maintained inside the hood.

10.3. O.G. Hood

The waste gases collected by the moveable skirt pass into the hood section which subsequently leads the waste gases into the gas cooler. The hood is in two sections, with the moveable skirt attached to the lower section. The upper section, which is equipped with the flux chute hole and the oxygen lance entry hole, is mounted on a carriage and may be moved away from its operating position to facilitate entry of the brick relining elevator. The necessary process fluxes are added to the B.O.F. during the oxygen blowing period through a system of gas seals.



THE O.G. GAS COLLECTION SKIRT SHOWN IN THE
LOWERED POSITION AT THE SAKAI 180 TON B.O.F. PLANT.
COURTESY OF YAWATA IRON & STEEL CO. LTD.

10.4. Gas Cooler

The waste gases pass from the upper section of the hood at a temperature of 2300°F, and are cooled to approximately 1850°F in the gas cooler before entering the gas cleaning plant. The gas cooling section has been designed as a radiation section only, and consists of a series of nested tubes supported in a mild steel circular outer jacket. The top of the radiation section incorporates a self-closing water cooled pressure relief door.

10.5. Gas Cleaning Plant

The waste gas cleaning plant for the O.G. system is similar to that described earlier for the wet scrubber plant, with the feature that the equipment is considerably reduced in size, and can be more readily accomodated within the steelplant building. The waste gases leaving the radiation section of the hood pass into a venturi quencher where the gases are cooled to an outlet temperature of approximately 170°F, at the same time some 85% of the dust entrained in the gases is removed. The cooled gases leaving the venturi quencher pass via an elbow separator into a variable throat venturi scrubber. The adjustable venturi throat in the O.G. system acts both as a highly efficient dust collecting unit and also as the means of controlling the pressure in the waste gas hood. This system maintains as effectively as possible a constant hood pressure during the oxygen blow by opening and closing the moveable throat inside the venturi. The dust particles remaining in the waste gases after the quencher are removed in the venturi scrubber.

The cleaned gases then pass via a second elbow separator into a simple mist eliminator, before finally being passed into a combustion chamber and burnt before discharge to atmosphere.

10.6. Secondary Ventilation

The secondary ventilation system shown on Fig.7 is designed mainly to collect the dirty fume emitted during hot metal charging, but it also performs the useful function of removing the minor quantities of fume and gas that escape from the collection skirt and hood during the blowing period. The quantity of dust to be collected is small and most types of dust collection methods are suitable. In this case a bag filter plant has been included.

11. DUST PELLETISING PLANT

The basis of comparison between the three gas cleaning systems considered in this paper has been to supply a dust pelletising plant in each case to recover the iron oxide dust in the form of handleable product.

It is recognised that in cases where an iron oxide slurry is produced it may be more economical to use other means of dust disposal.[8.9.]

The distinctive characteristics of the process dusts are shown on Figure 8.

Process	Dust Colour	Dust Particle Size		Chemical Analysis %		
		Less than 1.0 micron	More than 5 microns	FeO	Fe_2O_3	Metallic Fe
Combustion[10]	Red	85%	2%	1.5	90	-
O.G.	Black	10%	45%	60	7	11

12. COST COMPARISONS

12.1. Capital Cost

Fig.9 is a comparative display of the total capital cost of the three gas cleaning systems discussed. The capital costs are based on current U.K. selling prices, and include mechanicals, electrics, instruments, civils, erection and commissioning. (£1 sterling = $2.40 U.S.)

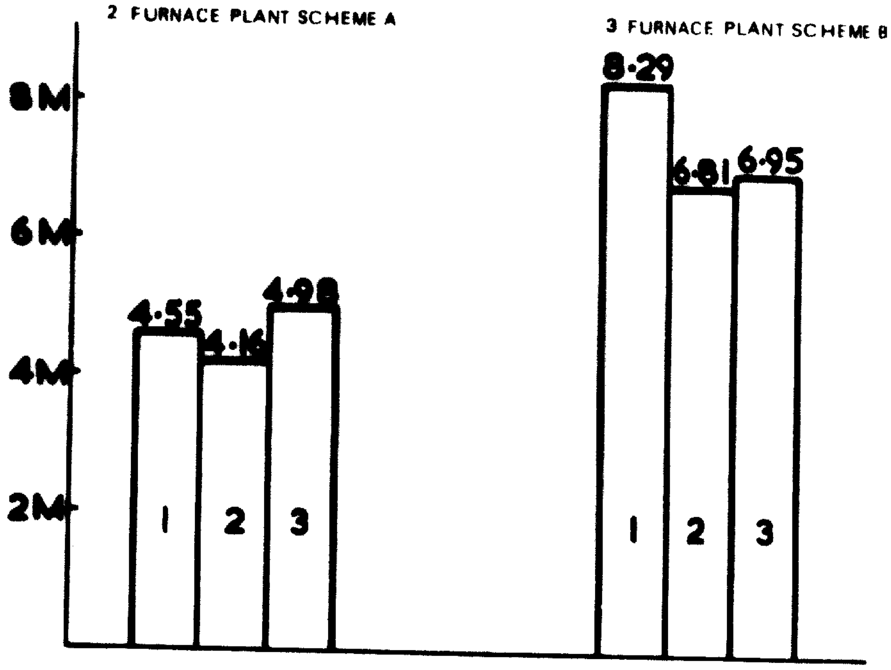


FIGURE 9: CAPITAL COST (U.S. DOLLARS)

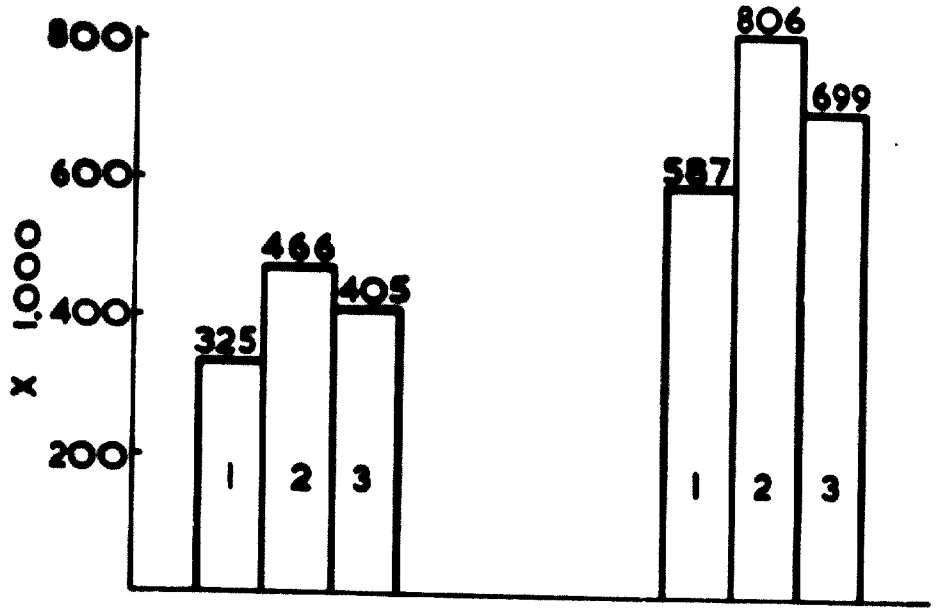


FIGURE 10: ANNUAL OPERATING COST (U.S. DOLLARS)

1 PRECIPITATOR SYSTEM
2 SCRUBBER SYSTEM
3 O.G. SYSTEM

Two Furnace Plant

The capital costs of the three gas cleaning systems compared are within 10% of each other. One would expect that with the substantial reduction in the waste gas volume treated in the Yawata O.G. system a capital cost advantage would result. However, due to the unburnt condition of the collected gases a separate gas cleaning plant is required for each furnace, and this fact eliminates the advantage of the smaller equipment.

The wet scrubber system has the lowest capital cost, which could be reduced by a further 10% if the thickener underflow is pumped to waste.

Three Furnace Plant

In both the precipitator and scrubber systems, the gas cleaning section is duplicated and this is proportionally reflected in the capital cost. However, in the case of the O.G. system, the number of gas cleaning units is increased from two to three and it becomes a more attractive proposition.

12.2. Operating Cost

Fig.10 is a comparative display of the annual cost of operating the plants. Detailed operating costs for each system are given in figures 11, 12 and 13.

The precipitator system has substantially lower operating costs than the alternative systems. This is due to the low electrical power requirement of the I.D. fan. The O.G. system has a similar power cost to the precipitator system due to the reduced gas volume, however, this advantage is lost in the cost of nitrogen gas.

Recent developments in O.G. technology indicate that nitrogen is no longer required and may be replaced by approximately 0.5 cubic metres of steam per ton of steel. The cost of operating the O.G. and the precipitator would in this event be similar.

The high operating costs of the scrubber system, are due to the I.D. fan power requirement.

ITEM	COST PER UNIT	CONSUMED PER ANNUM		$ COST PER ANNUM	
		SCHEME A	SCHEME B	SCHEME A	SCHEME B
1.0 ELECTRICAL POWER	0.85 CENTS PER K.W.H.	22.29×10^6	41.81×10^6	189.500	355 500
2.0 WATER					
2.1 SPRAY QUALITY	1.5 CENTS PER 1.000 GALLS.	207.6×10^6	345.3×10^6	3 000	5 000
2.2 BOILER QUALITY	45 CENTS PER 1.000 GALLS.	NOMINAL	NOMINAL	500	1 000
3.0 MAINTENANCE	1% OF CAPITAL COST OF EQUIPT.	-		36 500	66 500
4.0 LABOUR					
4.1 OPERATING	$ 2 80/MAN/HR	19 600	30 800	55 000	86 000
4.2 MAINTENANCE	$ 3 60/MAN/HR	7.100	14.200	25.500	51 000
5.0 REFRACTORIES	$ 45 PER TON INSTALLED	330	490	15.000	22.000
		TOTAL ANNUAL OPERATING COST $		325.000	587.000

FIGURE 11 : OPERATING COST FOR PRECIPITATOR SYSTEM

ITEM	COST PER UNIT	CONSUMED PER ANNUM		$ COST PER ANNUM	
		SCHEME A	SCHEME B	SCHEME A	SCHEME B
1.0 ELECTRICAL POWER	0.85 CENTS PER K.W.H.	40.96×10^6	73.67×10^6	348 000	626 000
2.0 WATER					
2.1 SPRAY QUALITY	1.5 CENTS PER 1,000 GALLS.	149×10^6	249×10^6	2 500	4 000
2.2 BOILER QUALITY	45 CENTS PER 1,000 GALLS	-	-	500	1,000
3.0 REFRACTORIES (TONS)	150 DOLLARS PER TON	22	44	3 500	6 500
4.0 MAINTENANCE	1% OF CAPITAL COST	-		31 000	53 000
5.0 LABOUR					
5.1 OPERATING	$ 2 80/MAN/HR	22 400	28.000	62 500	78 500
5.2 MAINTENANCE	$ 3.60/MAN/HR	5 100	10.200	18 500	37 000
		TOTAL ANNUAL OPERATING COST $		466 500	806 000

FIGURE 12 : OPERATING COST FOR SCRUBBER SYSTEM

ITEM	COST PER UNIT	CONSUMED PER ANNUM		$ COST PER ANNUM	
		SCHEME A	SCHEME B	SCHEME A	SCHEME B
1.0 ELECTRICAL POWER	0.85 CENTS PER K.W.H.	23.15×10^6	42.5×10^6	196.800	361.300
2.0 WATER					
2.1 SPRAY QUALITY	1.5 CENTS PER 1,000 GALLS	211×10^6	399×10^6	3 200	6 000
2.2 SOFT WATER	20 CENTS PER 1,000 GALLS.	100×10^6	170×10^6	20 000	34 000
3.0 MAINTENANCE	1% OF CAPITAL COST OF EQUIPT.	-	-	42.000	59 000
4.0 LABOUR					
4.1 OPERATING	$ 2.80/MAN/HR	16.800	25.200	47 000	70 500
4.2 MAINTENANCE	$ 3.60/MAN/HR	5.904	11.808	21 250	42 500
5.0 NITROGEN	FIXED SUPPLY COST	478×10^6	797×10^6	74 500	125 000
6.0 PILOT FLAME GAS	30 CENTS PER 1,000 cu.ft.	1.80×10^6	3.6×10^6	600	1 100
		TOTAL ANNUAL OPERATING COST $		405.350	699.400

FIGURE 13 : OPERATING COST FOR O.G. SYSTEM

12.3. Operating Credits

Increased Capital Cost

Fig.14 is a comparative display of the total capital cost of the three gas cleaning systems discussed, with the provision in the cases of the precipitator and wet scrubber plant of the necessary additional equipment for a steam exporting system including accumulators.

In the case of the O.G. system, additional equipment has been provided for the collection of the unburnt furnace gases in a gasholder.

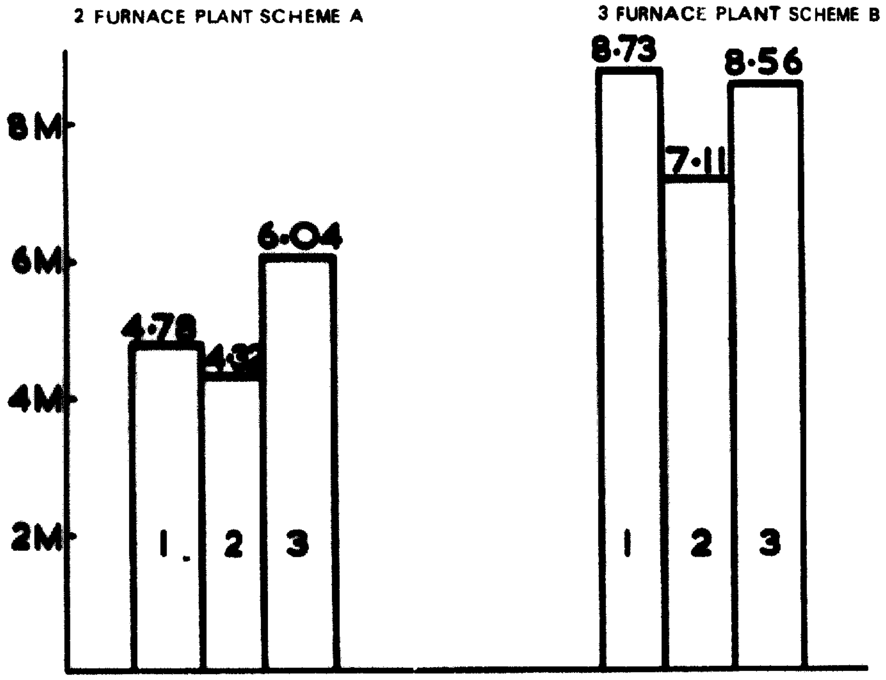


FIGURE 14: INCREASED CAPITAL COST (U.S. DOLLARS)

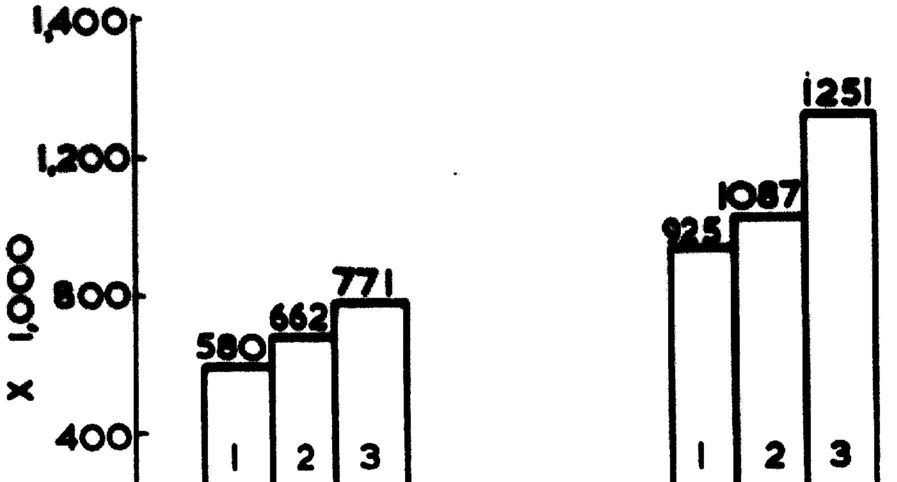


FIGURE 15 ANNUAL OPERATING CREDIT (U.S. DOLLARS)

1 PRECIPITATOR SYSTEM

2 SCRUBBER SYSTEM

3 O.G. SYSTEM

Fig. 15 is a comparative display of the credits that accrue from the installation of the above equipment. The display is based on the following figures :

Precipitator System (1)		Scheme A	Scheme B
Increased annual operating Cost	$	365,100	649,800
Annual credit for steam (75 cents/1000 lbs.)	$	945,000	1,575,000
Annual operating credit	$	579,900	925,200
Scrubber System (2)			
Increased annual operating Cost	$	495,500	842,400
Annual credit for steam (75 cents/1000 lbs.)	$	1,158,000	1,929,400
Annual operating credit	$	662,500	1,087,000
O.G. System (3)			
Increased annual operating cost	$	455,000	789,000
Annual credit for gas (20 cents/1000 cu.ft.)	$	1,226,000	2,040,000
Annual operating credit	$	771,000	1,251,000

It is suggested that a logical appraisal of each of the above systems should be made using the Discounted Cash Flow Method[11]. A conclusive example has not been provided as each case is entirely dependent upon the prevailing conditions of taxation, investment grants etc., which can vary appreciably according to plant location.

13. PROCESS YIELD

The most significant distinction between collected gas and burnt gas systems is the claim that [12.13.] operating the basic oxygen furnace with a closed hood system results in a substantial increase in ingot yield. Should this beneficial claim be established as fact, then it would have a most salutary effect on the selection of the waste gas cleaning process, and it is therefore a claim that warrants somewhat detail examination.

It is generally accepted that the tapping yield of the basic oxygen furnace process varies according to conditions of raw materials, oxygen blowing rate, furnace profile, and finished steel grades etc. At Yawata's integrated Tobata works, these conditions are similar for two separate B.O.F. plants, Tobata No. 1 and Tobata No.2.Both these melting shops receive similar hot metal from a common blast furnace plant, and produce similar steel qualities for the same plate and hot strip mill complex. Fig.16 is a monthly comparison of the process yields obtained at these two B.O.F. plants, and shows that the tapping yield at Tobata No. 2 B.O.F. plant is about 1% higher than at Tobata No. 1 B.O.F. plant, the No. 1 plant being equipped with 85 ton furnaces with a conventional hood system, and the No. 2 plant having 175 ton furnaces equipped with a closed hood system (see appendix C).

It would appear from the results obtained at this plant that there is a significant gain in process yield operating the closed hood system.

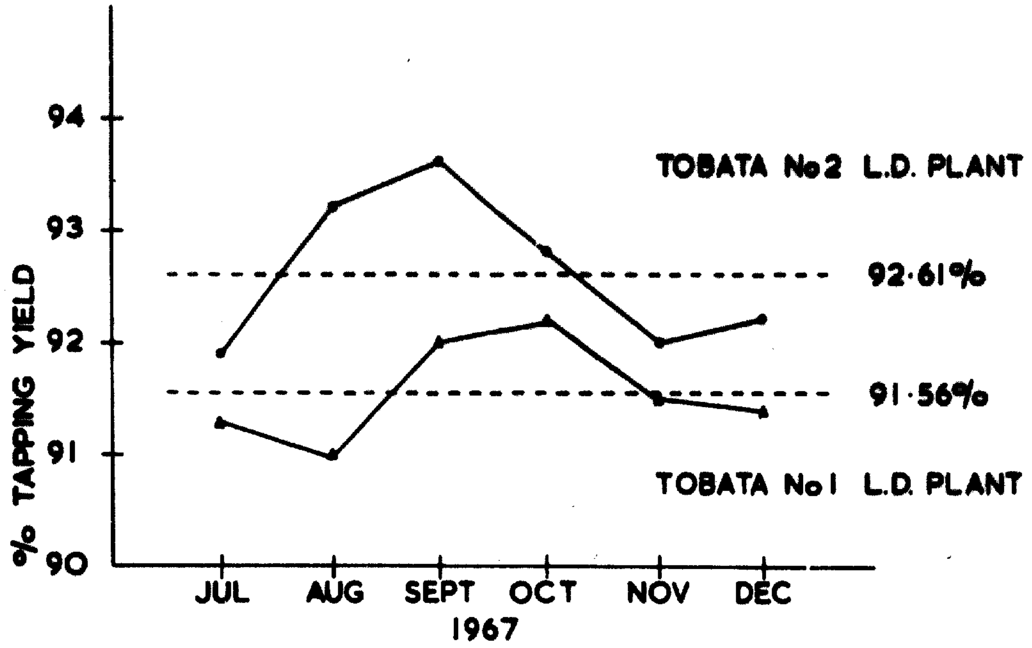


FIGURE 16: MONTHLY TAPPING YIELD OF TOBATA No.1 AND 2 L.D. PLANTS

Instinctively, many experienced steelplant operators would have reservations about bringing the hood adjacent to the furnace mouth during the blowing period. In particular those plants where a substantial proportion of the charge coolant requirement would be in the form of iron ore, or plants where the phosphorous content of the hot metal required high slag volumes and foaming slag steelmaking techniques. The closed hood system would appear to be the most advantageous at plants having a supply of low phosphorous hot metal engaged in the production of low carbon steel grades.

In considering the comparison of process yields, one should bear in mind the fact that the yield figures for the Japanese steel industry in general tend to be significantly higher than the figures obtained in the major European and North American steelworks, and undoubtedly the major contribution to this factor is the excellence of their raw materials and their general iron and steelmaking process control. However, the evidence suggests that to any oxygen steelmaker developing the required process skills for blowing the furnace with a closed hood system, then some increase in yield should accrue, and this type of gas collection system becomes extremely attractive e.g. 1.0 percent increase in yield in a 3.0 million tons per annum plant would amount to 30,000 tons per annum of steel.

At a nominal value of $50 per ton this would be an operating credit of $1,500,000 per annum, neglecting any credit for the ejections which would have accrued as scrap metal recovery.

ACKNOWLEDGEMENTS

The authors are indebted to the directors of Ashmore, Benson, Pease & Co. Ltd. for their permission to publish this paper and to the following companies who together with our friends in the steelmaking industry provided the information which made this comparison possible.

The companies concerned are :-

Yawata Iron & Steel Company, Tokyo, Japan.
International Combustion Ltd., Derby, England.
W.C. Holmes & Co. Ltd., Huddersfield, England.
Chemical Construction (G.B.) Ltd., Middlesex, England.

APPENDIX

A. Derivation of Waste Gas Volumes (see section 4)

Let H = heat size in ingot tons

Y_1 = ingot yield expressed as a percentage of the total metallic charge weight.

Y_2 = hot metal as a percentage of the total metallic charge.

Then hot metal charged $2000.H. \times \frac{Y_2}{Y_1}$ lbs.

Mean furnace gas flow rate V_F, is given by

$$V_F = \frac{C}{100.t} \times 2000.H \times \frac{Y_2}{Y_1} \times \frac{359}{12} \cdots \text{ n.c.f.m.}$$

CO Combustion in the hood

Let n = % CO_2 in the furnace gas with the balance CO

E = air excess factor allowed for CO combustion.

CO_2 in furnace gas $= \frac{n}{100} \cdot V_F$

CO in furnace gas $= \left[\frac{100 - n}{100}\right] V_F$

Air supplied for combustion

$$= \frac{100}{21} .E \left[\frac{1}{2} \cdot \left[\frac{100 - n}{100}\right]\right] V_F \quad \text{c.f.m.}$$

The gas composition after combustion will be as follows :

$CO_2 = V_F$ c.f.m. at N.T.P.

$N_2 = \left[\frac{79}{21}\right].E. \frac{1}{2} \cdot \left[\frac{100 - n}{100}\right] . V_F$ n.c.f.m.

$O_2 = (E - 1) . \frac{1}{2} . \left[\frac{100 - n}{100}\right] . V_F$ n.c.f.m.

The total waste gas volume $V_T = V_F \cdot \left[1 + \frac{1}{2} \left[\frac{100 - n}{100}\right] \left[4.76E - 1\right]\right]$ n.c.f.m.

For a particular case, taking

Y_1 = 88.5%

Y_2 = 80%

t = 22 mins.

n = 10%

APPENDIX B

COMPANY	PLANT	COUNTRY	B.O.F. CAPACITY (INGOT TONS)	COMM-ENCEMENT OF OPERATION	GAS RECOVERY
YAWATA IRON & STEEL CO., LTD.	TOBATA No.2	JAPAN	2 x 155/190	MAR. 1962	RECOVERING
SUMITOMO METAL INDUSTRIES LTD.	WAKAYAMA No.1	JAPAN	2 x 155/170 1 x 155/170	MAR. 1963 MAR. 1965	RECOVERING RECOVERING
OSAKA IRON & STEEL CO., LTD.	NISHIJIMA	JAPAN	2 x 35/40	DEC. 1964	NON-RECOVERING
NISSHIN STEEL CO., LTD.	KURE	JAPAN	2 x 65/90 1 x 65/90	APR. 1965 JAN. 1967	RECOVERING RECOVERING
YAWATA IRON & STEEL CO., LTD.	SAKAI	JAPAN	2 x 175/200 1 x 175/200	JUN. 1965 JUL. 1967	RECOVERING RECOVERING
YAWATA IRON & STEEL CO., LTD.	HIGASHIDA	JAPAN	1 x 85/90 2 x 85/90	AUG. 1966 JUL. 1967	RECOVERING RECOVERING
YAWATA IRON & STEEL CO., LTD.	KIMITSU	JAPAN	2 x 245/275	NOV. 1968	RECOVERING
ARMCO STEEL CORPORATION	MIDDLETOWN	U.S.A.	2 x 180/200	MAR. 1969	NON-RECOVERING
THE STEEL COMPANY OF WALES LIMITED	ABBEY WORKS	U.K.	2 x 300/330	JUL. 1969	NON-RECOVERING

APPENDIX C

1. <u>Tobata No. 1 L.D. Plant :</u>

2 furnaces out of 3 operation, 85 ton capacity B.O.F.

Gas Cleaning - Wet Scrubbers with Waste Heat Boilers

Tobata No. 2 L.D. Plant :

1 furnace out of 2 operation, 175 ton capacity B.O.F.

Gas Cleaning - O.G. System

2. Tapping Yield (%) =

$$\frac{\text{Molten Steel} \times 100}{\text{Hot metal} + \text{Cold iron} + \text{Scrap} + \text{Ferroalloys} + 0.6\,(\text{Iron Oxides})}$$

3. Major Products of both plants are steels for hot and cold strip.

4. 3 hole lance nozzles are used at both plants.

Furnace Gas Flow Rate V_F

$$V_F = \left[\frac{(2000)\,.\,(80)\,(359)}{(100)\quad(22)\;(88.5)\,(12)}\right] .\ \text{H.C.}$$

$$V_F = \underline{24.6.\ \text{H.C.}\quad \text{n.c.f.m.}}$$

Total waste gas after CO combustion V_T

$$V_T = V_F \left[1 + \left(\frac{1}{2}\right) \cdot \left[\frac{90}{100}\right) \quad (4.76E - 1)\right]\right]$$

$$\underline{V_T = 0.55\, V_F \quad (1 + 3.9E)}\quad \text{n.c.f.m.}$$

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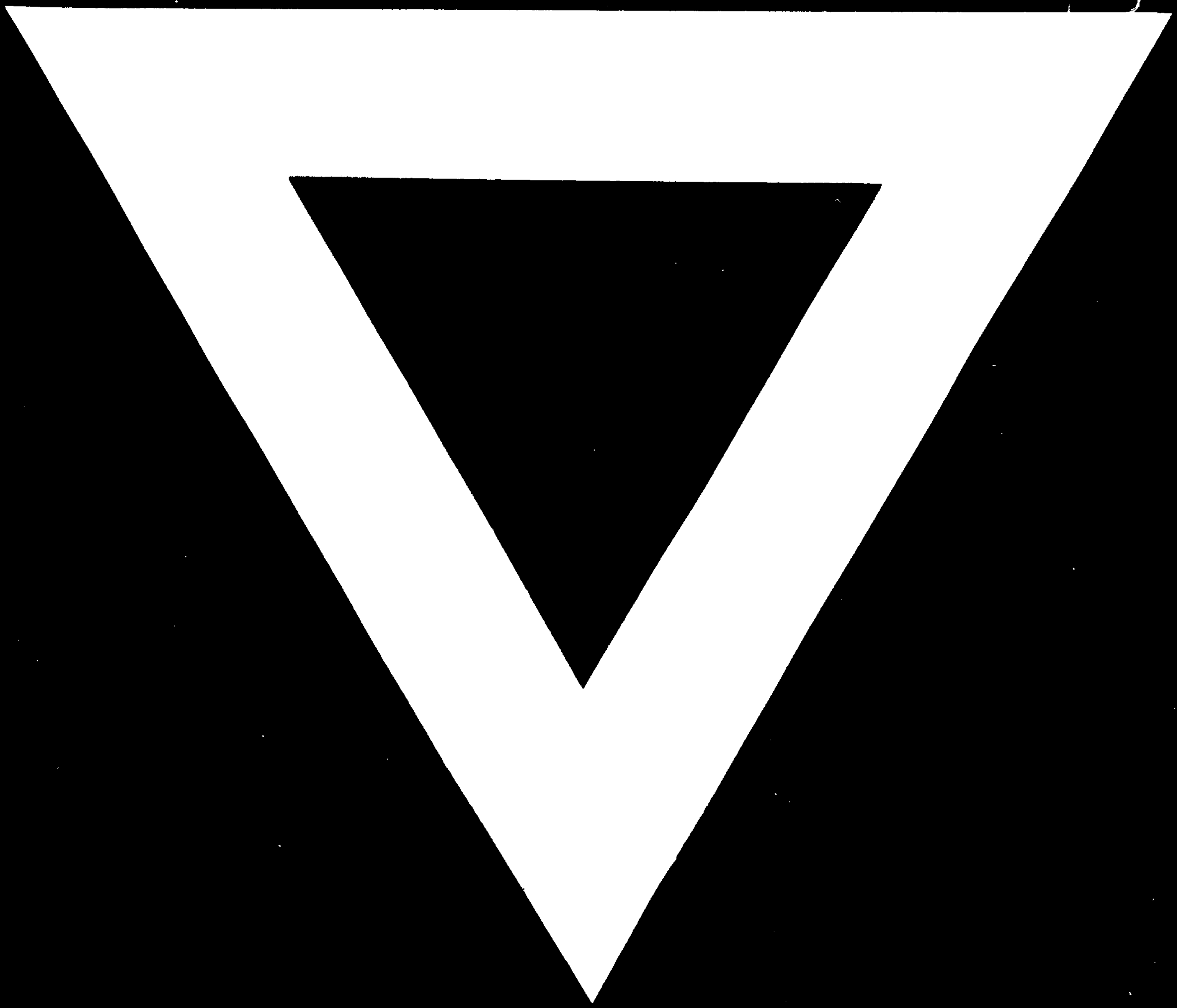

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