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MODERN DESIGN OF BLAST FURNACE [1]

by

K.Omori and T.Tsutsumi,
Japan

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MODERN DESIGNS OF BLAST FURNACE[1]

by

Masayasu Iimori and Teruo Tsutsumi,
Japan

SUMMARY

In Japan various celebration programmes are held on December 1 every year as "Memorial Day of Iron", for the purpose of appealing the interest in iron and steel to the public. This day was established in memory of the day when a European style blast furnace succeeded in tapping for the first time in Japan in 1857. This blast furnace was a charcoal furnace which was constructed by the Japanese under the technical writings acquired from Netherlands. It was about 7m high, the capacity of which was about 1 ton/day. The cold air was blasted through bellows by operating a water mill.

Then two Scotch style shell-type 25 ton/day charcoal blast furnaces were constructed near the first blast furnace. These furnaces were blown-in in 1880. They were purchased from England. They were equipped with hot stoves, blowers and boilers.

As there was a limit in using charcoal as a fuel for its supply and quality, these furnaces stopped temporarily operating. The success in producing good quality coke in 1894 germinated in modern production of pig iron by using coke as a fuel.

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* This is a summary of a paper issued under the same title as ID/WG.14/34.

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The development of iron producing equipment and techniques have attained under these pioneering experiments and by employing efficiently the newest technique developed in the United States, Germany, and other countries. Especially recently, it has been possible to mass-produce pig iron at low cost as the enlargement of the blast furnace equipment and the employment of the new techniques of pre-treatment of charge, humidity control blasting, oxygen enrichment, injection of auxiliary fuel, high temperature blasting, high top pressure operation resulted in enhancing the production efficiency and lowering coke rate. By employing these new techniques, the design of blast furnaces also has developed considerably.

We refer below to the achievement of the blast furnace design and further continuously developing improvements in Japan for the last 10 - 15 years, in the following 7 major sections.

1. Blast furnace design

1-1 Furnace construction: the blast furnaces operated in Japan nowadays are classified as follows.

(1) American-type, to support the furnace top by the mantle columns through shaft shell.

(2) German-type, to support the furnace top by the furnace scaffold (Gerust) but not by the mantle columns, the furnace itself is free standing.

(3) Combination-type of American-type and German-type.

(4) The type to hold the mantle by the brackets from furnace scaffold.

It is necessary to design the modern blast furnace, considering the resistance to the pressure caused by employing high top pressure operation, the resistance to the wear of the bricks of lower shaft and bosh caused by blowing with heavy oil in and the excellent working property in changing tuyeres and blow pipes.

1-2 Furnace proper: the enlargement of the blast furnaces has developed with the development of the blast furnace operation techniques. In Japan before the War the maximum blast furnaces were of 1,000 m^3 inner volume, and today's nine large blast furnaces of 2,000 m^3 inner volume have been installed, three of which are of over 2,500 m^3.

The furnace lines are decided at a certain proportion, though there is no change in the furnace height. Since carbon brick was used for the hearth, the life of the furnace has been extended and the molten iron has rarely outflown from the hearth wall. As the quality of fire clay brick has been better, the thickness of the furnace wall tends to be thinner. For this purpose it is necessary to employ the effective cooling method in the main parts of the furnace.

The following four systems are employed for cooling the furnace at present in Japan.

(1) External water spray system: The hearth jackets of the most blast furnaces are cooled by this system, and the bosh jackets of the blast furnaces with carbon bosh are also cooled by this system.

(2) Cooling plate system: The shafts of the most blast furnaces are cooled by this method. Cooling plates are also inserted into the brick of bosh area and iron notch area for cooling. It is necessary to employ the locking device in the high top pressure blast furnace for preventing the gas from leaking.

(3) Blister cooling system: This system is seldom employed, except an example of being employed for the bosh jackets.

(4) Stave cooling system: This system is employed for the hearth jackets in many countries. The researches on employing this stave cooling system for bosh and shaft are made, but there are some problems to be solved. As this system has the properties of excellent cooling effect, thinning the brick wall thickness, no gas leaking from furnace shell, possibility of evaporative cooling etc., the employment of this system for the blast furnace will increase.

The recent large furnaces are employed for the underhearth cooling system by the combined use of carbon hearth to protect foundation concrete.

Contents

Page

[illegible] 34

LIST OF FIGURES

Page

INTRODUCTION

In Japan, December 1st is "Memorial Day of Iron" and many events are arranged for promoting a better understanding of iron and steel among the public. The "Memorial Day of Iron" is set for commemorating the first sucess in Japan of tapping of pig iron in 1857 from the European style blast furnace. This first blast furnace including every equipment was constructed by the Japanese from the materials procured in Japan based on the techniques obtained through writings from the Netherlands which was then the only country through which Japan could absorb the European culture because the Japanese government completely isolated Japan. The capacity of the blast furnace was approximately one ton per day and charcoal was used as a fuel. This furnace was about seven meter high and constructed of stonework, internally lined with firebrick. The air for the blast was compressed by the bellows which were operated by a water wheel.

As is well known, the forerunner of the modern blast furnace, "hochofen" or "high furnace" was born in Germany during the early 14th century. This furnace was introduced into England during the early 16th century and then into American colonies during 17th century. Therefore, the iron making by the blast furnace in Japan was started by three to five centuries behind as compared with the European and American countries.

When Japan made her first step toward the modern iron making, that is at the middle of 19th century, in European and American countries, coke had been already used as a blast furnace fuel instead of charcoal. Moreover, blowing by steam engine, heating the air before it is blown into the furnace and recovering of the blast furnace top gas had all been practicized.

Whereas in England the blast furnace capacity was 14 to 15 tons on average, the maximum capacity being more than 40 tons per day, in America, the capacity ranged from one to six tons a day.

Upon opening Japan to foreign countries, many scientific and industrial technologies in various fields were introduced. Among them were included two steel shell type, Scottish charcoal blast furnaces each having the capacity of 25 tons/day. These furnaces were equipped with hot stoves, blowers, boilers, etc., and blown-in in 1880. Since then, these blast furnaces were blown out or shut down owing to the difficulties in supply and obtaining good quality charcoal. However, good quality coke production was succeeded in 1894 after extensive studies. Thus, the modern blast furnace practice using coke instead of charcoal was started for the first time and paved a way for further development.

At the peak of the iron and steel production during the World War the Second, 34 blast furnaces were operated. However, with the war ended Japan faced the complete destruction of her industry. In one period after the war, only three blast furnaces were operated. However, the Japanese iron and steel industry was reconstructed from the total destruction and has been further developed to the present level with the third in production and the first in export. The development has been achieved by the enthusiasm of the Japanese people for introducing the technologies of the technologically developed countries and by the effective use and adaptation of these technologies based upon the past experiences added step by step by the forerunners of the Japanese people in the iron and steel industry since the first blast furnace in Japan.

For example, the Technical Investigation Team from U.S.A. invited in 1952 recommended the Japanese iron and steel industry the reduction of the raw material cost, the improvement of the operation techniques, the modernization of the equipments and the integration of iron and steel making facilities. According to the recommendation, the burden preparation, the enlargement of blast furnace, steam addition and oxygen enrichment of blast, fuel injection, high temperature blast, high top pressure operation have been employed. Therefore, the production capacity has been increased and the coke rate has been remarkably decreased so that the production of pig iron at low cost in large quantity becomes possible.

As to the blast furnace design, it has been directed toward the enlargement of the blast furnace, automation and high efficiency accompanied with the advance of operation technique of the blast furnace. Especially for the past ten to fifteen years, remarkable progresses have been achieved.

The present report reveals the achievements of the blast furnace design and further continually developing improvements in the following major areas.

1. BLAST FURNACE DESIGN

1-1 Furnace Construction

The blast furnaces now operated in Japan can be divided into the following four types:-

(1) American-type, to support the furnace top by the mantle columns through shaft shell.

As shown in Fig. 1-1, this type of blast furnace requires no furnace scaffold so that the amount of the steels required is less, thereby reducing the installation cost. But the disadvantages are that the vibrations of the skip bridge and the furnace top equipment is directly transmitted to the furnace proper and the renovation is complex. In Japan, there exists seven blast furnaces of this type in operation which were constructed around in 1940 and improved or renovated. However, this type is not adopted in the recently constructed furnaces.

(2) German-type, to support the furnace top by the furnace scaffold (Gerust) but not by the mantle columns, the furnace itself is free standing.

As shown in Fig. 1-2, this type blast furnace has no mantle columns so that the layout of the mud gun, opener, cinder notch stopper, etc. can be effected in a simple manner. Furthermore, this type furnace offers the advantages of easy inspection and maintenance of the above described components and the tuyeres. However, the load or weight of the shaft portion is supported by the steel shell of the furnace proper and [illegible] so that the strength of the tuyere zone is weakened or reduced. Therefore, this type furnace are employed in a medium- and small-sized blast furnace whose working volume is less than 1,[illegible] m^3.

(3) Combination type of [illegible]

As shown in Fig. 1-3, the furnace proper is enclosed by the steel shell and the portion higher than the shaft is supported by the mantle columns. The furnace top equipment and the skip bridge are supported by the furnace scaffold. Therefore, the furnace is simple in construction and very much stable. This type is widely used in the newly constructed furnaces until a few years ago, and the number of furnaces in operation belonging to this type is highest in Japan.

(4) The type to hold the mantle by the brackets from furnace scaffold (bracket type)

As shown in Fig. 1-4, this type furnace is not equipped with the mantle columns so that the inspection and maintenance of the equipments such as tuyere, mud gun, etc. equipped around the furnace proper can be facilitated. Therefore, this type furnace is widely used in the recently constructed large-sized furnace.

In the construction of the mordern blast furnace, special attention must be taken to the following points: first the furnace structure must be stable in receiving the load due to the pressure when the high pressure operation system is employed and the weight of the furnace proper, and also stable in absorbing the thermal expansion: and secondly the replacement of the tuyeres, blow pipes, etc. and the inspection and maintenance of the mud gun, opener, cinder notch stopper, etc. must be easily made.

In the blast furnaces which have been erected in Japan recently the working volume is 2,000 to 3,000 m^3. The number of tuyeres must be increased with the enlargement of the blast furnace, thus, for example, reaching as many as 32 tuyeres. If the mantle columns are provided for such a large-sized blast furnace, the number of tuyeres would be of course limited and the tuyere pitch in the mantle columns is increased so that the uniform blowing of the air into the furnace could not be effected. Thus, smelting operation becomes unstable and the production capacity will be decreased.

Furthermore, the replacement operation of the tuyeres and blow pipes near the mantle columns and the inspection and maintenance of the mud gun, opener, etc. will become difficult. In view of the above, in the enlarged blast furnace the bracket type (4) is widely employed recently and this tendency will continue in the future.

1-2. Furnace Proper

Recently, the demands for steels for building constructions, ship-building, automobile manufacture are remarkably increasing. Thus, the production of the steel at low cost in a large quantity is demanded so that the enlargement of the high furnace has been made very rapidly with the advance of the operation techniques such as burden preparation, fuel injection, high top pressure operation, etc.

Fig. 1-5 shows the changes in the working volumes of the blast furnaces in Japan for the past ten years. Before the World War the Second, the maximum volume was of the order of 1,000 m^3 and in 1962, the volume has reached the order of about 2,000 m^3. Since then, almost all of the newly erected blast furnaces have the working volumes of the order higher than 2,000 m^3. At present there exists nine blast furnaces now in operation having the volume more than 2,000 m^3. Of these furnaces, three furnaces have the volumes more than 2,500 m^3. A blast furnace having the working volume of 3,000 m^3 is under construction and will be blown-in in 1969.

The relations between the dimensions of the profile of the furnace proper cannot be obtained by the theoretical calculations, but has been improved step by step by the results of the actual operation and experiments. As to the diameter of the hearth, the relation between the diameter and the volume is linear within the range of 600 to 2,000 m^3 Fig. 1-6. However, in the large-sized blast furnace whose working volume is larger than 2,000 m^3, the increment of the diameter becomes less.

As to the height of the furnace, the height must be determined depending upon the strength of the charging material, the flow resistance of the rising gas, the reduction speed, etc. According to the past experience, the relation between the effective height (from the tuyere level to the stock line level) and the working volume can be expressed by the relatively steep gradient curve but in the range beyond 1,700 m^3, the curve becomes flat from 25 to 26 meters because of the coke strength and the deflection of the furnace gas flow due to the increase of the flow resistance of the uprising gas (Fig. 1-7)

Therefore, the recent tendency of the design of the large-sized blast furnace is that the height is not increased but the diameter is increased. That is, "fat and shot" type.

In the conventional blast furnace low cost fire clay bricks having a relatively high heat-resistivity have been used. However, the trend from 1952 is that the carbon brick which are higher in cost but have the following remarkable merits as firebrick for furnace have been used in the furnace bottom and in the hearth molten pool.

(1) High anti-corrosivity against molten iron and slag;

(2) High thermal impact resistivity and mechanical strength;

(3) Low contraction rate after heat and chemically stable: and

(4) Thermal conductivity.

In case of laying carbon brick at the furnace bottom, carbon brick about 600 mm in thickness are laid in a few layers at the portion where molten iron is pooled. Below these carbon brick are laid high-alumina brick made of primarily clay and further below the high alumina brick layer are laid low-grade high-alumina brick in a few meters thickness.

Thus constructed bottom is cooled by air or water from the lowermost side of the low-grade high-alumina brick layer.

In some blast furnaces, fire clay brick having a better joining are laid in the upper portion while the carbon brick having a better thermal conductivity are laid in the lower portion. In some special blast furnaces in which the production capacity during the service life of the furnace is expected to be more than 10 million tons, carbon brick having a better thermal conductivity, that is having a better cooling effect are mainly used. Since no blast furnace having more than 2,000 m^3 has been renovated, the bottom corrosion condition is not clear so that it is not clear either of which the above brick layer constructions is superior to the other.

When carbon brick are used at the furnace bottom, due consideration must be given to the prevention of the rising of the brick caused by the molten iron. Generally two methods are employed in order to prevent the carbon brick from being raised: one being the method of using large-sized carbon block and the other, the method in which the end face of one carbon block is tapered so as to be held in position by the adjacent carbon block.

The size of the carbon block is dependent upon the capacity of a press, transportability, machinerability, etc. and in

Japan the biggest carbon block size is determined by the capacity of a press, and is about 800 kg. at present.

SK 34 Ione [illegible] high-alumina brick are normally used in the bosh, belly and lower shaft portions. Recently better fire clay bricks are available so that the fire brick wall thickness has been gradually reduced. However, the extreme damage of the brick at the bosh area has not yet been solved.

Therefore, there are a few blast furnaces in which carbon brick are used in the bosh area. However, the abrasion of the brick seems to be not so different from that of fire clay brick.

In order to extend the service life of the furnace wall, various effective cooling systems are used in order to cool the major portion of the furnace proper. In Japan, the following four systems are used at present.

(1) External Water Spray System

Around the external periphery of the steel shell are disposed annular spraying pipes and the water is sprayed through the nozzles attached to the pipes against the steel shell so as to cool the furnace. Almost all of the hearth jacket are cooled by this system and the bosh jackets of the blast furnaces constructed of carbon bosh are cooled also by this system.

(2) Cooling Plate System:

This is a system in which a cooling plate is interposed between the layers of firebrick of the furnace proper and water is circulated in the cooling plate so as to cool the brick wall. Cooling plates can be interposed between the brick layers in the bosh area or the tapping hole area so as to cool the brick.

The locking device is used in the cooling plate system for the high top pressure blast furnace in order to prevent a leakage of gas.

(3) Blister Cooling System:

This is a method in which an outer plate is disposed around the steel shell or jacket so as to flow the cooling water there between. By this method, the furnace wall can be uniformly cooled.

This system is best suited for cooling the bosh wall and is widely used.

(4) Stave Cooling System:

Whereas this system has been used in many countries in order to cool the hearth walls, it has not been employed in Japan. In many countries, this system began to be employed recently in cooling bosh and shaft. In this system, a cast iron, rectangular block called "stave" is disposed inside the steel shell and the cooling medium such as water or steam is passed through the stave so as to cool the furnace wall brick. This system has the following features:-

(1) The furnace brick is uniformly cooled so that the structual strength of the brick, and the resistivity against the abrasion and wear can be increased. Furthermore, even if the brick falls down from the wall, the protective layer of slag is formed upon the stave surface so that the life of the furnace can be extended.

(2) The thickness of the firebrick wall can be made thinner so that the working volume of the furnace can be increased by a few percent with the same steel shell size.

(3) Since the size of the steel shell opening can be made smaller, gas sealing can be made in a simple and positive manner. This feature is remarkable especially in case of a high top pressure blast furnace.

(4) The evaporative cooling can be effected. In this case, the natural circulation can be effected by the difference of the specific gravities between the water and steam.

In Japan, the stave cooling system was first adopted in 1967 together with the evaporative cooling system combined with the water cooling system for cooling the bosh and shaft. Since then, this system has been operating in good condition.(Fig. 1-8)

It is expected that this system will be widely used for cooling the furnace proper of the blast furnace. However, the use of this system in Japan has a short history and this system has various unsolved problems such as cracking of the stave as encountered in other countries. Therefore, this system is a cooling system still having much left to be improved.

1-3 Furnace Top Equipment

McKee type distributor having a large and a small bells is widely used when the normal top pressure of the blast furnace was in the range of 500 to 1,000 mm Aq. However, since the end of the World War the Second, the trend of the blast furnace has been to use a high top pressure in order to increase the production capacity. In Japan, the first high top pressure blast furnace was started in 1962 and since then some of the normal top pressure operated blast furnaces have been renovated or remodeled into the high top pressure blast furnaces. At the same time, high pressure blast furnaces have been erected. At present a total of 21 high top pressure blast furnaces are operated in Japan. In the furnace top equipment for the normal pressure blast furnace, the pressure difference between the small and large bells is less so that even if the gas leakage occurs at the bell seat portions, the leaking flow rate is very small, whereby the bells are subjected only to the wear by the raw material, not to the cutting by gases.

On the other hand, in the high top pressure blast furnace, the pressure difference between the bells sometimes reaches the furnace top pressure, so that the leaking flow velocity from the seat portion reaches almost the speed of sound, whereby the bells are subjected not only to the severe gas cutting but also to the abrasion and wear due to the raw material. Therefore, the service life of the bell is extremely shortened so that the bells must be replaced from time to time.

In order to overcome these problems of the furnace top equipment of the high pressure blast furnace, various furnace top equipments have been proposed and developed. The furnace top equipments being developed can be divided into two groups. One is intended to further strengthen the conventional McKee distributor and at the same time to provide the improvements by which the worn parts or components can be replaced in as short time as possible. The other is intended to develop the novel furnace top equipment which is entirely different from the conventional McKee distributor. In Japan, much efforts have been directed to the latter and the valve seal top utilizing the three-bell system has been developed and successfully used in practice.

Fig. 1 - 9 shows the two-bell system McKee type distributor, Fig. 1-10 shows the three-bell top, and Fig. 1-11 shows the valve seal top.

In the valve seal top, two seal valves are used instead of the small bell in the three-bell top. The revolving chute is sealingly housed within a sealed container as a raw material distributor and is fixed to a hollow cylinder shaft having a small diameter. The shaft is rotatably journalled upwardly, outwardly of the bell hopper and is turned at a predetermined angle.

The main features of this valve seal top are as follows:-

(1) The valve seal top eliminates the use of the grease seal device disposed around the revolving hopper and

in case of the two-bell or three-bell top. Therefore, it is only necessary to seal the small diameter shaft of the revolving chute by means of a gland packing so that the complete gas-tight hopper can be obtained, thus overcoming the gas leakage problems.

(2) Instead of the small bell of the conventional three-bell top, is used the seal valve whose valve seat is not made in contact with the raw material and whose valve disk can be retracted out of the raw material passage. Therefore, the seal valve is not subjected to the abrasion and wear due to the raw material so that a flexible, soft material such as rubber can be used in the seat portion, thereby effecting the complete gas sealing.

(3) When the gas leakage from the seat portion of the seal valve becomes greater, the rubber seat can be replaced in a simple manner when the blast furnace is shut down. The replacement of the rubber seats twice a year is enough and other parts or components are permanently serviceable.

As in the case of the middle bell of the three-bell top, at the small bell of the valve seal top is produced the pressure difference between the upper and lower sides of the bell so that the bell seat surface is subjected to gas cutting due to the gas leakage. In order to encounter this problem, a silicon rubber seat is attached to the small bell for preventing the gas leakage.

The abrasion and wear of the small bell seat portion can be remarkably reduced when the small bell is fabricated from a material such as high chrome cast iron which has an excellent abrasion resistivity. In this case, the abrasion is such that only one mm abrasion of the seat portion occurs every 500 thousand ton production. The large bell is made of hard faced cast steel. At the large bell, no pressure difference is produced between the upper and lower sides of the large bell as in the case of the large bell of the three-bell top. Therefore, the service life of the large bell is same with that of the normal pressure blast furnace.

As shown in Fig. 1-12, the valve seal tops are used in 10 out of 20 high top pressure blast furnaces now operated in Japan, and will be used in 17 out of 28 high top pressure furnaces including high top pressure furnaces newly erected and renovated or remodeled in this year and next year.

It must be pointed out here that almost all of the high top pressure furnaces constructed since 1966 use the valve seal tops and this tendency proves that the valve seal top equipment is excellent in operation.

The valve seal top can be used not only with the large-sized high top pressure blast furnace now under construction but also with the blast furnaces which have now the two-bell tops. Four out of the high top pressure blast furnaces now in operation equipped with the valve seal tops have been remodeled from the two-bell top equipped blast furnaces.

2. BURDEN PREPARATION

It is clearly understood that the burden preparation has played an important roll in the rapid advancement of the blast furnace operation technique in Japan. That is, Japan is importing about 90% of its iron ores and about 60% of coking coal so that it has been an important problem of the iron and steel making industry how to compensate the high raw material cost. To solve this problem, the intensified sizing operation in which the size of raw material particle is regulated and the fine ore is removed and the use of the self-fluxing sinter pellet having a better reducibility or reduction characteristics and a better particle size composition are now being employed so that the ventilation within the furnace has been much improved, whereby the furnace operation is stabilized, the large quantity of blowing air can be accomplished, the gas utilization rate can be increased, the high temperature air blowing can be effected and the fuel injection can be achieved, thereby remarkably contributing much to the improvement of the productivity and to the reduction of the coke rate.

2-1 Sizing of Ore

Until fifteen years ago, one stage crushing was made in order to crush large lumps of ore into the particle less than 50 mm. However, the sizing equipments have been intensively improved because the fine mixtureratio of the imported iron ore has increased, the demand for reducing the maximum particle size has increased so that the quantity of the finely divided ore is increased and it has been clarified that the removal of the finely divided iron ore much affects the improvement of the operation of the blast furnace.

Fig. 2-1 shows the improvement from one stage crushing to the two-stage crushing and two-stage screening.

Since then two-stage crushing and multi-stage screening process has been introduced. As described above, the maximum particle size has been 50 mm in case of the commercial blast furnace charge, but the size has been reduced further to 40 mm, 35 mm, and so on in order to reduce the reduction time. Thus the regulation of the maximum particle size and the removal of the finely divided ore become the major problems in the industry.

In order to overcome the above problems, the circulate system shown in Fig. 2-2 in which the ore particles larger than the maximum particle size are returned to the crusher again was first adopted in 1955. Since then, various improvements and new installations of this systems have been made so that the sizing process is effected in more stages than before. [illegible] all of the sizing plants employ the circulate system. According to this system, it is possible to control the particle size within the narrow range of 25 to 10 mm.

Fig. 2-3 shows the flow sheet of the recently constructed sizing plant.

Generally, a gyratory crusher is used as a first stage crusher and a cone crusher is used as the secondary stage crusher.

In order to regulate strictly the particle size, the setting of the secondary stage crusher must be adjusted at frequent intervals. A hydro cone crusher is widely used as a crusher to fulfil this purpose. However, when the strict particle sizing is stressed, a large quantity of finely divided particle ore is produced. Therefore, it is desired to develop a novel crusher which can prevent the generation of such fine particle ore.

In screening process, the vibrating screens are widely used, but in case of processing the coking coal, the efficiency of the vibrating screens is reduced remarkably.

In order to encounter this problem, the loose-rod deck screens are employed and at the same time the screening process is effected in many stages. However, it is desired that the coking coal is screened and water-washed in more improved manner at the coal mine itself.

2-2 Sintering

As described above, 90% of iron ore consumed in Japan is being imported. Therefore it is necessary to select the iron ore which can be obtained at lower cost. Moreover, because of the intensified sizing process as described above, a large quantity of finely divided particle ores is produced, thus, the ratio of the finely divided ore to the whole raw material is remarkably increasing.

Furthermore, it has been clarified that self-fluxing sinter blended with lime powder contributes much to the reduction of coke rate and to the production efficiency of pig iron Therefore, the sintering plant is a must in the iron making industry.

The sinter blending equipment is incorporating a constant feed weight which is adapted to maintain constant the blending ratio by the signals from the centralized control room. The neutron water content measuring instrument has been come to be practically used in continuously measuring the water content of coke and in controlling the water contents of the blended raw materials so that the instrument serves to a great extent to stabilize the quality of the pig iron produced and the operation of furnace.

In order to improve the apprent particle size of the blended material and to increase the productivity, the blended raw material which has passed through the first or primary mixer is charged into the secondary mixer for agglomeration prior to being charged into the sintering machine. In some plants, the semi-pellet method in which only fine particle ore is agglomerated by the drum type or disk type agglomerating machine is used.

In order to control the hopper level, the load cell type, electrode sounding type or radio isopte type method is employed with a satisfactory result in operation.

Prior to 1957, A.I.B. type, Greenawalt type, Dwight Lloyd type sintering machines had been operated, but the sintering machines constructed after 1958 are all of D.L. type. Until the large-sized sintering machine whose effective area is 113 m^2 (2.46 m x 46.36 m) was first introduced in July, 1960, the largest sintering machine had the effective area of 66 m^2 (2 m x 33 m).

In December, 1960, the sintering machine having the effective area of 130 m^2 (25 m x 52 m) was constructed, producing more than 4,500 tons a day.

As the blast furnace is enlarged, the sintering equipments are also enlarged. In 1964, the sintering machine having the effective area of 182 m^2 (3.5 m x 52 m) was constructed while in 1966, two sintering machines having the effective area of 150 m^2 were erected. Further more in 1967, the large-sized sintering machine having as much as 183 m^2 was newly installed. The above sintering machines are all producing more than 5,500 tons per day. The number of the sintering machines whose effective area is larger than 150 m^2 and which are under construction or to be constructed is as many as nine.

The main exhauster whose capacity is sufficient enough to handle the effective area up to 200 m^2 can be fabricated, thanks to the improvement of the fabrication techniques. In some plants, two main exhausters each having the same capacity are installed in order to encounter the breakdown or failure. Such tendency will be applied to a large-sized sintering plant. The negative pressure of the order of 1200 to 1,300 mm Aq. in normal, but in some plants, the high suction blower of the order of the negative pressure of 1,400 mm Aq is used.

As the dust catching devices, the cyclones or multiclones are widely used, but recently the electrical dust catchers are installed in some plants.

2-3 Pelletizing

In Japan, the pelletizing plant is not so popular as the sintering plant, because the raw materials suited for pelletizing are less available in Japan. That is, the raw materials for pelletizing must be stable in particle size, and also physically and chemically. Even a slight change of these properties much affects the productivity and to the quality whereas the raw materials for sintering have the large range of permissibility.

One of the pelletizing plants operated in Japan is aimed at pelletizing pyrite cinder whose sintering characteristics is worse. In this plant, the ore wetting method has been developed and the production of hard pellet by means of the shaft furnace sintering is successfully achieved.

One of two other plants has shaft furnaces whose capacities of 120 tons/day x 3,250 tons/day x 8 and 400 dons/day x 6, and producing pellets in the diameter ranging from 15 to 35 mm. The feature of this plant is the low thermal or heat consumption. The other plant was constructed in 1966 and employs the grate-kiln system designed for processing or treating various hematite and magnetite. This plant is producing the self-fluxing pellet 3,600 to 4,000 tons a day. The flow sheet of the sintering process is shown in Fig. 2-4.

3. FURNACE CHARGING EQUIPMENT

One of the most remarkable tendencies in the blast furnace design in Japan is to employ the charging equipment comprising the belt conveyor instead of the skip cars.

In Fig. 3-1, the number of blast furnaces erected and the numbers of blast furnaces each equipped with skip type and belt conveyor type charging equipments for the past ten years from 1957 and 1968 in Japan are shown.

Among fifty-five blast furnaces now operated in Japan, 37 blast furnaces (67%) are equipped with the skip type charging equipments whereas 8 blast furnaces (15%), with the bucket type charging equipment and 10 (18%) of blast furnaces, with the belt conveyor type charging equipment.

It must be particularly pointed out here that of the 25 blast furnaces erected from 1960 to 1968, ten blast furnaces are equipped with the belt conveyor type charging equipments, that is 40% of the blast furnaces are equipped with the belt conveyor type charging equipment.

This tendency is remarkable in the large-sized blast furnaces having the volume of more than 2,000 m^3 which will be erected in the near future. Of five blast furnaces which will be erected until the end of 1969, four blast furnaces will be equipped with the belt conveyor type charging equipments.

Since of nine blast furnaces now operated having the volume more than 2,000 m^3, four furnaces are equipped with the belt conveyor type charging equipments, of 14 blast furnaces having the working volume of more than 2,000 m^3 including the furnaces erected until the end of 1969, 8 blast furnaces will become of the belt conveyor type (See Fig. 3-2).

When the blast furnaces having the working volume of more than 2,000 m^3 are divided into two groups, that is one group to which belong the blast furnaces having the working volume of between 2,000 to 2,500 m^3 and the other group including the blast furnaces having the working volume of more than 2,500 m^3, six blast furnaces belong to the first group while eight blast furnaces, to the second group. Of six blast furnaces belonging to the first group, three blast furnaces are of belt conveyor type (See Fig. 3-3) while of eight blast furnaces belonging to the second group, five blast furnaces will become of the belt conveyor type (See Fig. 3-4).

Therefore, more than one half of the blast furnaces, that is 50% and 62.5% will become of the belt conveyor type.

On the other hand, the bucket type charging equipments have been used in the blast furnace whose working volume is less than 1,100 m^3. But because of the complex mechanism and the limit of the capacity, no bucket type charging equipment has been recently installed in newly erected blast furnaces.

Therefore, the number of blast furnaces provided with the bucket type charging equipments will be decreased in the future.

So far the tendency of the blast furnaces equipped with the belt conveyor type charging equipments accompanied with the enlargement of the blast furnace has been described, and next the adaptability of the skip type and belt conveyor type charging equipments to the blast furnaces will be compared and the superiority of the belt conveyor type charging equipments over the skip type charging equipment in case of the enlarged blast furnaces will be proved.

In Fig. 3-5, the capacity of a skip car is plotted along the abscissa while the ore charging capacity and the pig iron production corresponding to the ore charging capacity are plotted along the ordinate. In case of the belt conveyor type charging equipment, the width of belt is plotted along the abscissa while the ore charging capacity and the pig iron production capacity corresponding to the ore charging capacity are plotted along the ordinate. Thus the capacity limits in both of the skip type and belt conveyor type charging equipments are shown.

In calculating the production capacity from the charging capacity, the ore ratio is assumed to be 1.8 tons/ton of iron while the over-filling capacity to be 50%.

As is clear from Fig. 3-5 in case of the skip type charging equipment the production capacity limit is considered to be 6,850 tons per day (top speed 150 m/min) to 7,200 tons per day (top speed, 180 m/min). On the other hand, the belt conveyor type charging equipment can be applicable to the blast furnace whose production capacity is between 21,500 to 43,500 tons per day. That is, at the present Japanese engineering level, the belt conveyor type charging equipment has the capacity 3.5 to 6.3 times the capacity of the skip type charging equipment. Since the production capacity of a blast furnace having a working volume of more than 2,500 m^3 is designed to have the production capacity of 6,700 to 8,000 tons per day, the belt conveyor type charging equipment is more and more used as a blast furnace is enlarged. This tendency will continue in the future.

Next the construction costs will be compared with reference to a blast furnace having a working volume of about 2,140 m^3.

In this case, the construction cost of the skip type charging equipment is 1.69 times, 1.36 times and 1.24 times higher than those of the belt conveyor type charging equipment in mechanical, structual and electrical parts respectively. Thus, it is generally accepted that the construction cost of the belt conveyor type charging equipment is lower than that of the skip type charging equipment.

In the general design of a blast furnace plant, the belt conveyor type charging equipment has a disadvantage that the distance between the furnace and the stock house will become longer. But the advantages of the rationalized and unlimited arrangements of the cast house, transportation of molten iron and slag and other auxiliary equipments in addition to the simple electrical and control installations for operation can sufficiently cover the above disadvantage.

So far the comparison between the skip type and belt conveyor type charging equipments has been made. It is considered that the tendency of employing the belt conveyor type charging equipment in many blast furnaces will be increased in consideration of the low construction cost, the efficient adaptability, the rationalization and improvement of the over-all efficiency of blast furnace, etc.

4. HOT STOVES

Recently Japan has made a rapid progress in the operation and equipment in pig iron production, and stands the highest in the world concerning the reduction in coke rate, which depends on the pre-treatment and high quality of the charge materials.

At present, over 950°C high temperature blast, 1155 °C in the highest, is operated, with the development of burden preparation, blast humidification and fuel injection.

The equipment with the resistance to 1250° - 1300°C blast is required.

Fig. 4-1 shows the highest blast temperature in hot stoves in the past 10 years.

According to this figure, it is evident that the blast temperature has rapidly increased since 1965. The increase of blast temperature has the advantages not only of saving in coke but also of saving in limestone due to reduction of ash come from coke.

Therefore it is possible to increase the charging amounts of ferrous materials and increase production. The effect of blast temperature to coke rate depends on the operating conditions. The 20-30 kg reduction of coke rate is expected per 100 °C temperature increase of blast. The pig iron production increases 0.09 t/d/m^3 per 100°C temperature increase of blast.

[illegible]- **Furnace top equipment:** McKee-type distributors had been mostly employed before the high top pressure operation was practiced. By employing the high top pressure operation, however, the life of the equipment has been remarkably shortened. Therefore, various new furnace top equipment are being developed. The development is divided roughly into two directions. One is to strengthening the McKee-type distributor and at the same time to improve the sealing of the system of parts under high pressure, and the other is to develop the new equipment which are fundamentally different from McKee-type distributors. The [illegible] has been emphasized, and the valve seal system [illegible] with the exception of [illegible]-bell system. The high top pressure blast furnaces with the valve seal system [illegible] blast furnaces operated at present in Japan. The form of [illegible] from the conventional McKee top.

The development of the wear resisting materials has been in advance, and high chromium cast iron has been successfully used for small bell and hard faced cast steel has been used for large bell. The life of the large bell under high top pressure has been extended to the level of normal top pressure blast furnace by employing valve seal system.

2. Burden preparation

2-1 **Sizing of ore:** Iron ore was charged by crushing lump ore to under [illegible] mm fifteen years ago, but at present all the plants employ the circulated crushing and screening system to limit the range of the size [illegible] - [illegible] mm, as it has been proved that the removal of fine ores helps to enhance the operation results of the blast furnace.

2-2 **Sintering:** Sintering was developed for the purpose of fine ore recovery. The equipment of sintering has been expanded since ten years ago self-fluxing sinter is proved to be very efficient for lowering coke rate and increasing furnace productivity as it has better reducibility in comparison with raw iron ores. The sintering machines have been larger in size with the advance in enlarging the blast furnaces. At present, sintering machines of more than [illegible] m² effective area are operating, under construction or planned.

2-3 **Pelletizing:** In Japan pelletizing plants are not so widely employed as sintering plants, and mainly imported pellets are charged into the blast furnace. The plant which was constructed in 1966, employing grate-kiln system, produces 3,600 - 4,000 ton/day self-fluxing pellets.

3. Furnace charging equipment

Of 55 blast furnaces operated in Japan at present the blast furnaces of skip system are 37 (67%), bucket system 8 (15%), and belt conveyor system 10 (18%). Four of five large blast furnaces, which are planned to be constructed by 1969, are to employ belt conveyor systems. It is advantageous for the large blast furnaces of more than 2,000 m^3 capacity to employ belt conveyor systems. It is because the belt conveyer system has much larger charging capacity and lower construction cost than the skip system, and it is possible to layout cast house without considering the charging equipment.

4. Hot stoves

In Japan hot stove was employed for the first time in 1880, but the hot blast temperature was 500 - 700°C about 15 years ago. At present the hot blast temperature is generally 1,000 - 1,100°C by employing burden preparation, humidity controlled blast and fuel injection. Moreover, even 1,250 - 1,300°C temperature stoves have been constructed. These high temperature stoves depend mainly on the improvement of refractories for hot stoves and the improvement of stove burners and valves. The stabilization of operation has been possible by introducing external combustion chamber design stoves. External combustion chamber design stove was constructed for the first time in 1965, and since then this type stove accounts for a half of hot stoves. Automatic stove reversal equipment is widely employed all over Japan.

5. Blowing equipment

About 100 years ago the blowing equipment was the bellows powered by water mill, which was followed by reciprocating compressor and then centrifugal type blower. At present axial-flow blower is widely employed. With the enlargement of the blast furnaces and the employment of high top pressure operation, the blower of large volume and high pressure has been required; the blower of [illegible] KW, 7,400 Nm³/min and [illegible] are under construction. The various operating conditions have also been required. Therefore, the blower should be of safety and high efficiency in wide range as it is frequently used beyond optimum design conditions. For this purpose, it is widely employed to control flow volume by varying the angle of stator blade of the blower.

6. Gas cleaning equipment

As it is required to use more cleaner blast furnace gas as fuel for coke ovens or hot stoves, gas cleaning equipment is generally designed under the condition of less than [illegible] mg/Nm³ dust content. Dust, coarse particles of which are removed by conventional dust catcher, is generally cleaned by gas cleaning equipment in two stages, primary stage and secondary stage. The combination of these two stages was mainly the combination of gas washer and electrostatic precipitator, but since high top pressure operation was employed, venturi scrubber which requires large pressure drop has been employed as a primary stage. Some plants employ venturi scrubber as a secondary stage, by making efficient use of the advantages that the installation cost is low, operation and maintenance is easy and installation space is small.

7. Cast house layout and mechanization

The casting time has increased with the blast furnace capacity increase, which resulted in less sufficient time for maintenance of troughs and runners. In Japan the blast furnace with two tapholes has been employed since 1962, which was the opening of the rationalization in cast house practice. All the blast furnaces of more than [illegible] ton/day constructed or remodelled since then have two tapholes.

Molten iron is transported to BOF plant by torpedo-type mixer car. The method to dispose the slag to the dry slag pits adjacent to the blast furnace has been recently employed widely as a method of large amounts of slag treatment at low cost.

Mud gun, taphole drill and slag notch stopper are all remote-controlled, which are equipped to all the blast furnaces. Several plants employ effectively tuyere changing machine, runner maintenance machine and replaceable troughs as a mechanization of cast house practice.

2 OF 2

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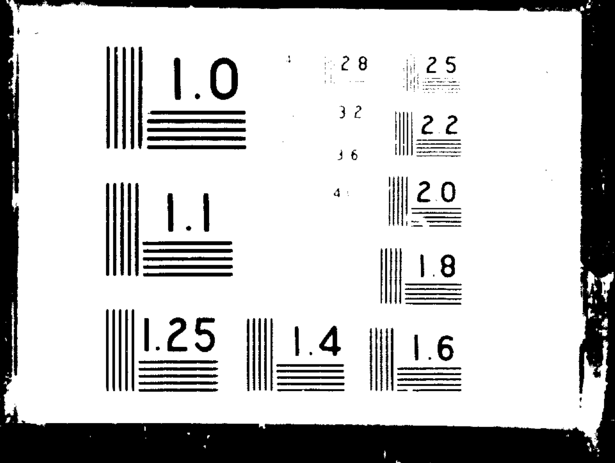


A remote-controlled shovel loader for slag pits has been developed as the operation surroundings are not so good.

Tapping hammer for opening taphole and mud gun for closing are remotely controlled. Commonly the former is pneumatic type and the latter is electro-mechanical type. Mechnical slag notch bott is also employed in the modern blast furnace. However, in the recent blast furnace operation, generally slag is seldom flushed independently, but at the same time of tapping.

Recently the mechanization and rationalization of cast house operation, which was by man power, has been advanced positively, and replaceable trough, runner maintenance machine and tuyere changing machine are effectively employed. Fig. 7-2 shows the arrangement of cast house of the newest blast furnace.

This blast furnace has two tapholes and one slag notch, and is equipped with suspension type tuyere changing machine to easily change tuyeres and bend pieces, with replaceable trough to use continuously for long hours and to repair easily, and with rotary crane to operate possibilily in wide range. Fig. 7-3 shows the example of suspension type tuyere changing machine.

Fig. 7-4 shows the example of floor type tuyere changing machine, which is employed in a few blast furnaces.

Fig. 7-5 shows runner maintenance machine, which is specially used for breaking and stamping of runner materials.

CONCLUSION

Iron and steel industry in Japan, which was almost ruined in the World War II, has made a rapid progress, as shown in Fig C-1, materialized through the first rationalization plan starting in 1951.

In 1967 Japan produced 62, 164, 000 ton of crude steel, ranking third place in the world next to U.S.A and U.S.S.R.

Various factors are accounted for the rapid progress, and one of main factors is that Japan agressively introduced into her steel industry new technologies, and not only absorbed them in a short period of time but also at the same time excelled in many cases the level of the introduced technologies of advanced countries, such growth of higher technological capability may be largely attributed to potentiality of people engaged in the industry.

Looking back Japanese history, Japan remodelled into a new and modern nation at Meiji Restoration taking place exactly 100 years ago.

Due to wide spread of education as strongly promoted by the new government of Japan with highest of education ratio was reaching at a certain advanced stage of industrial development even before the World War II.

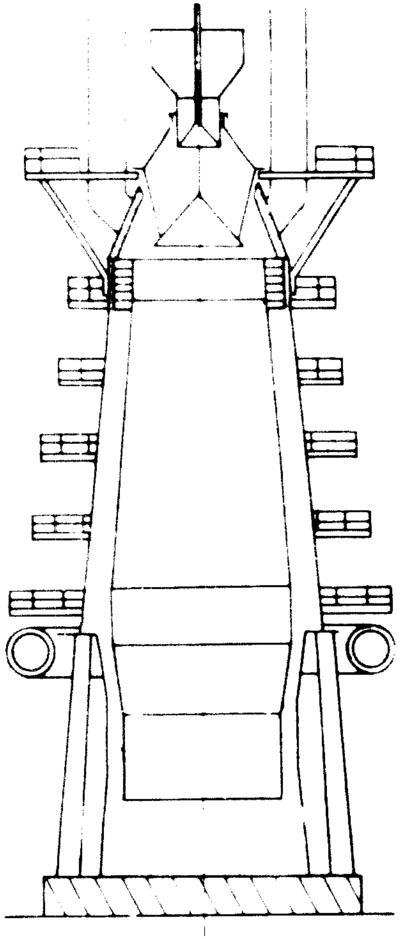
Fig C-2 shows the progress of the technology in the Blast Furnace field.

Japan has gained better fruits from the newly introduced technologies, than they are employed in the original supplier of the technologies, such as ore preparation, as imported from U.S.A. Oil Injection. from France, High Top Pressure Operation from U.S.A and High temperature hot stove from W. Germany.

Fig. C-3 shows the import and export of technology from 1951 to 1967.

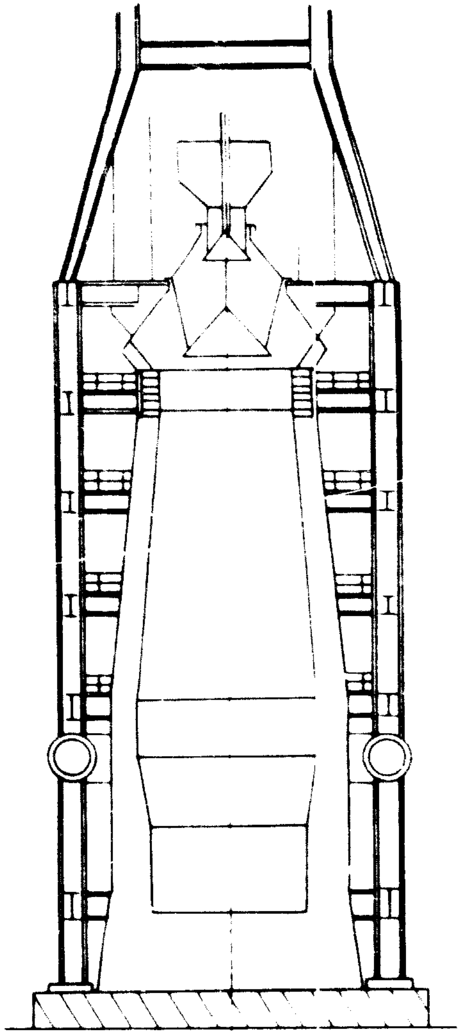
Japan, which had long been a onesided technology-importing country, began to export them since 1964.

In future, it is expected that our export of technology will increase more and more with the higher growth in Iron and steel industry.



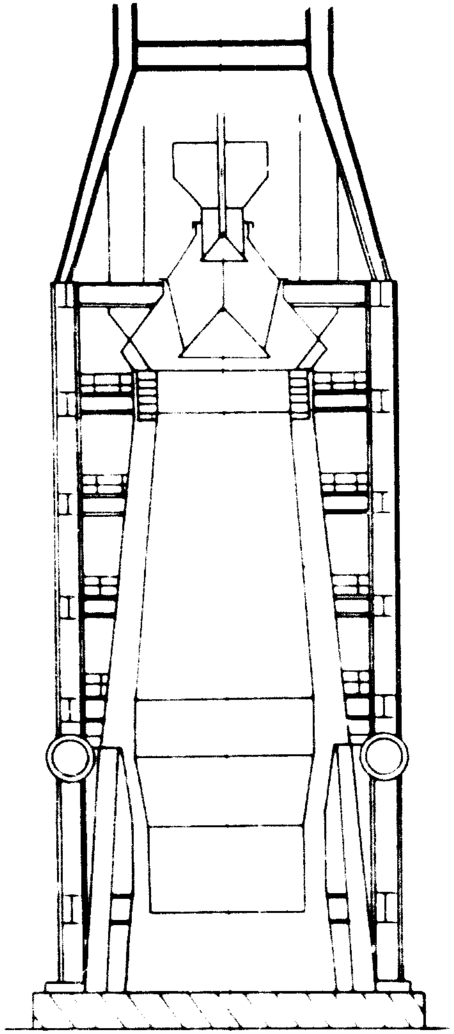
AMERICAN TYPE

Fig. 1-1



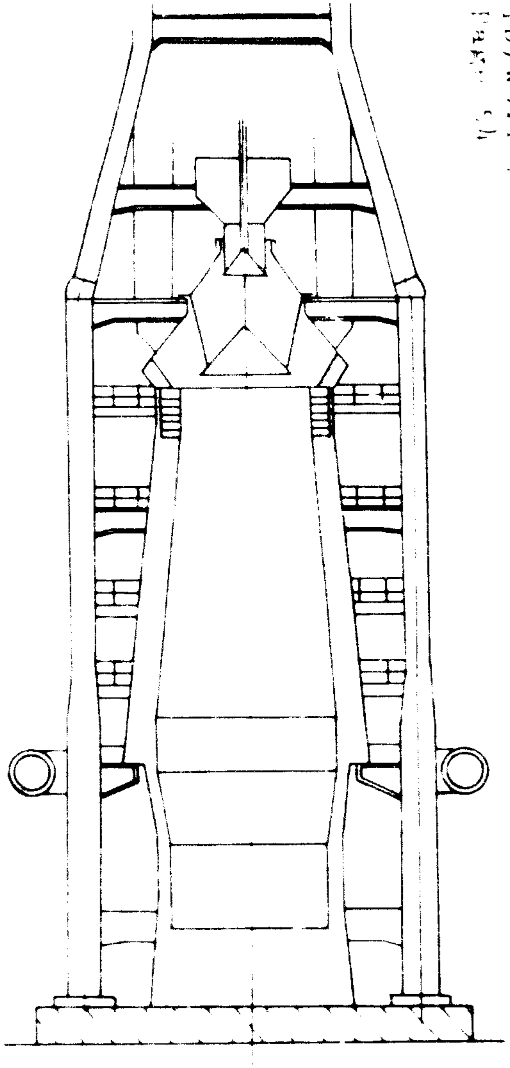
GERMAN TYPE

Fig. 1-2



COMBINATION TYPE

Fig. 1-3



BRACKET TYPE

Fig. 1-4

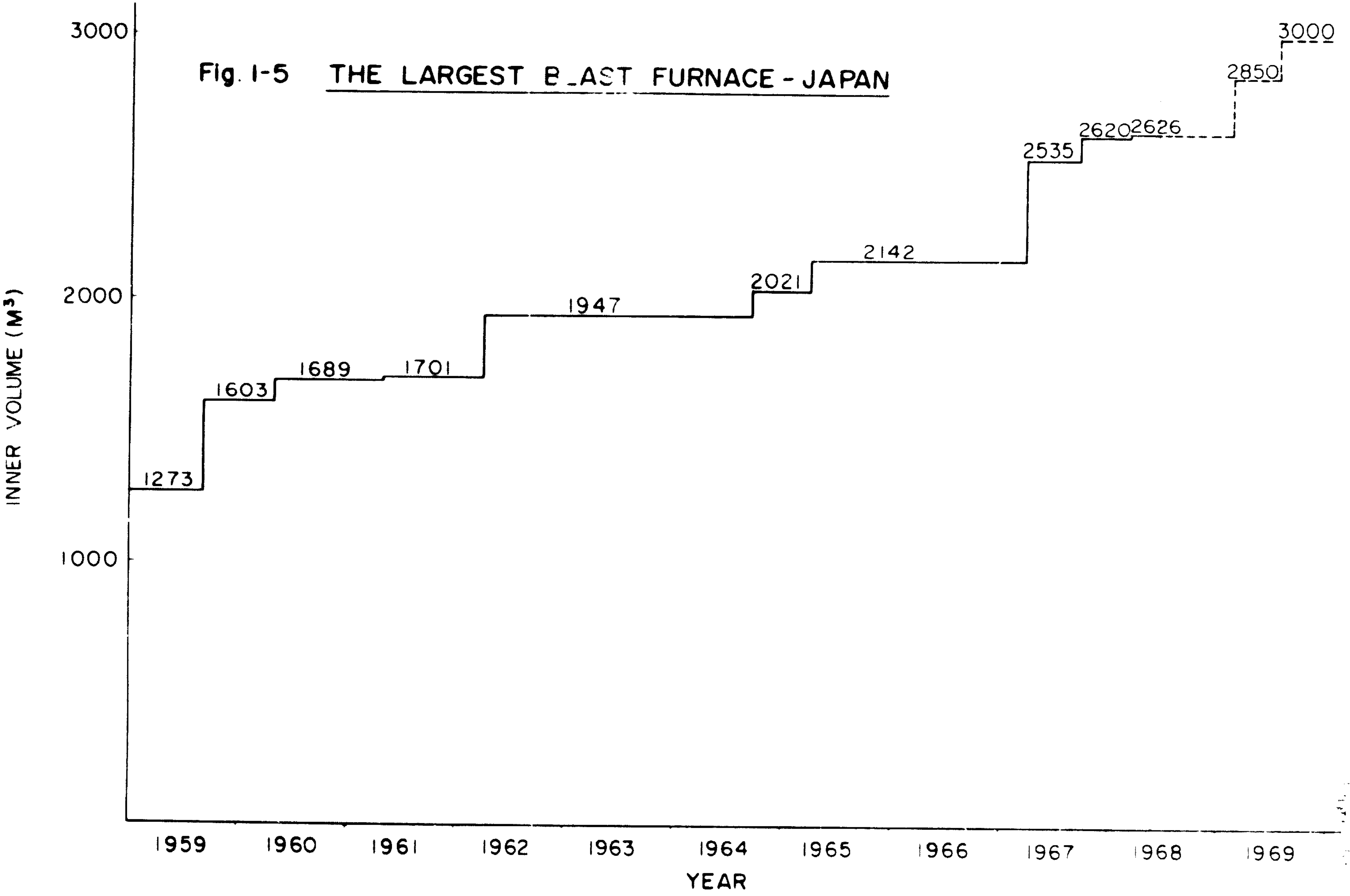


Fig. 1-5 THE LARGEST BLAST FURNACE - JAPAN

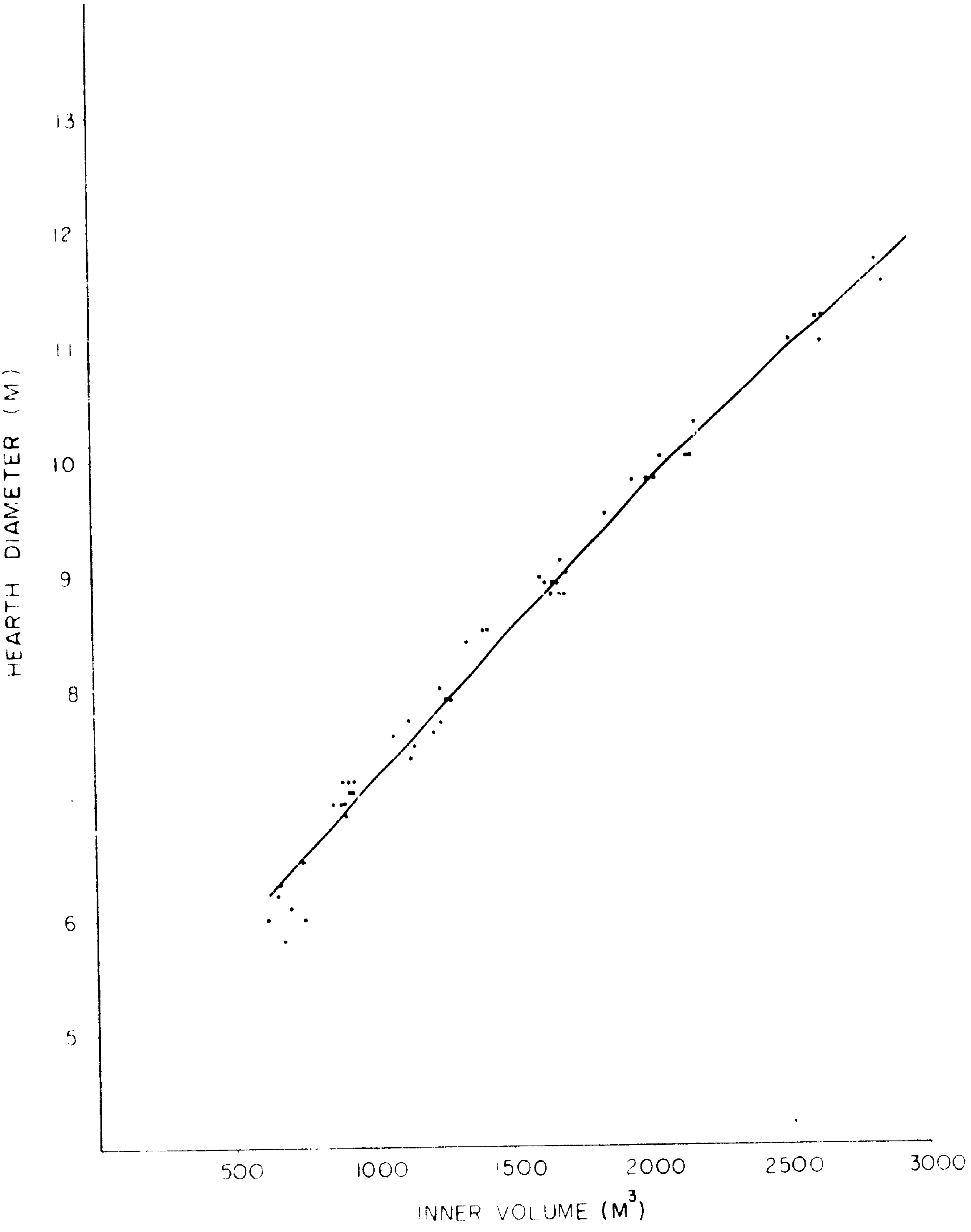


Fig 1-6 RELATION BETWEEN HEARTH DIA. AND INNER VOLUME

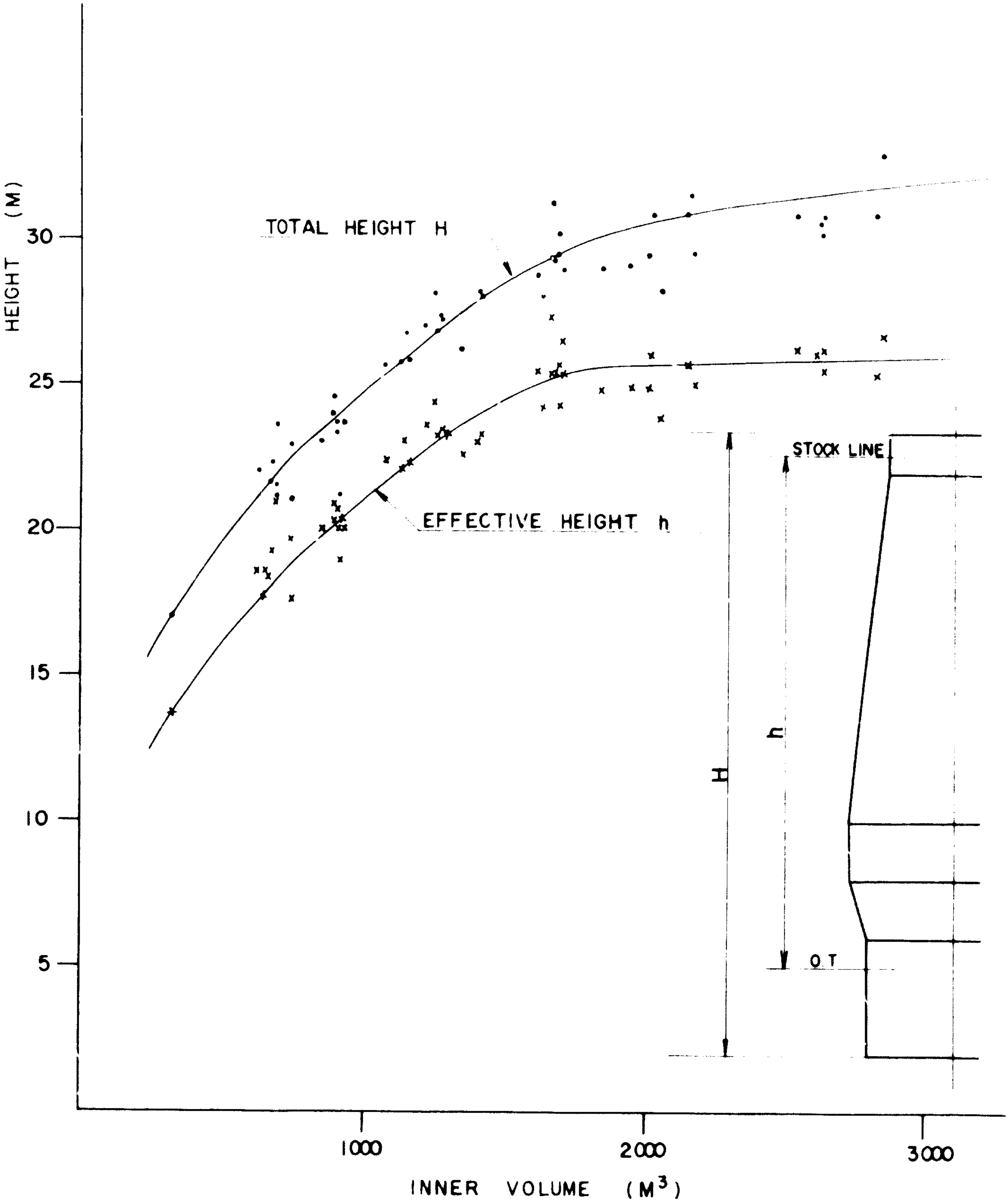
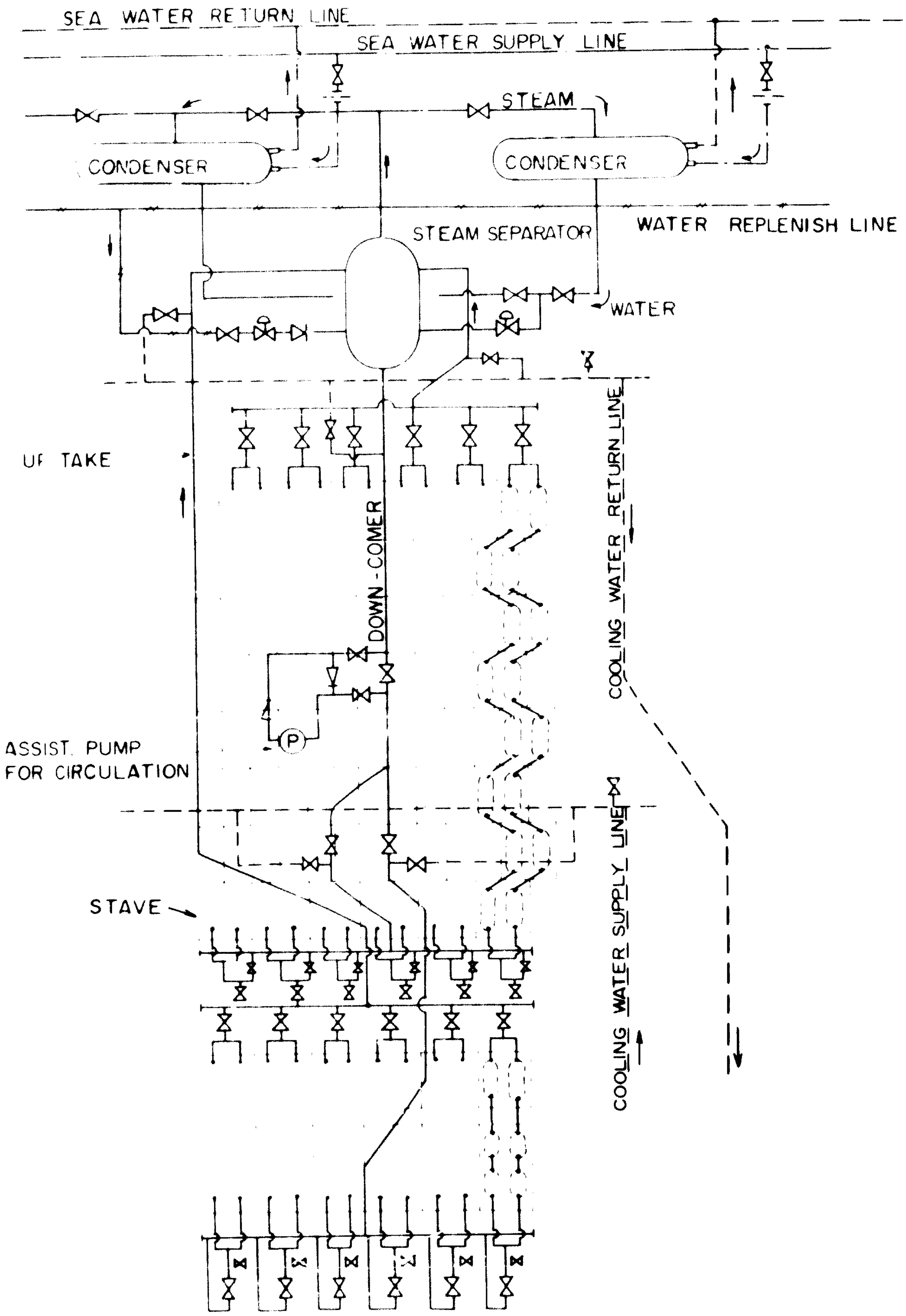


Fig. 1-7 RELATION BETWEEN FURNACE HEIGHT AND INNER VOLUME

Fig. 1-8 STAVE COOLING SYSTEM COMBINING EVAPORATIVE SYSTEM AND RECIRCULATION COOLING WATER SYSTEM



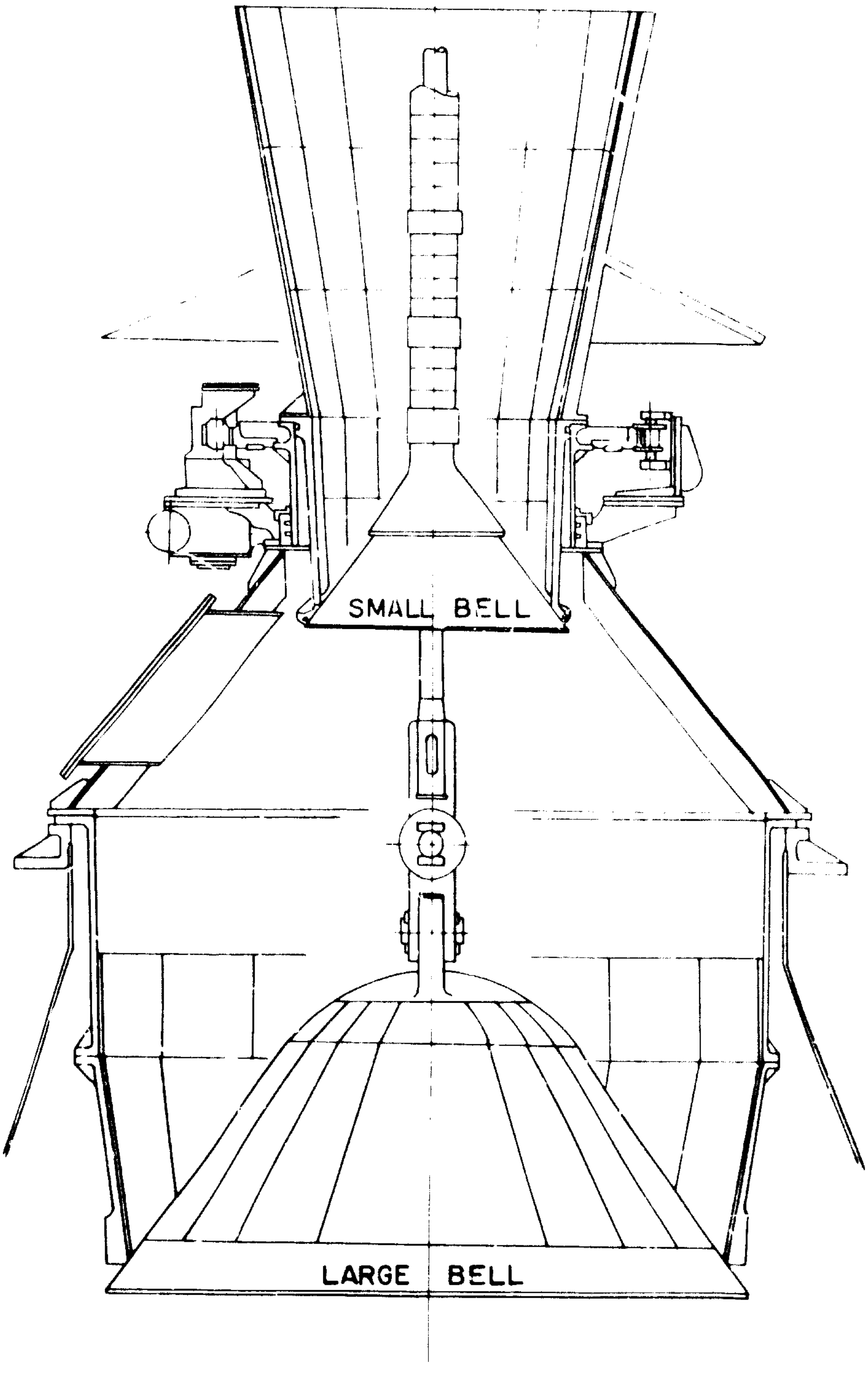


Fig. 1-9. MCKEE TOP (2 BELL TOP)

[illegible]

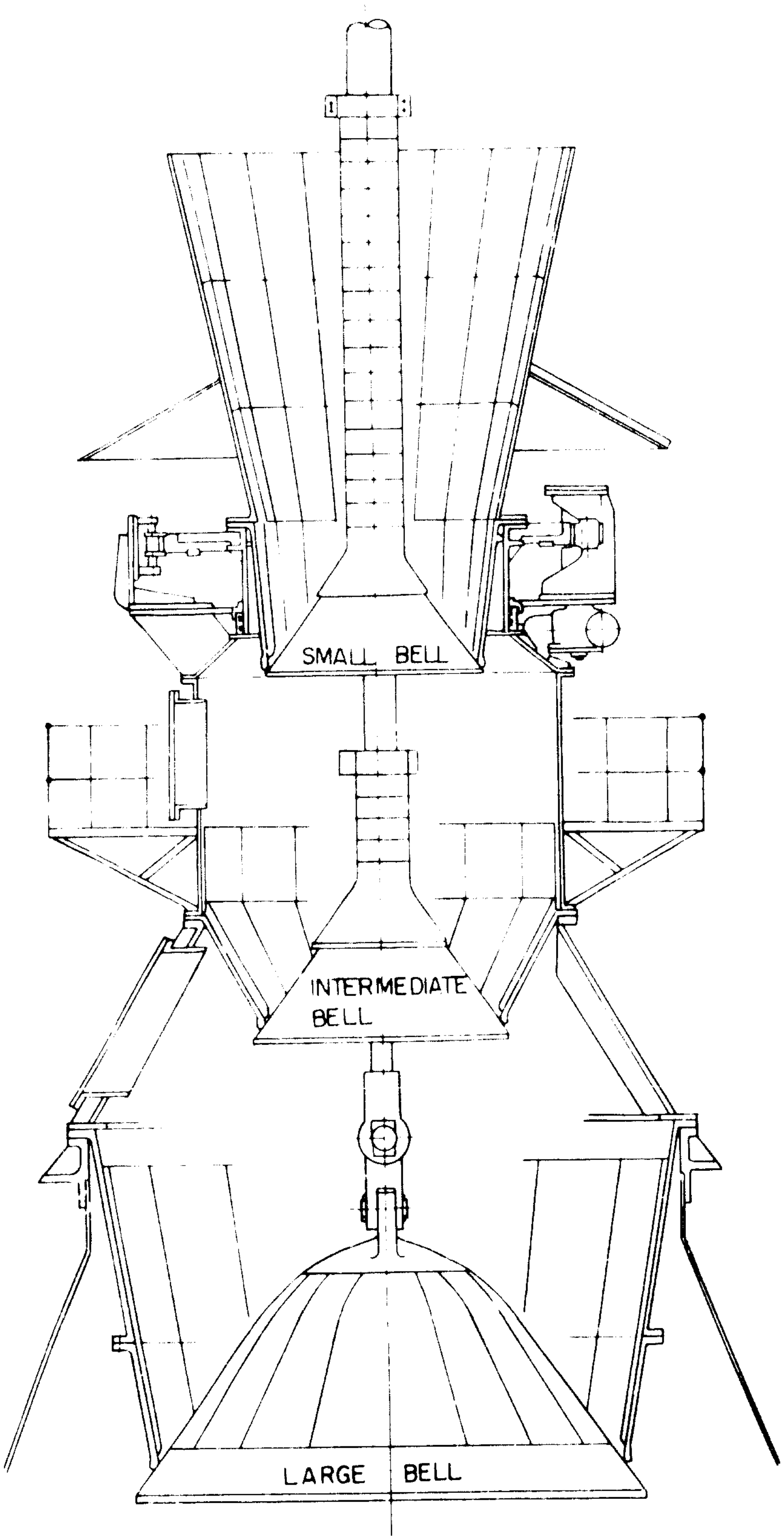


Fig 1-10 3-BELL TOP

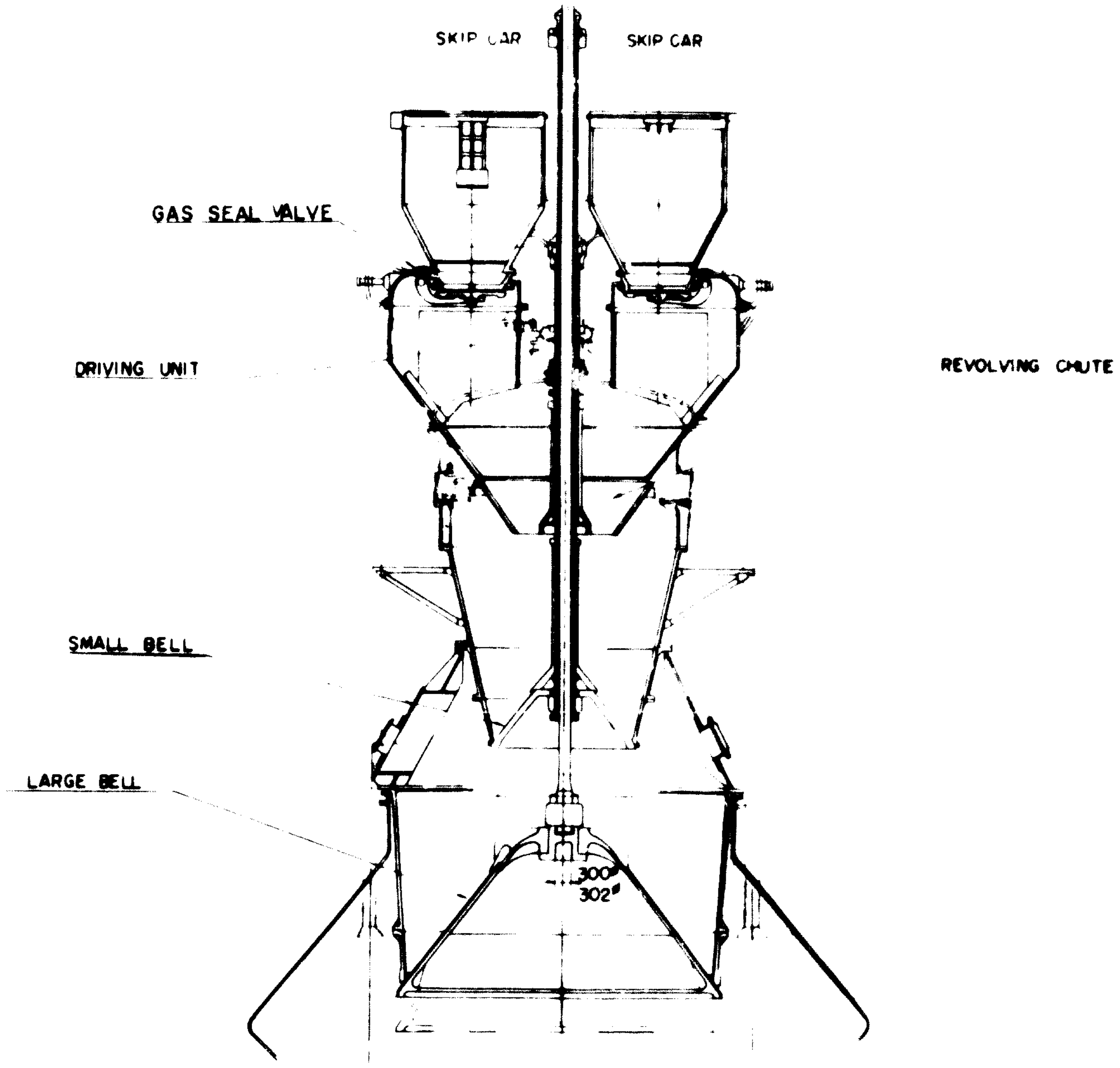
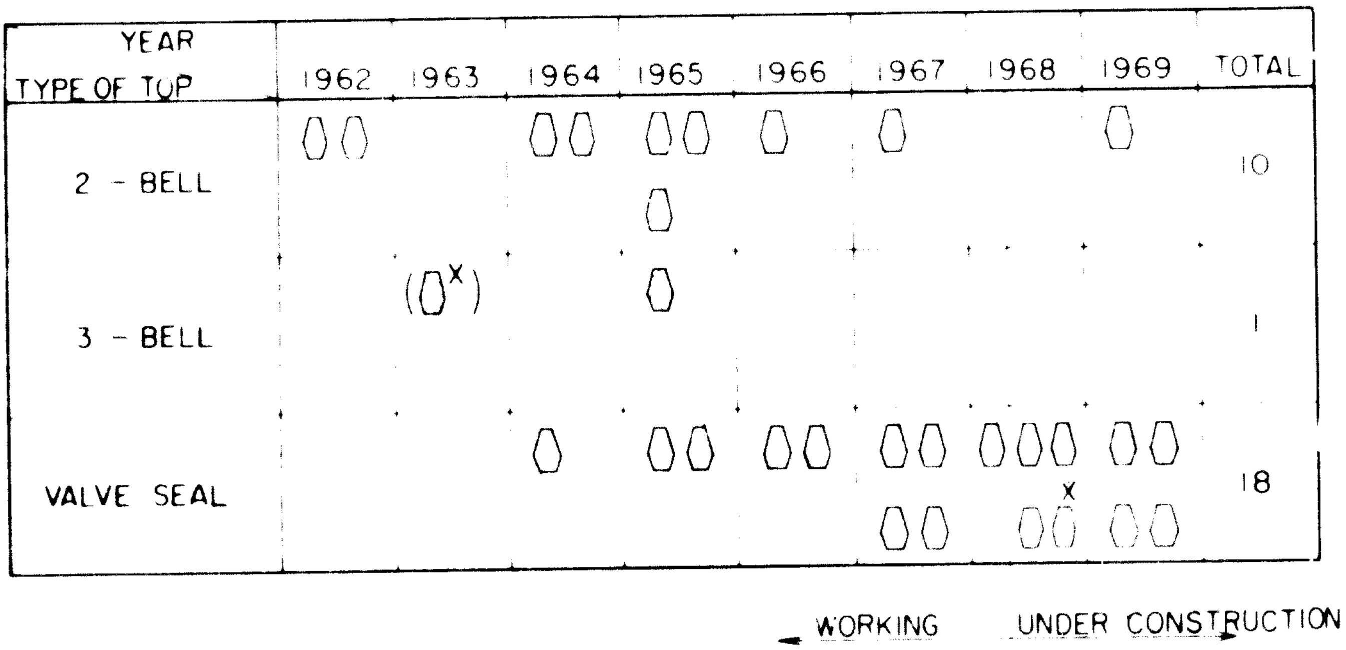


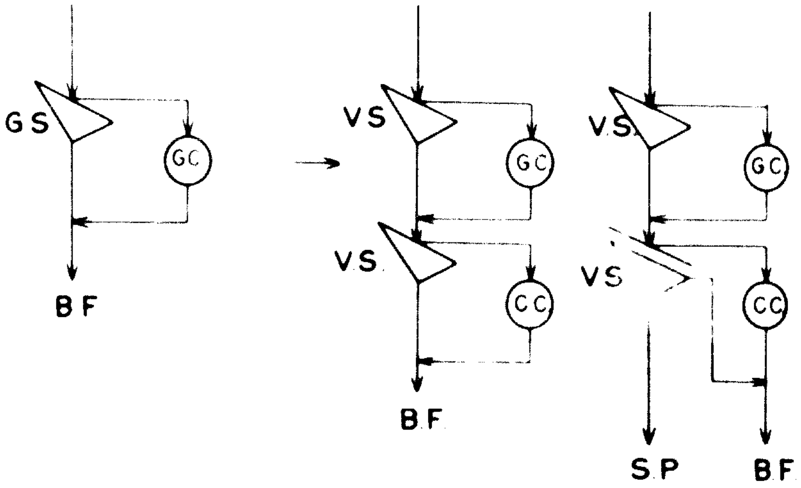
Fig. 1-11 VALVE SEAL TOP



X REMODELED TO VALVE SEAL TOP IN 1968

Fig 1-12 NO OF HIGH TOP PRESSURE BLAST FURNACE (CLASSIFIED BY TYPE OF FURNACE TOP)

Fig 2-1 FLOWSHEET OF OLD SIZING PLANT



G.S. GRIZZLY SCREEN

G.C. GYRATORY CRUSHER

C.C. : CONE CRUSHER

V.S. : VIBRATING SCREEN

S.P : SINTER PLANT

B.F. : BLAST FURNACE

Fig 2-2 FLOWSHEET OF CIRCULATE SYSTEM

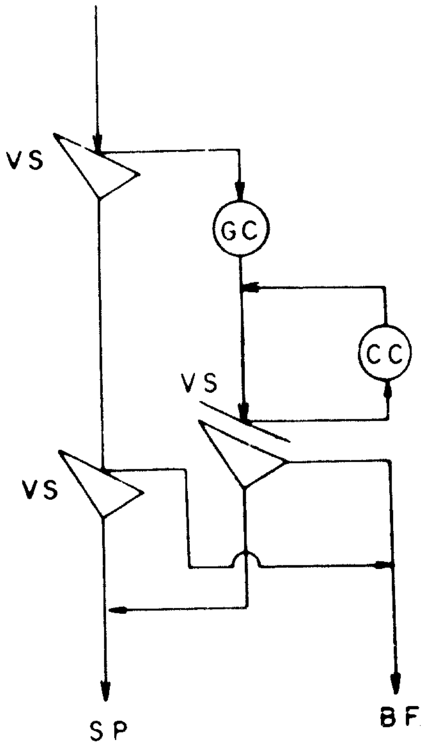


Fig. 2-3 FLOWSHEET OF RECENT SIZING PLANT

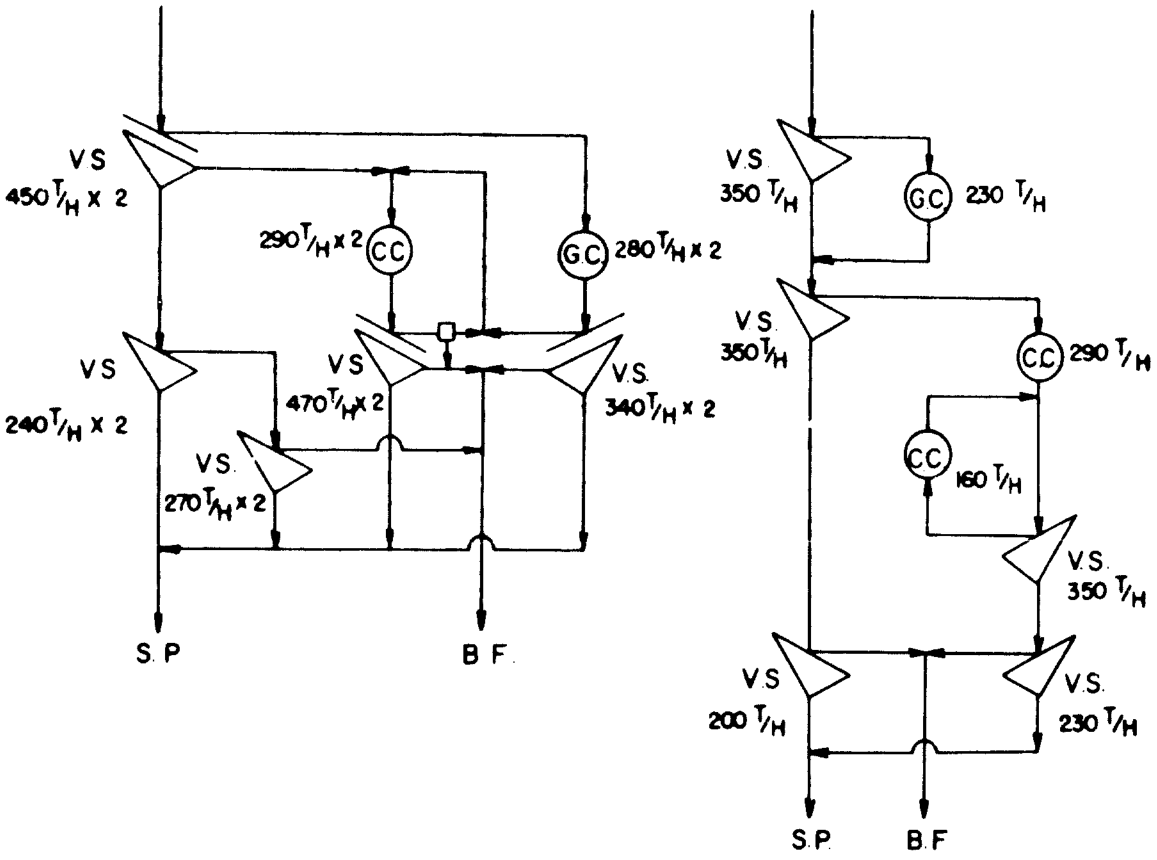


Fig 2-4 FLOWSHEET OF INDURATION PROCESS

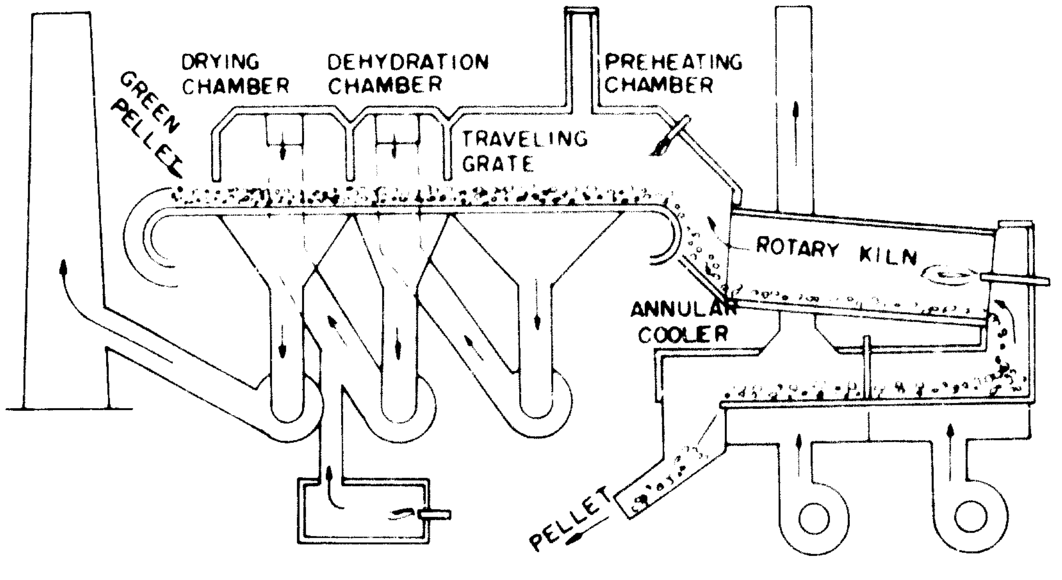


Fig 3-1 CHRONOLOGICAL CHANGE OF CHARGING SYSTEMS

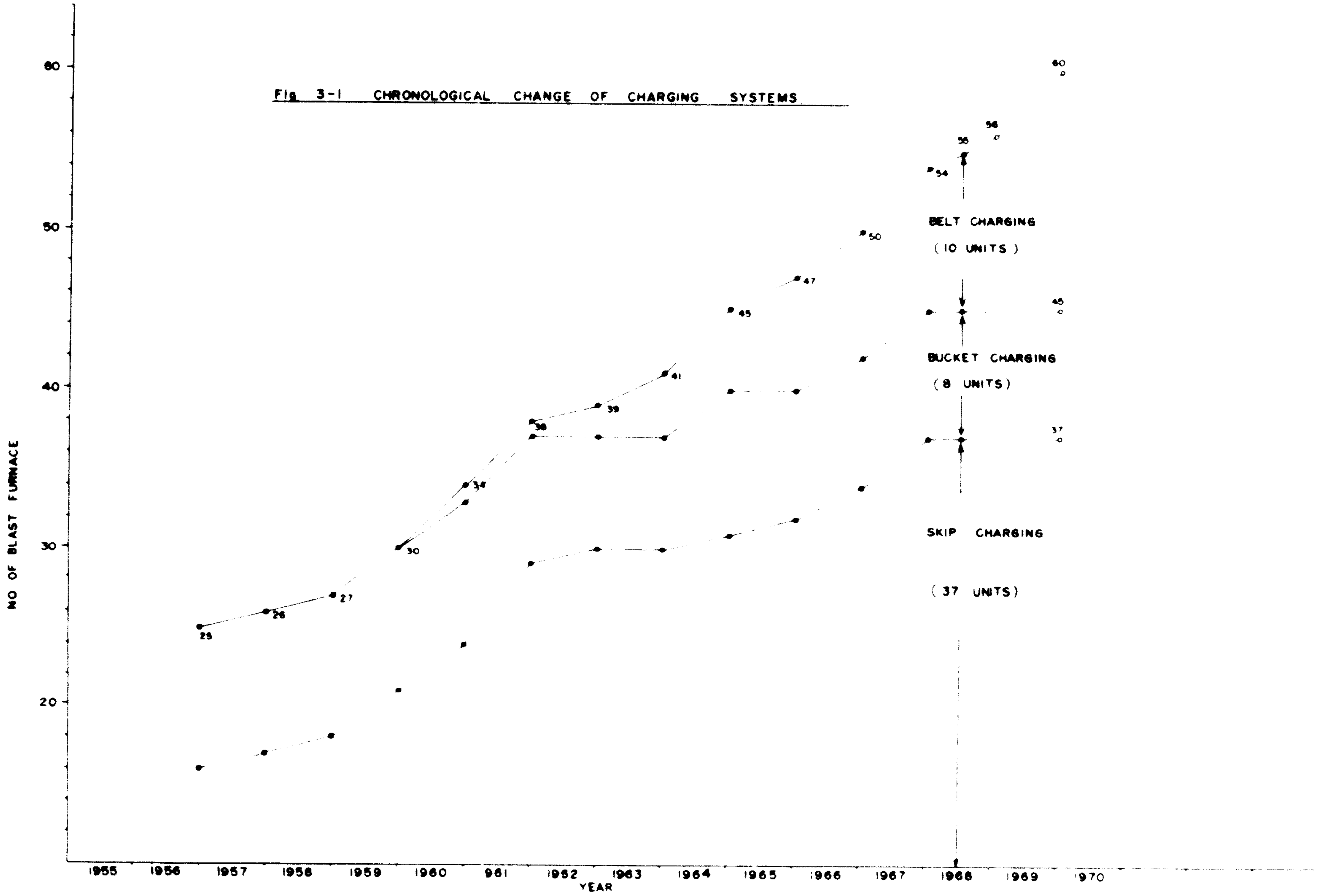


Fig.3-2 TYPE OF CHARGING SYSTEM FOR MORE THAN 2000m^3 BLAST FURNACES

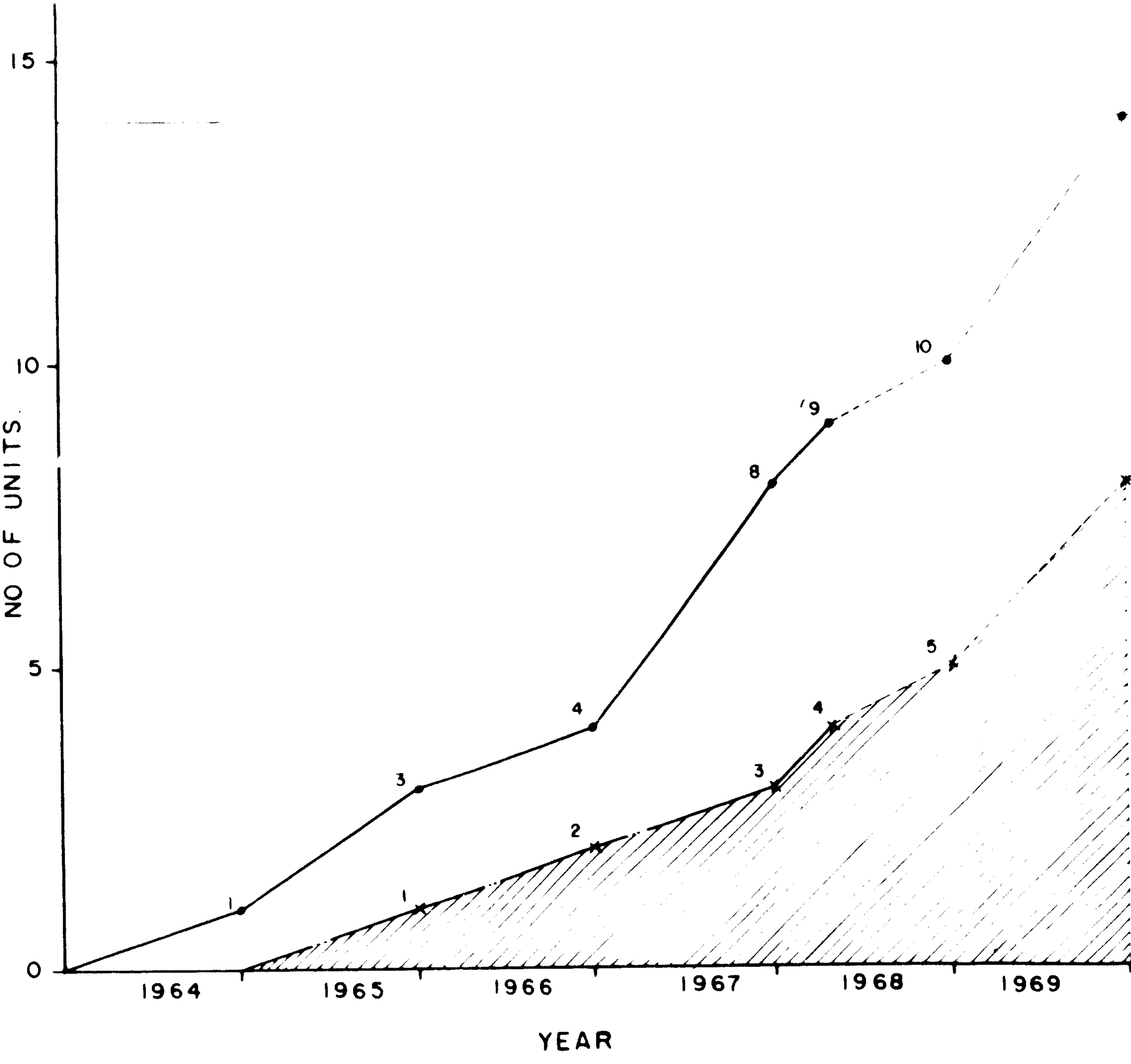


Fig. 3-3 TYPE OF CHARGING SYSTEM FOR 2000m³~2500m³ BLAST FURNACES

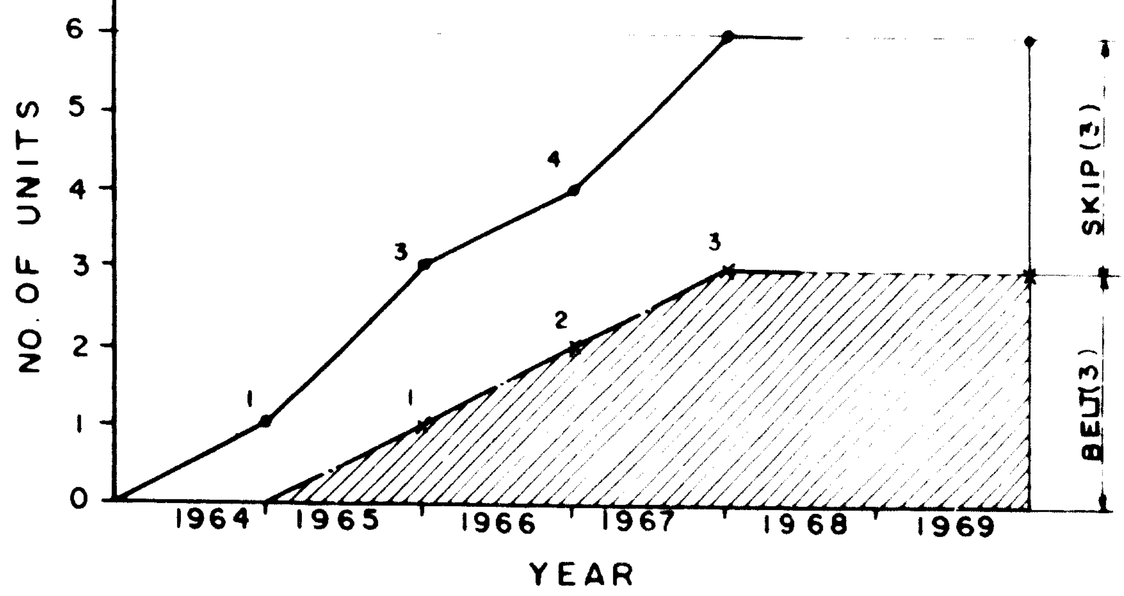


Fig. 3-4 TYPE OF CHARGING SYSTEM FOR MORE THAN 2500m³ BLAST FURNACES

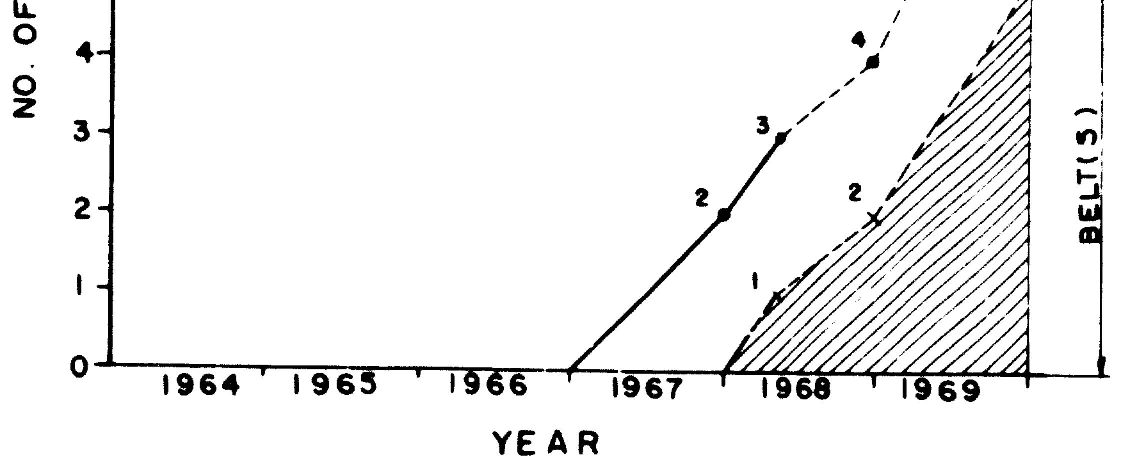


Fig 3-5 CHARGING CAPACITY - SKIP VS BELT

ASSUMPTION ORE RATE 1.8
OVER-FILLING CAPACITY 50 %

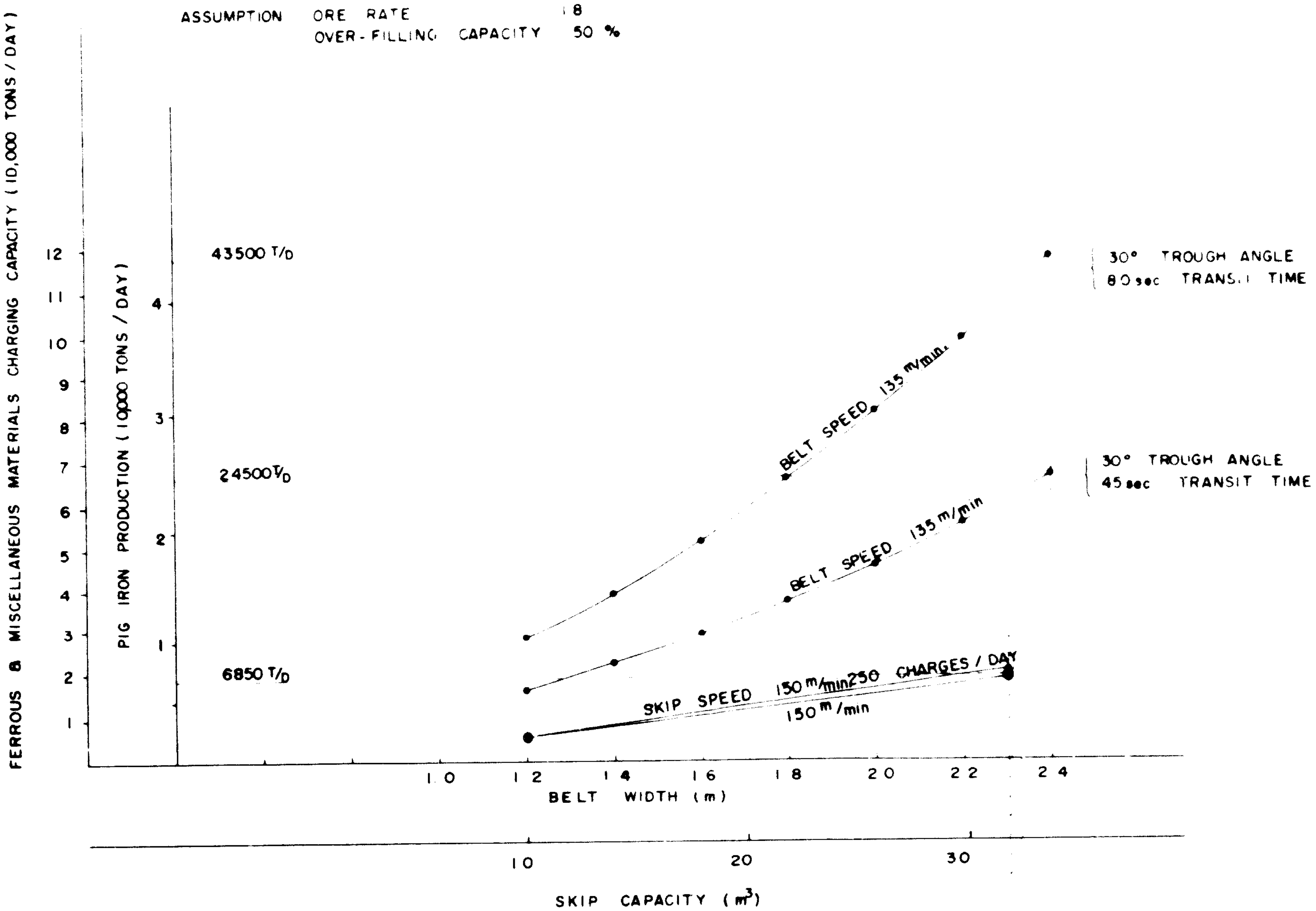


Fig. 4-1 MAXIMUM DESIGNED STRAIGHT LINE TEMPERTURE OF HOT BLAST

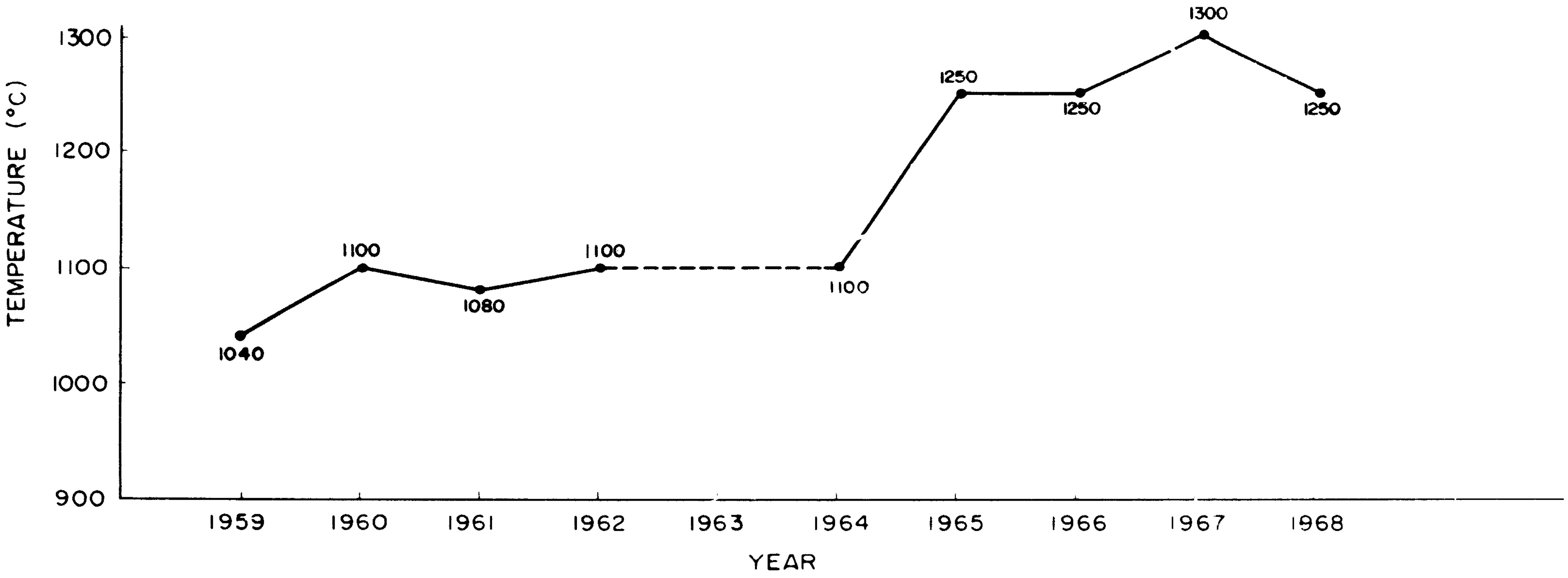


Fig. 4-2 HOT STOVE REFRACTORIES

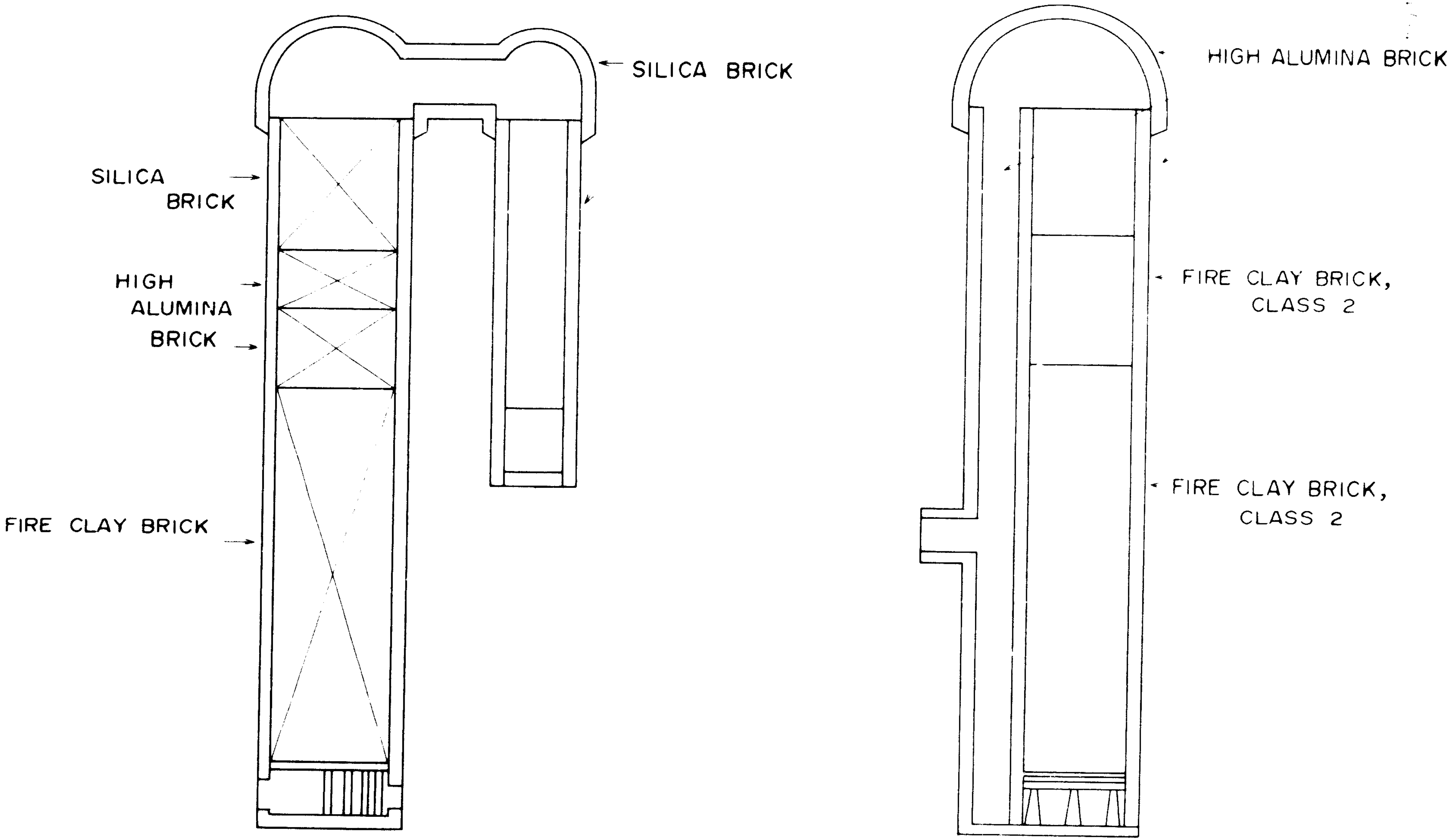


Fig. 4-3 NO. AND TYPE OF STOVE CONSTRUCTED DURING THE LAST 10 YEARS.

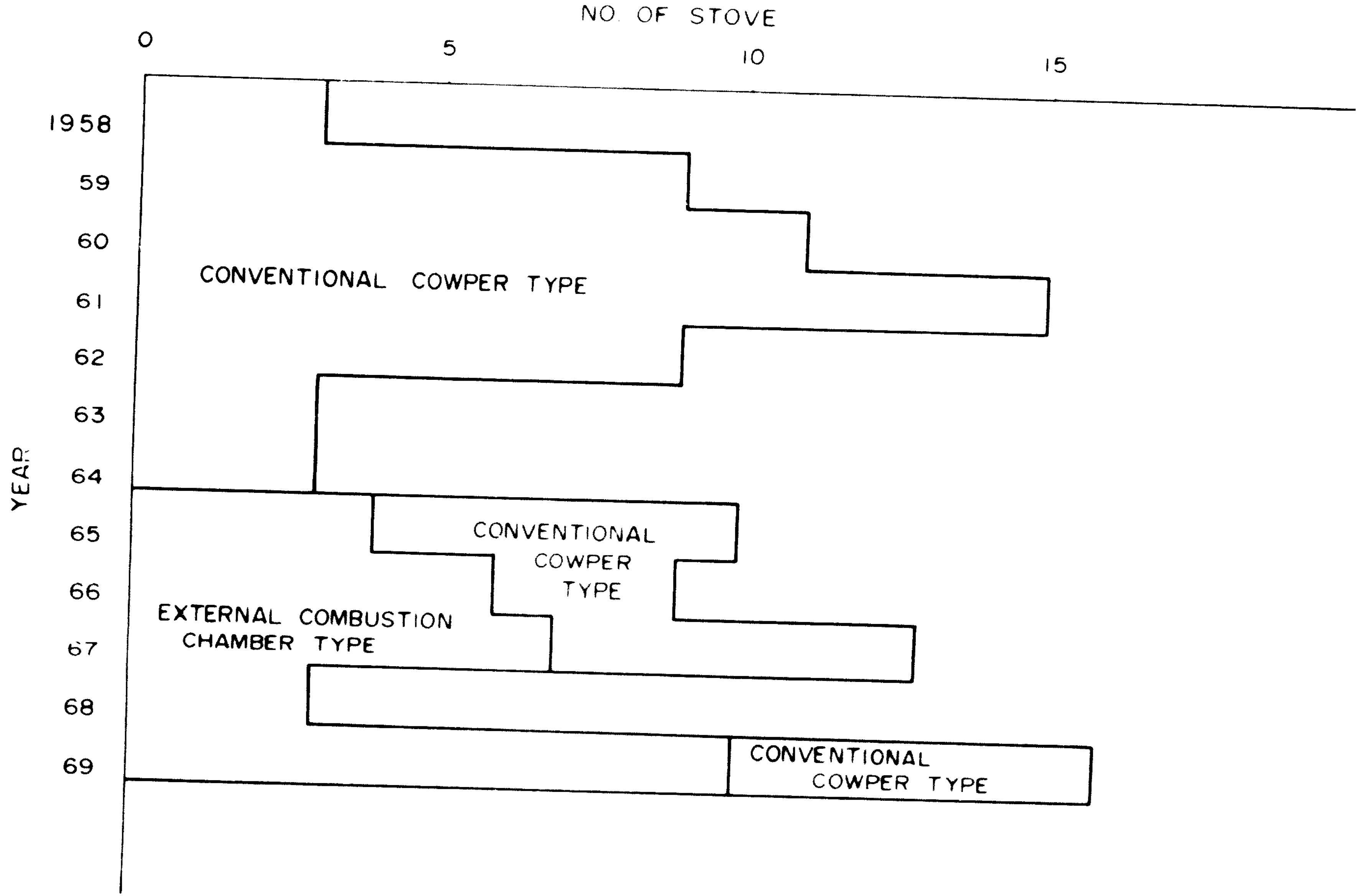


Fig. 4-4 COKE RATE VS. TOP GAS CALORIFIC VALUE

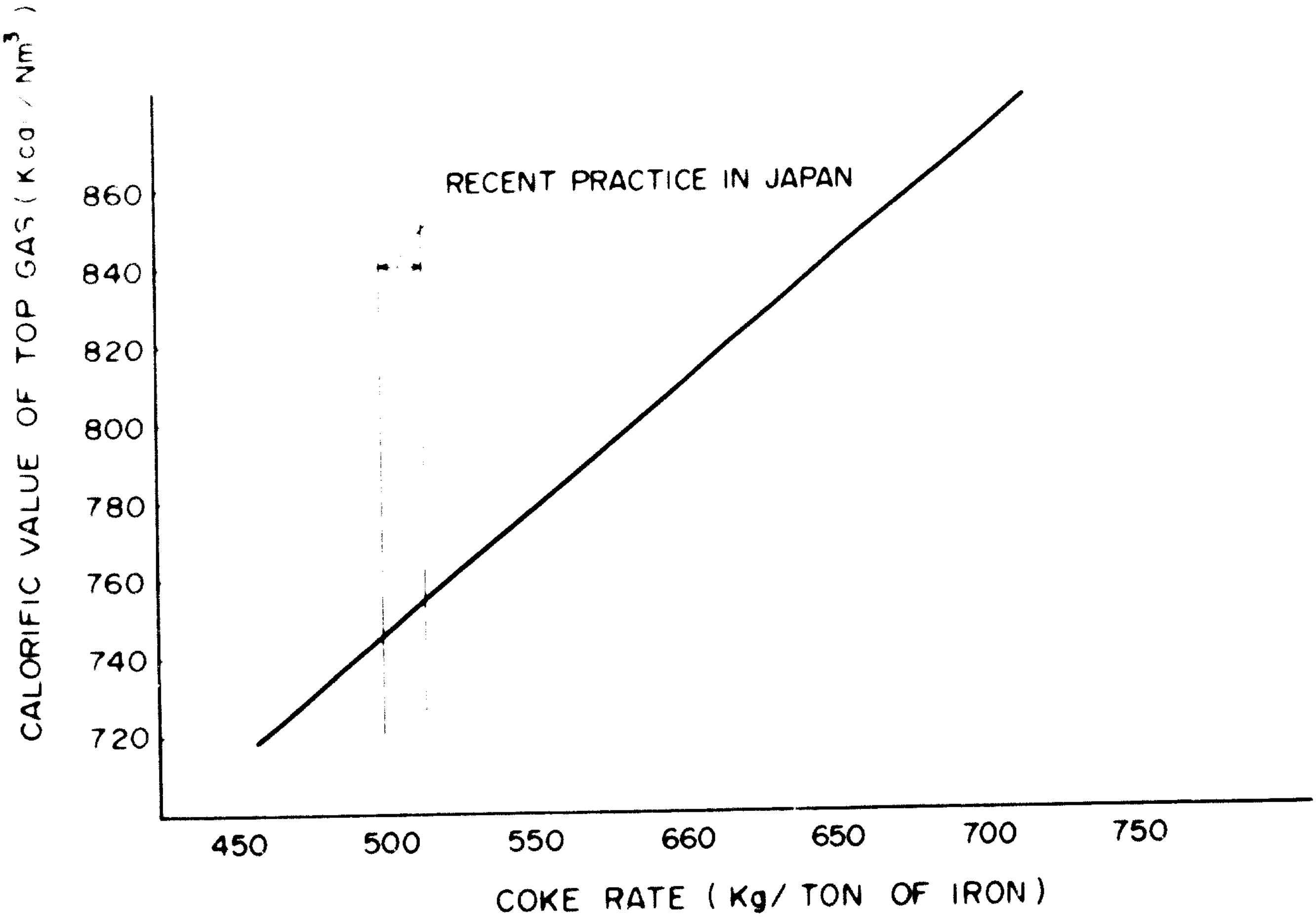


Fig. 4-5 CALORIFIC VALUE OF MIXED GAS

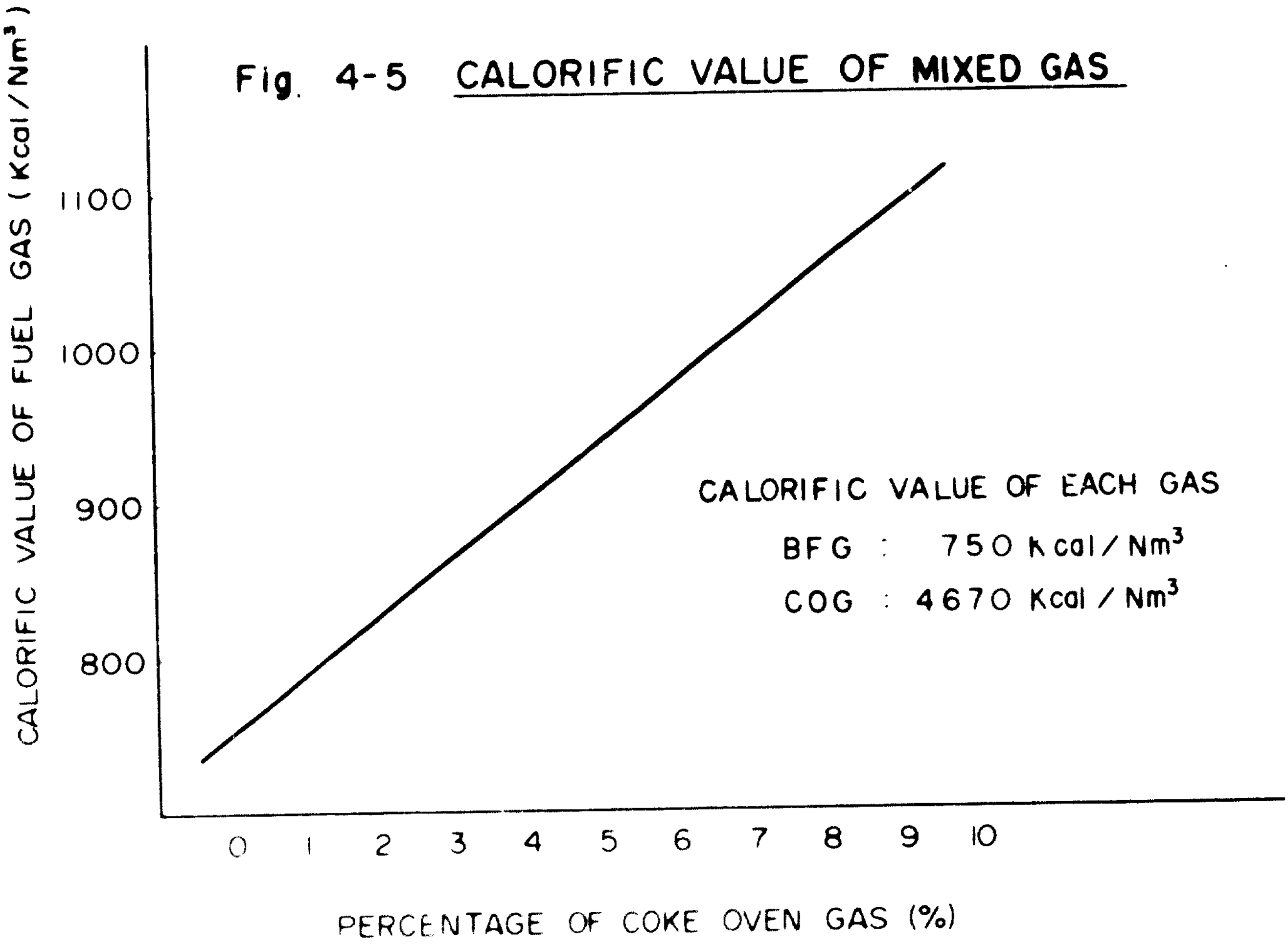
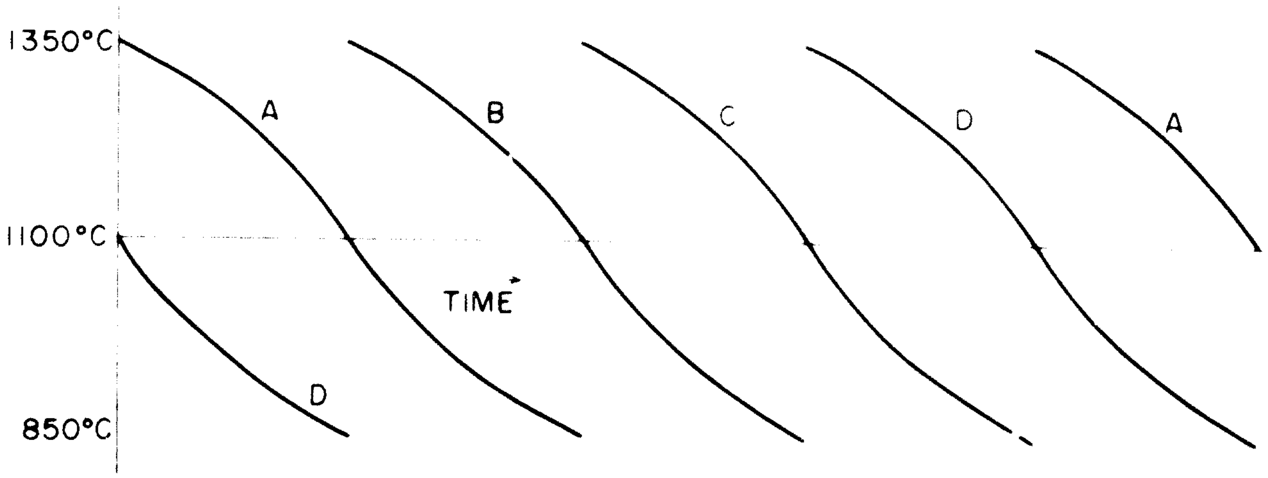
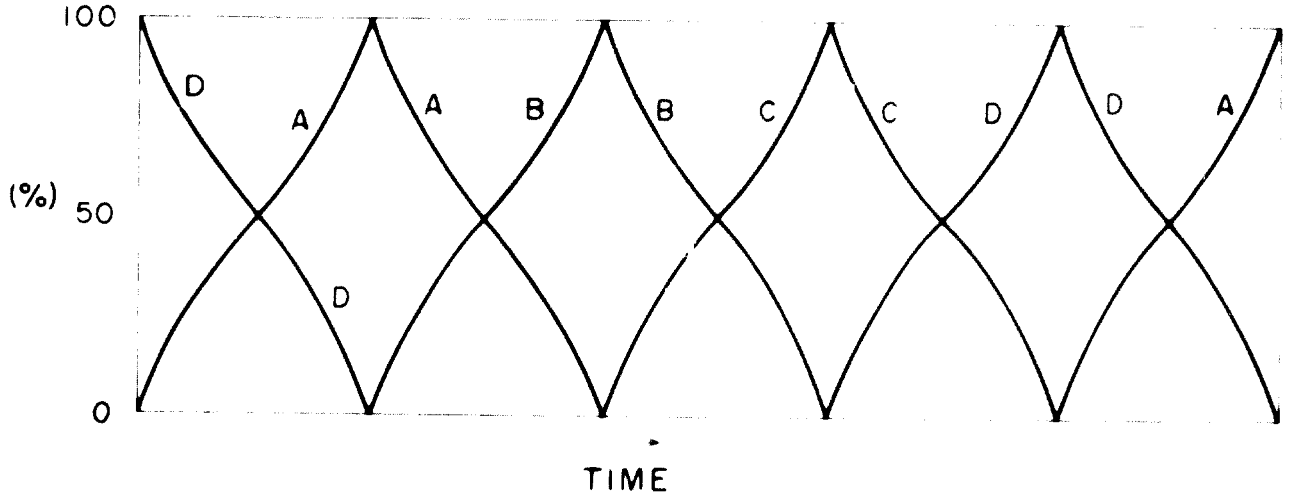


Fig. 4-6 STAGGERED PARALLEL STOVE CHANGING METHOD

(a) TEMPERATURE GRADIENT OF BLAST AT EACH STOVE



(b) RATE OF BLAST VOLUME IN EACH STOVE



(c) ON-BLAST AND ON-GAS CYCLES

STOVE "A"	ON-BLAST (HIGH TEMP)	(LOW TEMP)	ON-GAS		ON-BLAST (HIGH TEMP)
STOVE "B"	ON-GAS	ON-BLAST (HIGH TEMP)	(LOW TEMP)	ON-GAS	
STOVE "C"	ON-GAS		ON-BLAST (HIGH TEMP)	(LOW TEMP)	ON-GAS
STOVE "D"	ON-BLAST (LOW TEMP)	ON-GAS		ON-BLAST (HIGH TEMP)	(LOW TEMP)

TIME

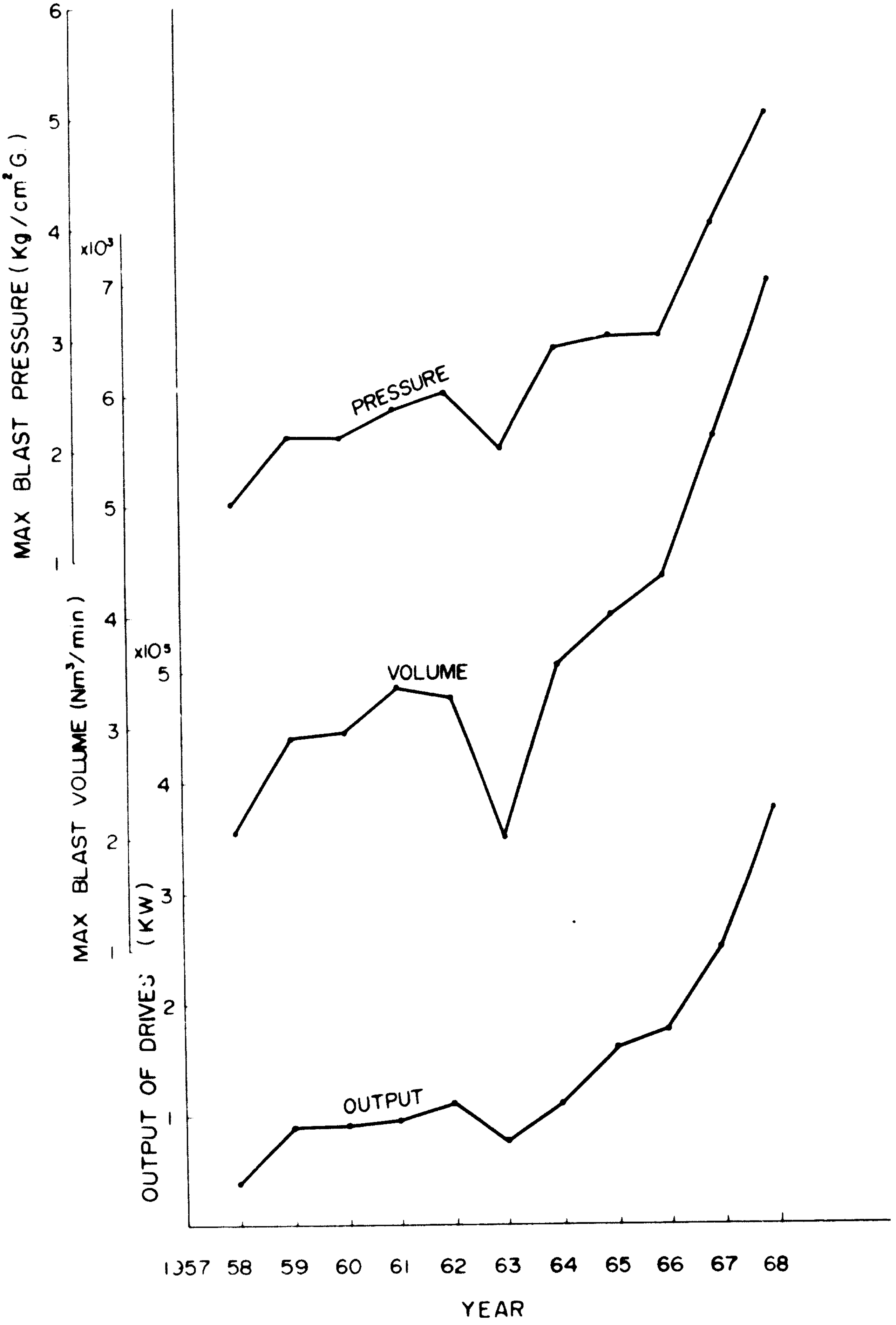


Fig 5-1 CHRONOLOGICAL CHANGE OF BLOWER CAPACITY

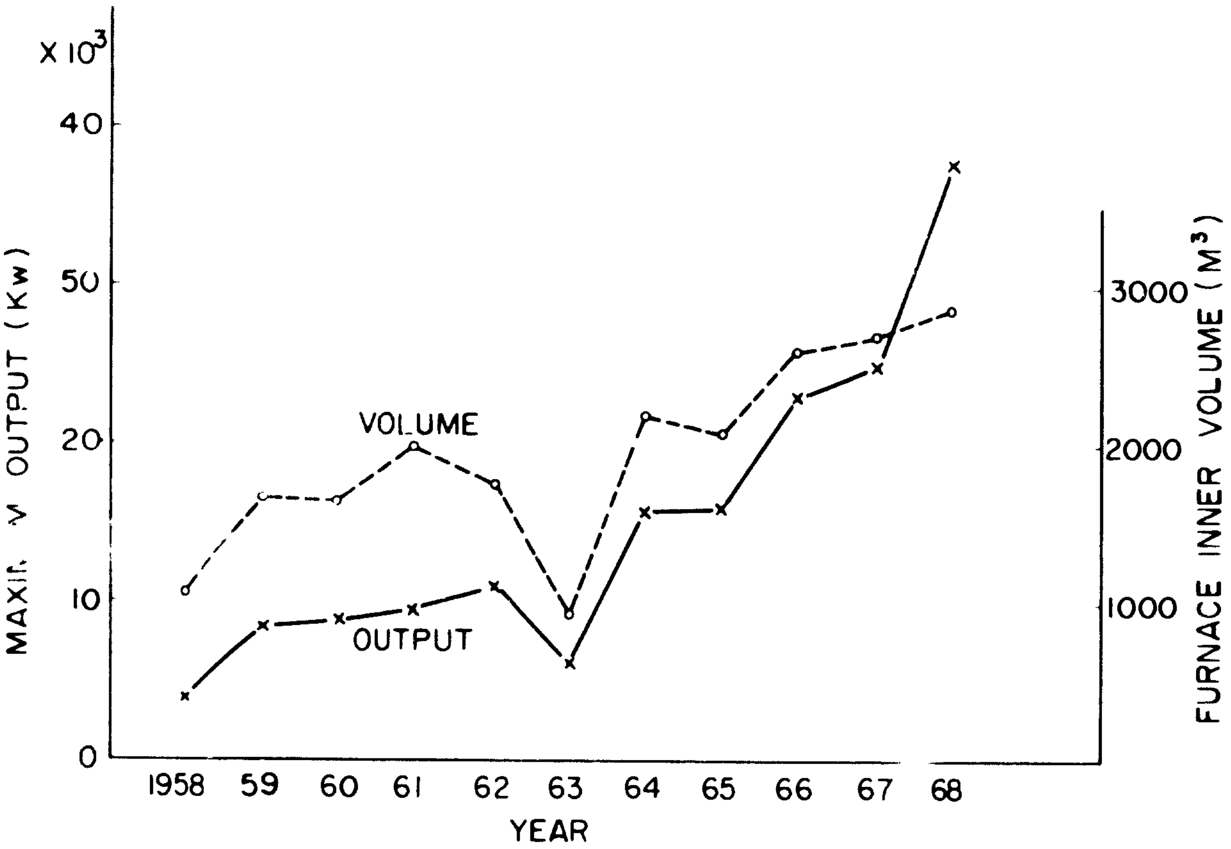


Fig.5-2 CORELATION BETWEEN BLOWER CAPACITY AND FURNACE VOLUME

Fig. 6-1 TRENDS OF GAS CLEANING SYSTEM.

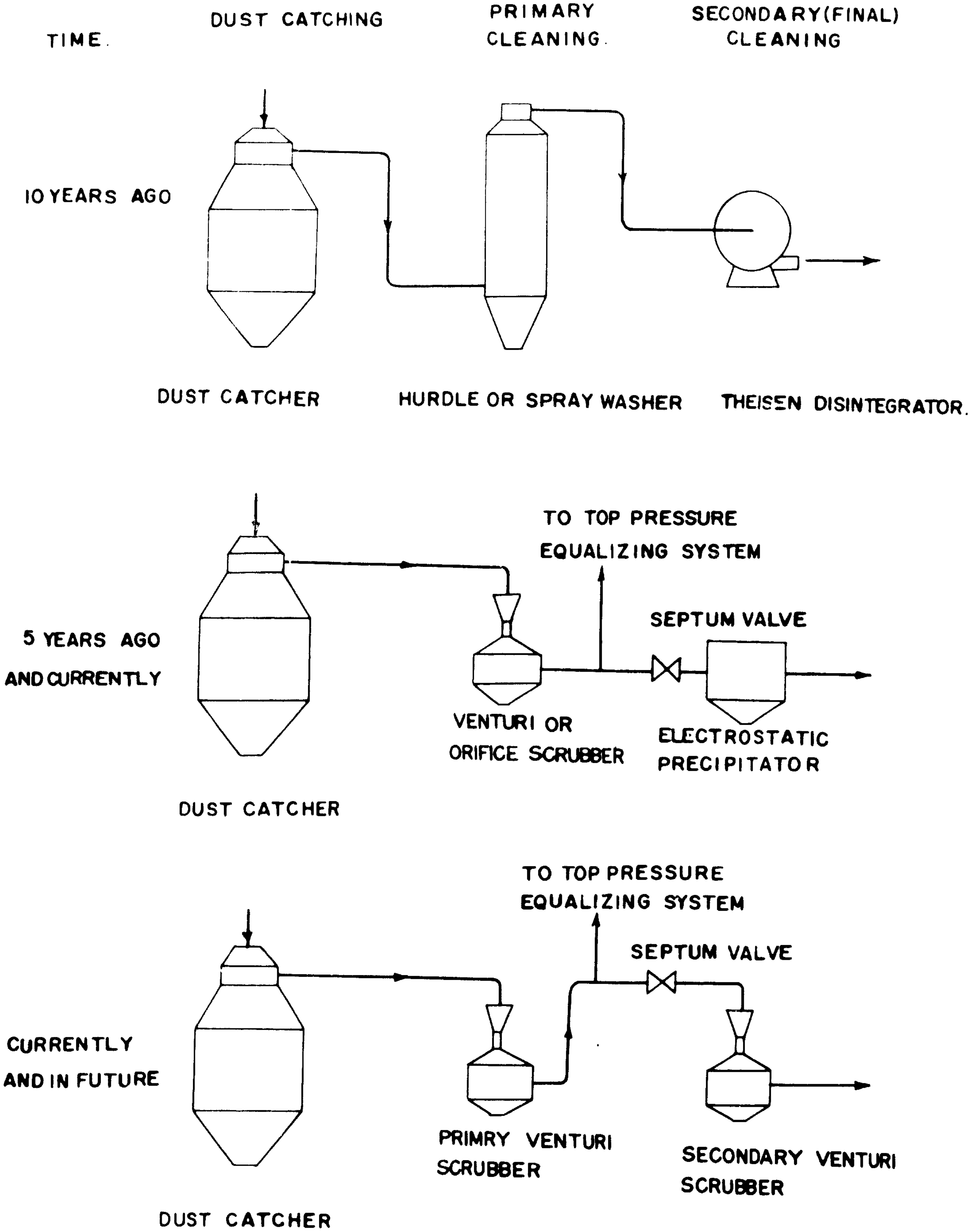


Fig. 7-1 TYPICAL CAST HOUSE WITH TWO TAP HOLES

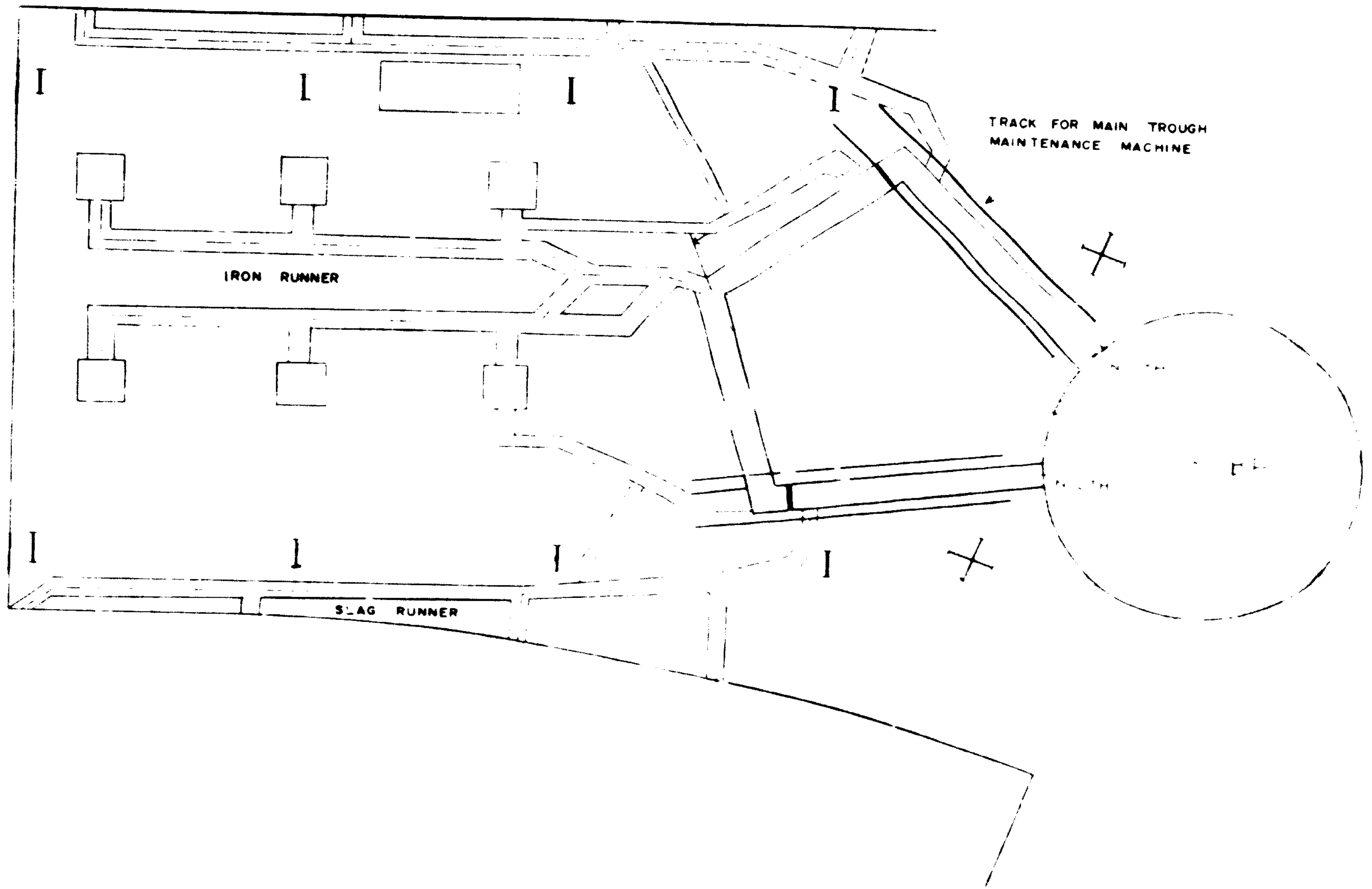


Fig 7-2 TYPICAL CAST HOUSE WITH TWO TOP HOLES.

REPLACEABLE TROUGH AND SUSPENSION TYPE TUYERE CHANGING MACHINE

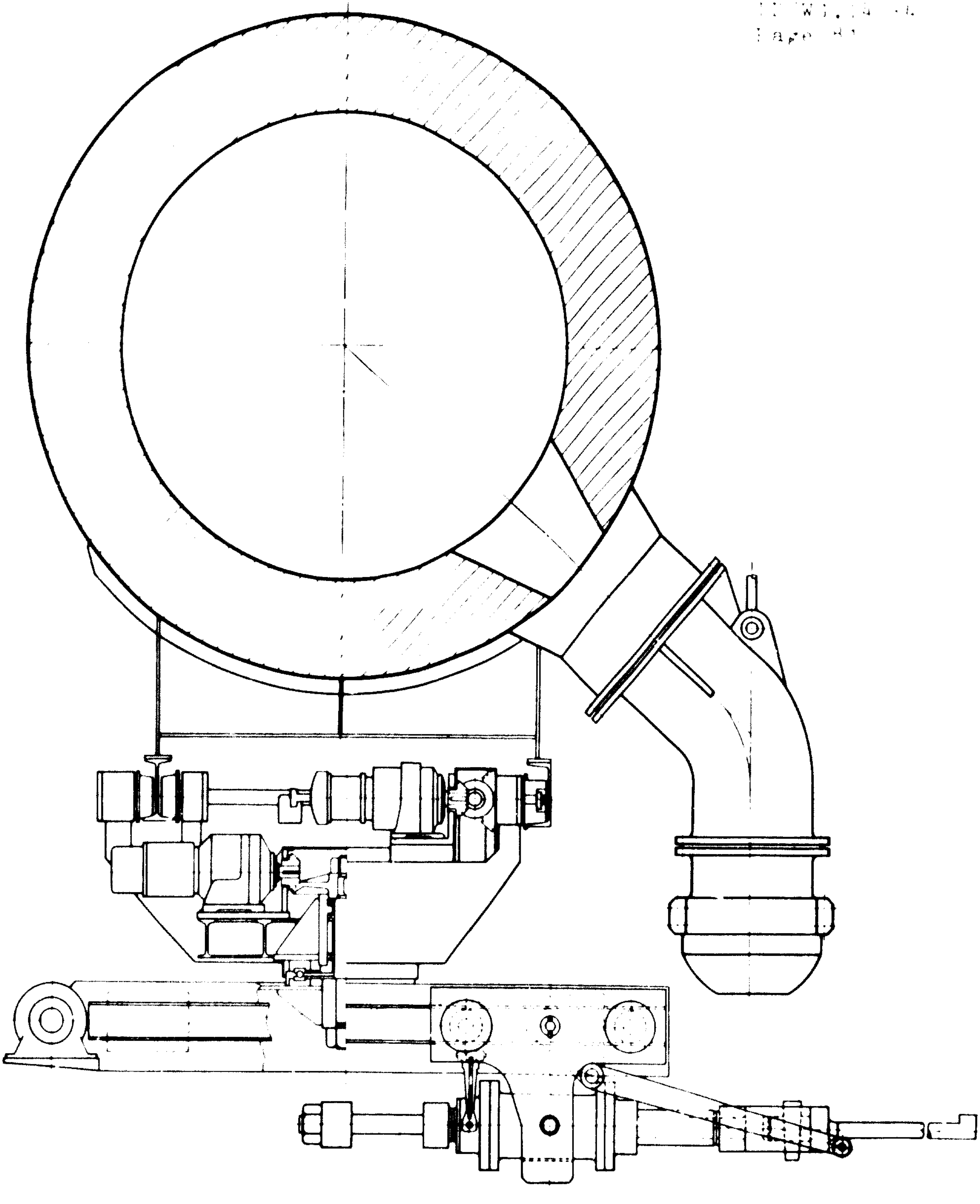


Fig. 7-3 GENERAL ARRANGEMENT

(TUYERE CHANGING MACHINE FOR TUYERE ONLY . SUSPENSION TYPE)

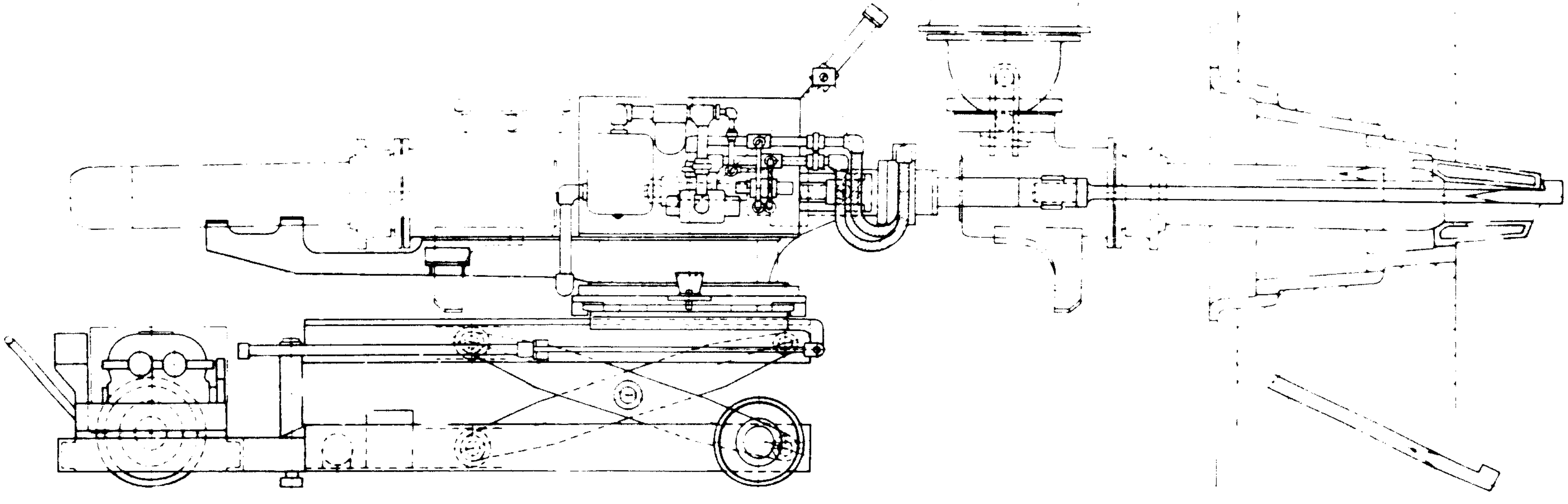


Fig. 7-4 GENERAL ARRANGEMENT (TUYERE CHANGING MACHINE FOR GENERAL USE, PORTABLE TYPE)

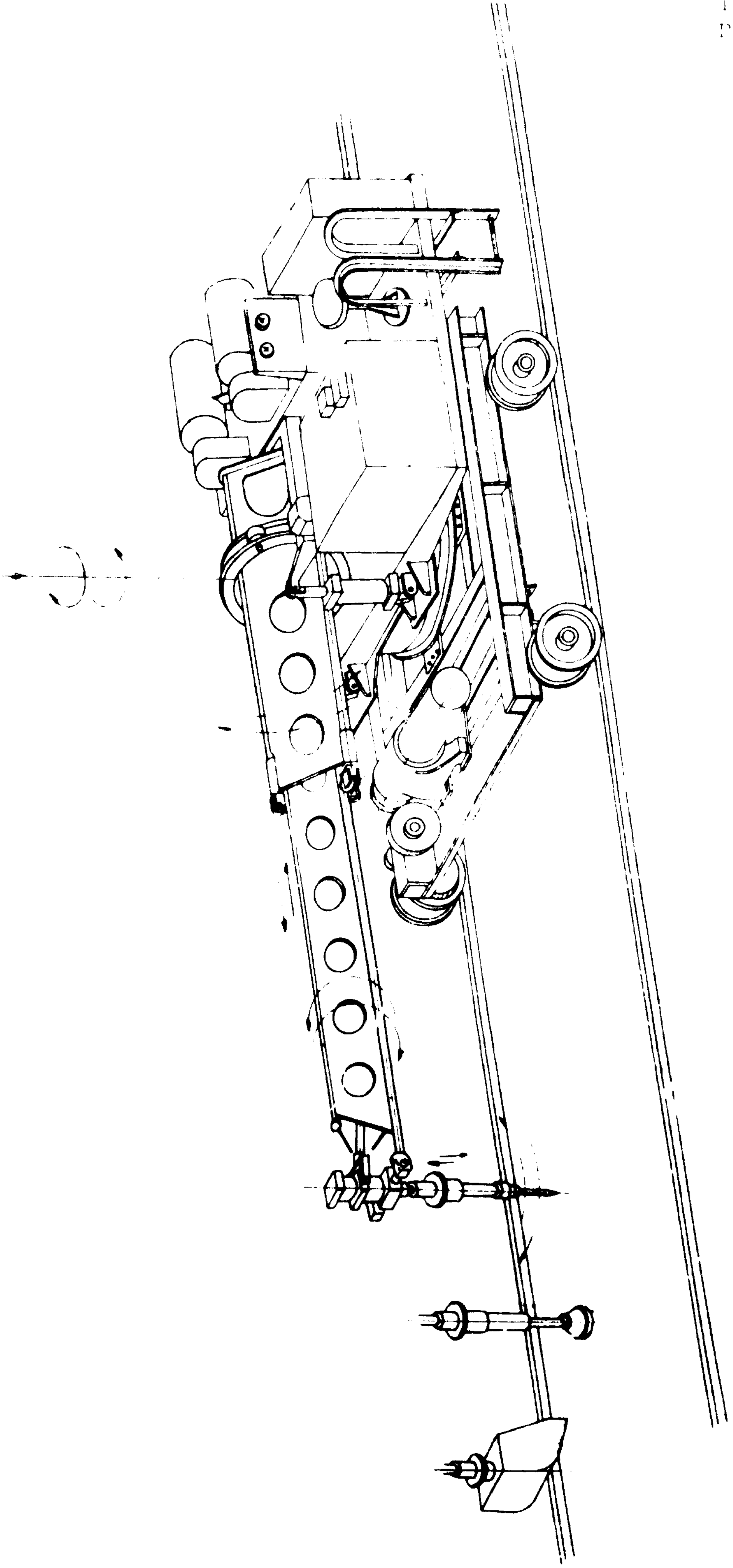
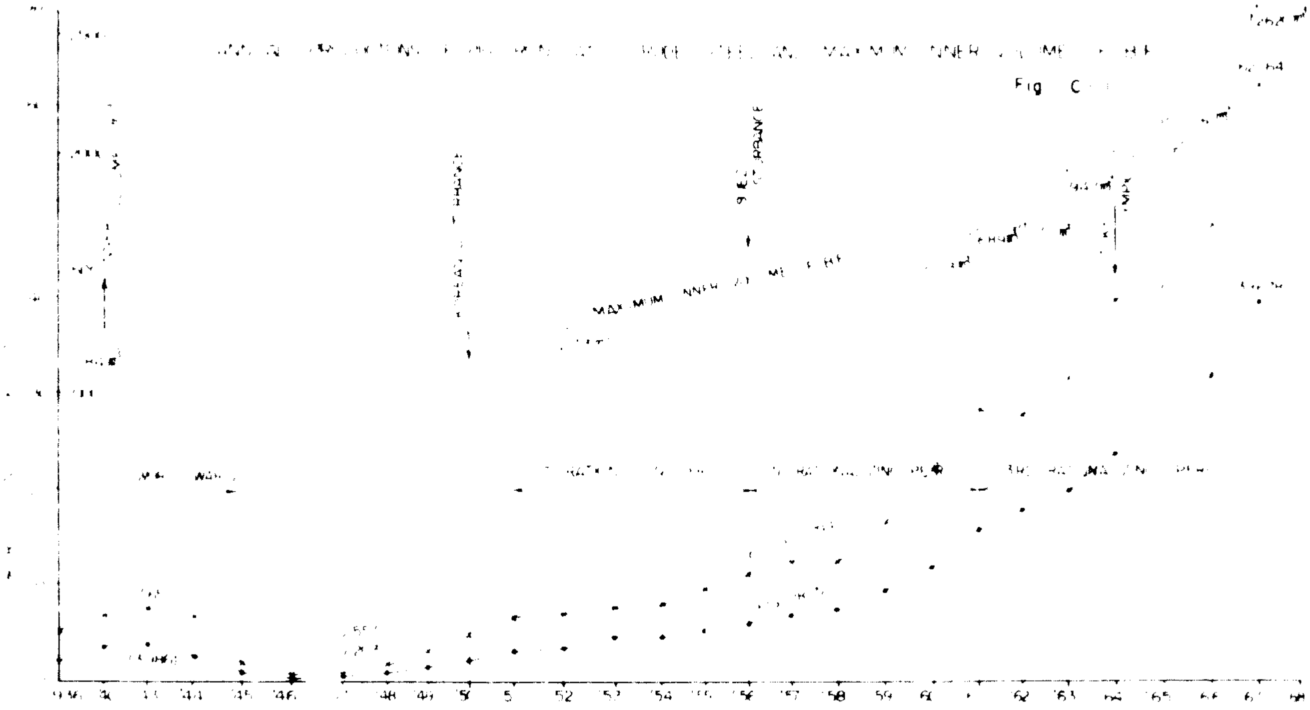
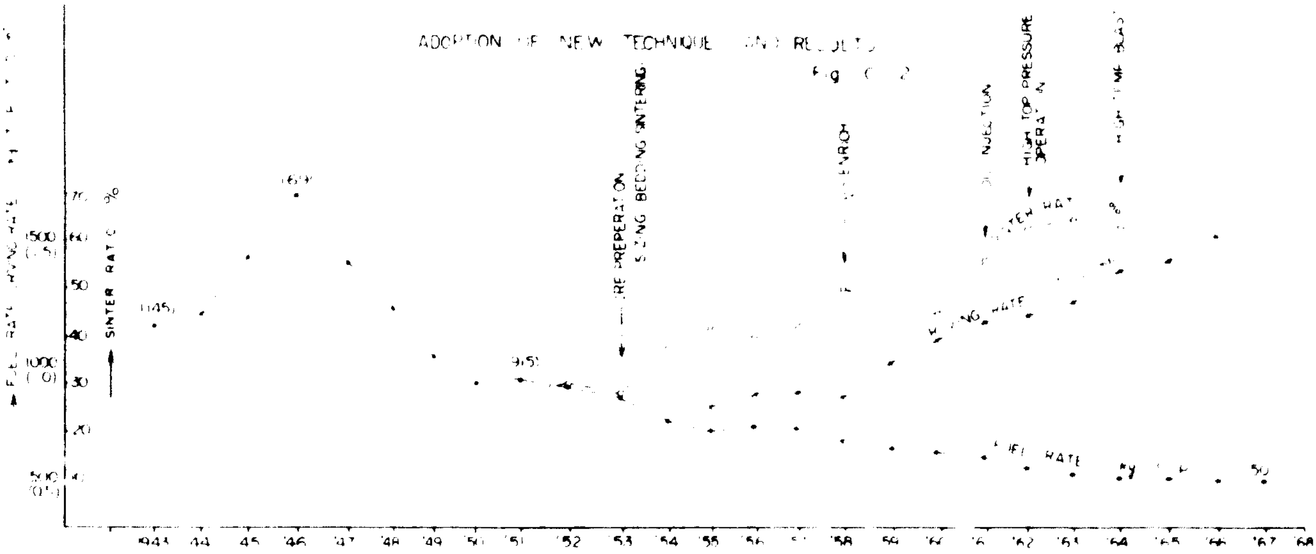
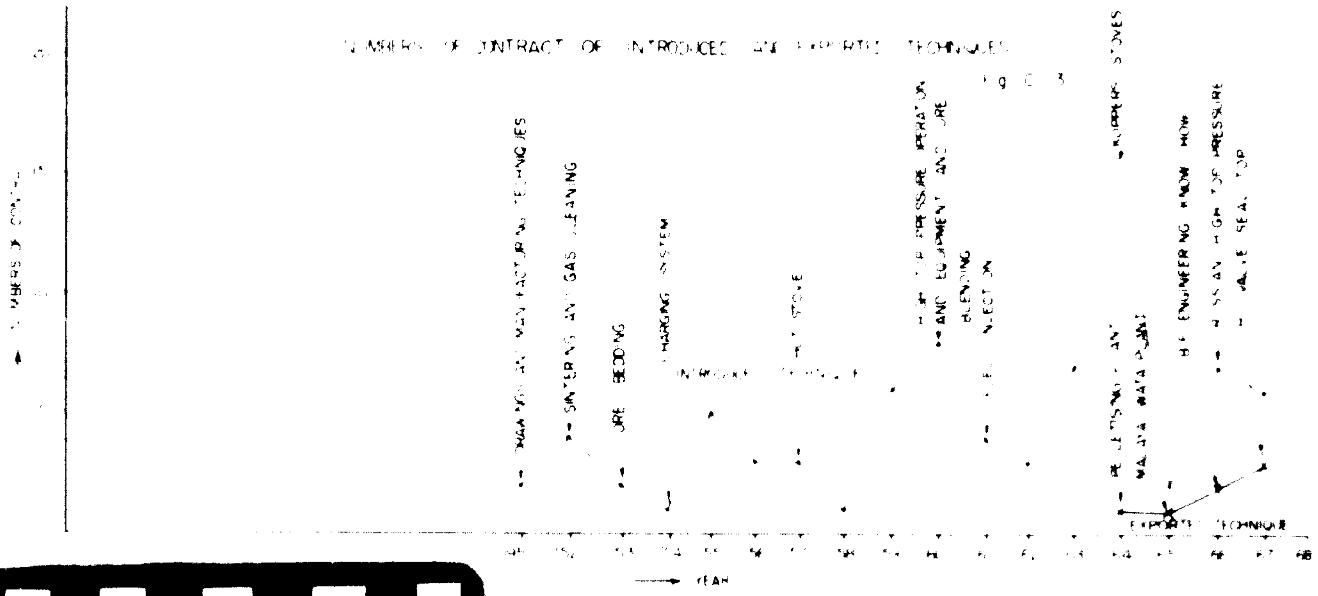
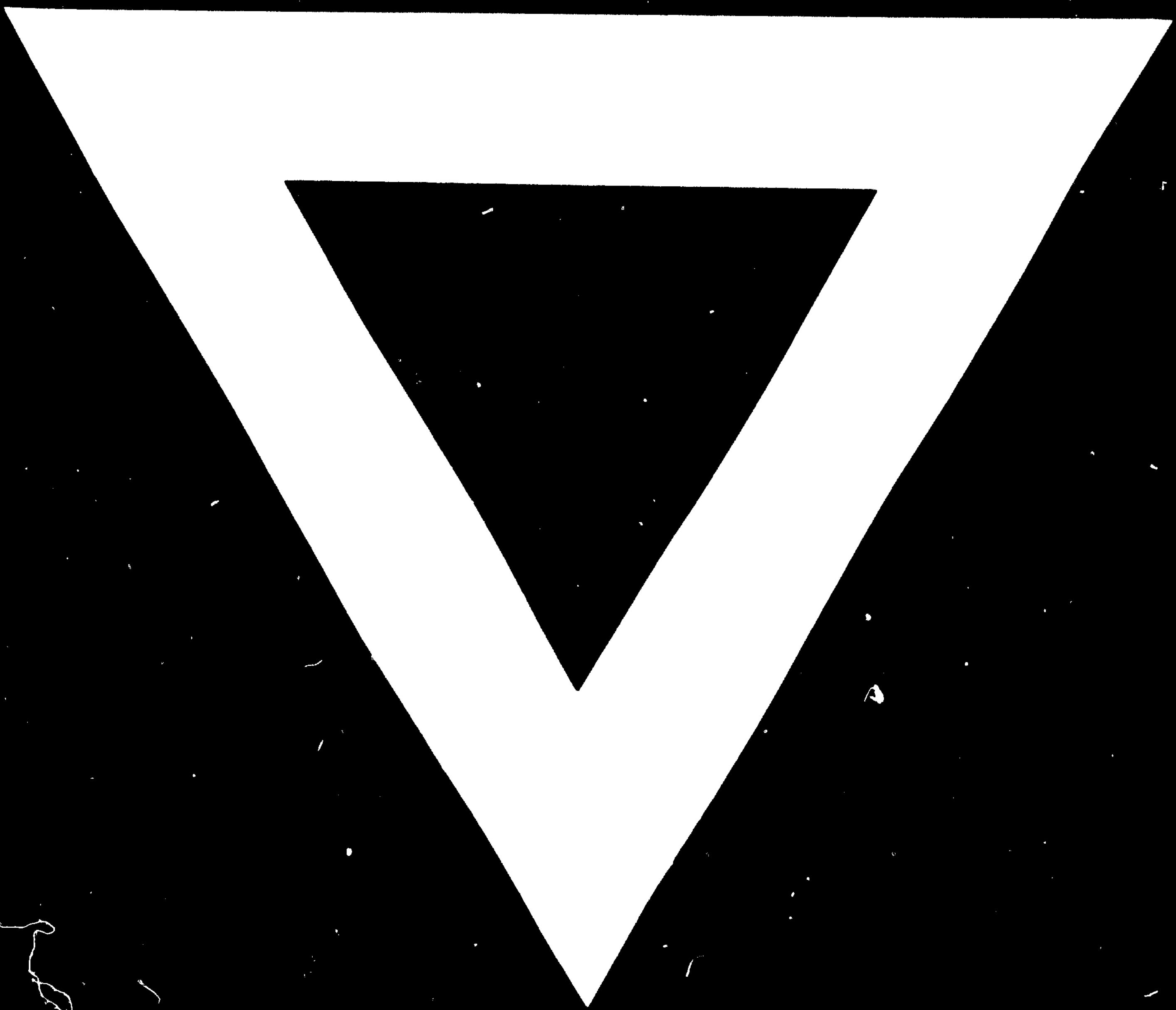


Fig 7-6 RUNNER MAINTENANCE MACHINE


ANNUAL PRODUCTION OF PIG IRON, CRUDE STEEL AND MAXIMUM INNER VOLUME OF B.F.
Fig C-1
MAXIMUM INNER VOLUME OF B.F.
2626 m³
1936
'43
'44
'45
'46
'48
'49
'50
'51
'52
'53
'54
'56
'57
'58
'59
'60
'62
'63
'64
'65
'66
'67
'68


ADOPTION OF NEW TECHNIQUE AND RESULTS
Fig C-2
FUEL RATE
1500
1000
500
70
60
50
40
30
20
10
SINTER RATIO
ORE PREPERATION
SIZING BEDDING SINTERING
INJECTION
HIGH TOP PRESSURE OPERATION
HIGH TEMP BLAST
SINTER RATIO
FUEL RATE
1943
'44
'45
'46
'47
'48
'49
'50
'51
'52
'53
'54
'55
'56
'58
'59
'62
'63
'64
'65
'66
'67
'68


NUMBERS OF CONTRACT OF INTRODUCED AND EXPORTED TECHNIQUES
Fig C-3
NUMBERS OF CONTRACT
MANUFACTURING TECHNIQUES
SINTERING AND GAS CLEANING
ORE BEDDING
CHARGING SYSTEM
INTRODUCE
STOVE
HIGH TOP PRESSURE OPERATION
AND EQUIPMENT AND ORE BLENDING
INJECTION
KOPPERS STOVES
ENGINEERING KNOW HOW
HIGH TOP PRESSURE
VALVE SEAL TOP
EXPORTED TECHNIQUE
'52
'53
'54
'55
'56
'58
'64
'66
'67
'68
YEAR



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