Hot blast cupola with a recuperator using ceramic pellets as the heat exchange medium

--Operating record in Japan and analysis of operating results—

By Etsuo Murata (president, Naniwa Roki Co., Ltd.,)

Hirotoshi Murata (senior managing director, Naniwa Roki Co. Ltd.)

Takashi Okabe (technical advisor, Naniwa Roki Co. Ltd.)

Toru Ishino (honorary professor at Kinki University, former president of Japan Foundry Engineering Society)

Hiroyuki Yoneda (professor, Kinki University)

Abstract

In this paper we explain the mechanism of a recuperator using ceramic pellets as the heat exchange medium and describe examples of its use in cupolas in Japan. In an analysis of these examples of use, we consider the heat exchanging efficiency of the recuperator, the ease of maintenance of the recuperator, and the influence on the various operational parameters accompanied by the increase in blast temperature.

The increase in thermal efficiency of this recuperator in contrast to the conventional recuperator, its economical merit, and the increase in the yield rate of molten metal components due to the higher blast temperature are also discussed.

Introduction

Making use of the heat in cupola exhaust gas to preheat the blast blown into the cupola began around 1830. In the beginning, the blast pipe was embedded in the furnace lining or set in the cupola shaft so that the sensible heat in the exhaust gas rising in the furnace would be absorbed by the blast air. In the course of time, the heat exchanger was developed to heat the blast with the radiation or convection heat on the outside of a steel pipe generated by the combustion of carbon monoxide in the exhaust gas mixed with secondary air introduced after it is discharged from the furnace and deducted.

However the conventional heat exchanger has the following disadvantage.

After long use, the transfer of heat is hindered by the adherence of substances (such as FeO, SiO_2) which are liable to vitrify onto the internal surface of the exchanger.

Even in the case of a long campaign cupola, operation is often halted at night, so the repeated heating and cooling of the exchanger and the consequent repeated expansion and contraction of every part of the equipment can lead to damage to the tubing joints and consequent blast leakage.

When the blast temperature is over 500 ℃, the useful life of the exchanger is remarkably reduced.[1)]

A statistical investigation of recuperator problems revealed that most problems, as shown in Figure 1[2)], are related to damaged fin tubes or fin tube roots caused by the repeated expansion and contraction of the fin tubes which leads to insufficient blast volume as a result of blast leaking from this part, reduced dust collecting capability, unstable operation, etc.

In order to overcome these disadvantages, a heat exchanger based on the new concept of using ceramic pellets as the heat exchange medium was recently developed. In Japan, several of these new heat exchangers are already in use, and increased blast temperatures, easy maintenance, increased yield of molten metal components and economical benefits have been reported.

In this paper, two examples of actual operation are described, and a metallurgical analysis of the results is reported.

Mechanism of the recuperator using ceramic pellets as the heat exchange medium[1)]

The first atempt to use ceramic granules in a recuperator to preheat cupola blast was made in 1976 by ECONO-THERM Corp., U.S.A.[3)], and a cupola system incorporating this novel recuperator was later produced by KGT GmbH., Germany. The structure of the recuperator is shown in Figure 2[4)]. It consists of a combustion chamber to burn the carbon monoxide gas in the exhaust gas, a gas section where heat is stored in the pellets, a wind section where the heat stored in the pellets is absorbed by moving air, and a pellet conveyer for carrying the pellets back to the gas section. The pellets carried to the top are distributed uniformly and descend through several layers of perforated stainless steel plates (trays) after absorbing the heat from the high-temperature exhaust gas from the combustion chamber, and enter the wind section. The wind section also contains several layers of distribution plates (trays), the hot pellets fall through the perforations, and heat the upcoming cold air. This heated air is blown into the cupola furnace through the tuyeres and the cooled pellets are collected in the bottom and conveyed to the gas section again. This cycle of heat storage and heat exchange is constantly repeated. The cupola exhaust gas, after heating the pellets and thereby preheating the blast, passes through a heat exchanger and is discharged into the atmosphere after dedusting. This system is illustrated in Figure 3[4].

The greatest advantage of this recuperator lies in the fact that it allows the heat transmitting area to be changed by changing the pellet transfer rate, permitting considerably free adjustment of blast temperature.

The gas and wind sections are cylinders with an internal diameter of about 1800 mm for a 12 t/h cupola, and about 2800 mm for a 38 t/h cupola. The composition of the pellets is Al_2O_3 85~90%, with a trace of SiO_2, TiO_2, Fe_2O_3, and particle diameter is 1~2 mm. Blast temperature is 600~800 ℃ at the tuyeres[5].

Examples of use in Japan

Company A[6]

This company produces automobile parts (mainly, cylinder heads, cylinder blocks, crankshafts, wheel parts , etc.) in the amount of 8,400 tons/month.

Layout of melting equipment and process flow

The melting equipment layout is shown in Figure 4. In this plant, not only the dust in the cupola exhaust gas but all the dust generated in the material charging and melting process system is removed by means of dust collectors. There is also an emergency power generator, a dehumidifier, and an automatic control system for unmanned operation.

The cupola process flow, shown in Figure 5, consists of cupola, recuperator, exhaust gas cooler, dust collector, etc. The molten iron, after being continuously desulphurized in a desulphurizing ladle, is kept hot in a holding furnace, and transferred to a low frequency induction furnace. The slag is cooled and collected in the granulating line. The cupola exhaust gas is drawn into the combustion chamber by the dust collecting fan, and after being heated with a kerosene burner, the high-temperature exhaust gas heats the pellets in the regenerative chamber, passes through the gas cooler, then the dust collector, and is discharged from a funnel to the atmosphere.

The recuperator holds a given amount of pellets. The pellet are transferred by means of air with the pellet sender and circulated. The temperature of the combustion chamber is kept at a given level by the cooling air.

The specifications of this system are shown in Table 1 and the main operating parameters are shown in Table 2.

Recuperator

The structure and main dimensions of the recuperator are shown in Figure 6.

In order to control the cupola-recuperator system automatically, the entire system has been designed so that by installing a gas analyzer, monitoring camera, and material detector on top of the furnace and a differential pressure gauge, thermocouple (PR-type) thermometer, optical radiation pyrometer, and gas and air flow meters to each part, all the measured values can be entered into the process computer (μx1) system, stored and processed, and commands can be issued to each monitor to maintain the selected operating parameters (Table 2).

Company B[7)]

This company's plant manufactures cast-iron cylinder blocks for diesel engines, and has a production capacity of 3,000 tons per month,.

Layout of melting equipment and process flow

The layout of the melting equipment is shown in Figure 7 and the specifications are listed in Table 3.

As the melting furnace, a cupola was adopted in order to treat a large amount of low-cost galvanized steel scrap generated within the corporate group. Two cupolas were installed to assume continuous operation even when one furnace is shut down for repairs or maintenance.

Operators are stationed in the central control room, pouring monitor room, and furnace repair shop.

The melting process flow is shown in Figure 8 and the specifications of the cupola are shown in Table 4.

Table 5 shows the standard charge mixture and typical composition of the molten iron.

Recuperator

The conventional recuperator using a metal pipe has the disadvantage of blast intrusion owing to the cracks caused by heat shock, resulting in a lower melting rate and the discharge of unburned gas from the furnace top. The recuperator using ceramic pellets raises the temperature of the hot blast because it has a large heat transfer area and a higher heat recovery rate. For example, with a charge coke ratio of 10.4%, a blast temperature of 620 ℃ can be obtained, producing thermal efficiency of 36.8~37.7%.

The ceramic pellets used are spheres 0.8~1.5 mm in diameter, with the major constituent being Al_2O_3.

At first, the possibility of rapid pellet wear due to the pulverizing action caused by the collision of pellets was anticipated but the wear rate proved to be half the expected value, just 0.18 kg per ton of molten iron.

During the trial run, occasionally all the pellets accumulated in the wind section, leaving the gas section empty, so blast air blew directly to the discharge side. This problem was solved by adjusting flow rate of the air that moves the pellets. Three years have passed since the start of operation; there have been no major problems and good conditions have been maintained.

Analysis of operating results

Higher blast temperature produces higher tapping temperature and lower coke ratio.

It can be expected that, with a ceramic pellet recuperator, an increase in pellet circulation leads to an increase in heat accumulation and in heat transfer area, resulting in an increase in blast temperature. At company A, by increasing the pellet circulation rate from 20 tons/hour to 25 tons/hour and the blast rate from 150 Nm^3/min to 160 Nm^3/min, and decreasing the open pore area of the trays, a hot blast of 600℃±30℃ was obtained.[6)]

It is well known that an increase in blast temperature causes an increase in tapping temperature, which has been demonstrated by Ishino et al.[8)], as shown in Figure 9. H. Jungbluth[9)] pointed out in his paper in 1955 that the relationship between blast temperature, tapping temperature and coke ratio is as shown in Figure 10, where measured values are plotted up to the blast temperature of 500℃, and the predicted effect of an additional increase in blast temperature is shown by the broken lines.

The measured values at company A are plotted in the same figure(◎). They fall on the broken lines in Jungbluth's drawing, confirming that by increasing blast temperature to about 600℃ with the highly efficient recuperator using ceramic pellets, a higher molten iron temperature and lower coke ratio can be obtained.

Blast temperature and melting rate

It can be expected that with an increase in blast temperature will produce an increase in both the combustion rate of coke and the melting rate of metallic materials in the furnace.

Figure 11[6)] shows the measured values of melting rate and tapping temperature with blast temperatures of 590° ,620° and 650 ℃ at company A[6)]. From this figure, the following is clear. When tapping temperature is the same, increasing blast temperature tends to increase melting rate. When blast temperature is the same, decreasing tapping temperature increases the melting rate.

Because increasing the blast temperature increases the melting rate, increasing the thermal efficiency of the recuperator and increasing the blast temperature will increase the melting capacity of the furnace, even with the same cupola.

Blast temperature and molten iron properties

Yield of components

Ishino et al. measured the relationship between blast temperature and yield rate of melting using an experimental cupola with a 500 mm inner diameter. He confirmed that increasing the blast temperature increases the yield rate, as shown in Figure 9[8]. W. Bardenheuer reported that increasing the blast temperature decreases Si loss in liquid iron, as shown in Figure 12[5].

Company A reported that, applying a high-temperature blast of about 600 ℃ with the recuperator using ceramic pellets produced an increase in the yield of metallic elements as well as the scrap charge ratio, an increase in the carbon content of liquid iron and a decrease in sulfur content[6]. Company B reported the average iron constituents shown in Table 5[7].

Mechanical properties

W.J. Hayburn claimed that tensile strength is higher, as shown in Figure 13, for hot blast operation at the same CE value, when comparing cold blast and hot blast cupola operation[10].

Thermal efficiency

Company A reported the thermal balance calculation shown in Figure 14[6] in the case of 600 ℃ blast temperature when using a ceramic pellet recuperator.

As this figure indicates, about 50% of the sensible heat and latent heat of the exhaust gas is absorbed by the hot blast, and a considerably high melting efficiency of 40.53% can be obtained.

Conclusion

We have been trying to promote the use of the recuperator using ceramic pellets as the heat exchange medium. With the support of Dr. P.W. Bardenheuer, starting with company A and company B, several automobile part manufacturing foundries are now using the recuperator with great success.

Compared with the type of recuperator in which blast air is preheated by radiation and convection of a steel pipe, this type of recuperator readily produces higher temperature hot blast of over 600 ℃, needs less maintenance, and has a large economical benefit. It has been confirmed that the increase in tapping temperature caused by the higher blast temperature, increases the carbon pickup rate, the yield rate of the components, and improves mechanical properties.

The authors are firmly determined to help this type of recuperator be put into widespread use in modern foundries and will make every effort to make the recuperator more efficient.

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(Tables)

Table 1 Specifications of cupola system facilities at company A

Cupola	15 tons/hour, KGT water cooled liningless type (mfd. by Naniwa Roki)
Recuperator	Heat exchanging medium: alumina pellet Continuous countercurrent type
Blower	220 Nm^3/min BPT-CH type (mfd. by Hitachi)
Continuous desulphurizing device	N_2 bubbling type, 18 tons/hour
Dehumidifier	180 Nm^3/min, refrigerating type
Dust collector	1000 m^3/min, filter cloth type
Charging equipment	20 tons/hour, Weighing truck type
Control system	μx1 computer system(mfd. by Yokogawa)

Table 2 Cupola operating parameters at company A

Materials mixture	10.5% coke, 25% steel scrap, 15% pig iron, 60% returns
Blast volume	562~600 Nm^3/ton {160~170 Nm^3/min}
Blast temperature	600±30 ℃
Tapping temperature	1520±10 ℃
Melting rate	17.5±2 tons/hour
Exhaust gas volume	746 Nm^3/ton (including cooling air)
Slag discharge amount	25 kg/ton
Pellet circulation rate	25 tons/hour
Pellet consumption rate	0.67 kg/ton

Table 3 Specifications of melting equipment at company B

Cupola (2)	13~18(normally 15) tons/hour Water-cooled liningless hot blast operation 6 weeks continuous operation (tapping hole 2/set)
Recuperator	Maximum temperature 620℃(wind box) EconoTherm type
Coke breeze injector	Blowing rate 54~450 kg/hour
Cupola dust collector	1400 m^3/min 800 mmAq Filtering air speed 0.8 m/min at 150℃
Materials feeding equipment	Number of bunkers 12 (coke 1/limestone 1/returns 1/steel scrap, alloy 3/briquet, pig iron 1)
Gate breaker	200 ton hydraulic press
Lifting magnet crane (2)	Lifting load 4.8 tons(with automatic function)
Holding furnace (2)	36/30 tons 750 kW 2 furnaces,2 power sources, with load cell
Ladle transfer crane	Lifting load 4.8 tons
Molten iron transfer equipment	Remote control semiautomatic operation 3 tons/batch
Automatic pouring furnace	15/10 tons 350kW W stopper - N_2 pressurizing type
Automatic inoculation device	Capable of three varieties setting

Table 4 Specifications of cupola at company B

Melting capacity (tons/hour)	15
Furnace inner diameter (mm)	1890
Number of tuyeres	6
Tuyere inner diameter (mm)	140
Blast volume (Nm^3/min)	163
Blast temperature (℃)	Max. 620

Table 5 Standard mixture and iron composition at company B

Steel scrap %	51.5	Coke breeze %	1.11
Returns %	34.3	C mixed %	1.68
Briquette %	14.2	Si mixed %	2.84
Fe-Si %	1.79	Mn mixed %	0.91
Fe-Mn %	0.52	C tapped %	3.31
Si-Cr %	0.15	Si tapped %	2.00
Limestone %	3.50	Mn tapped %	0.64
Charge coke ratio %	9.27		

(Figures)

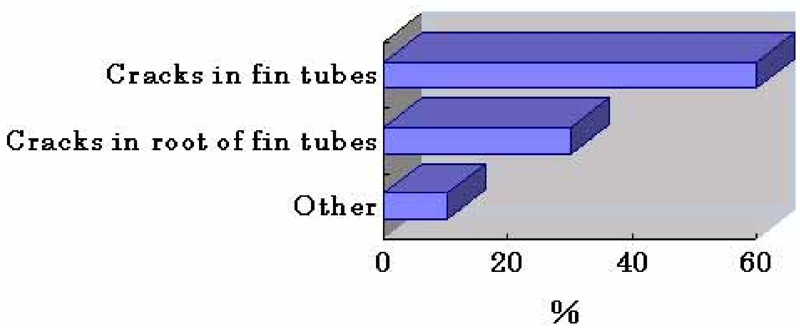


Fig.1 Common problems in conventional recuperators.

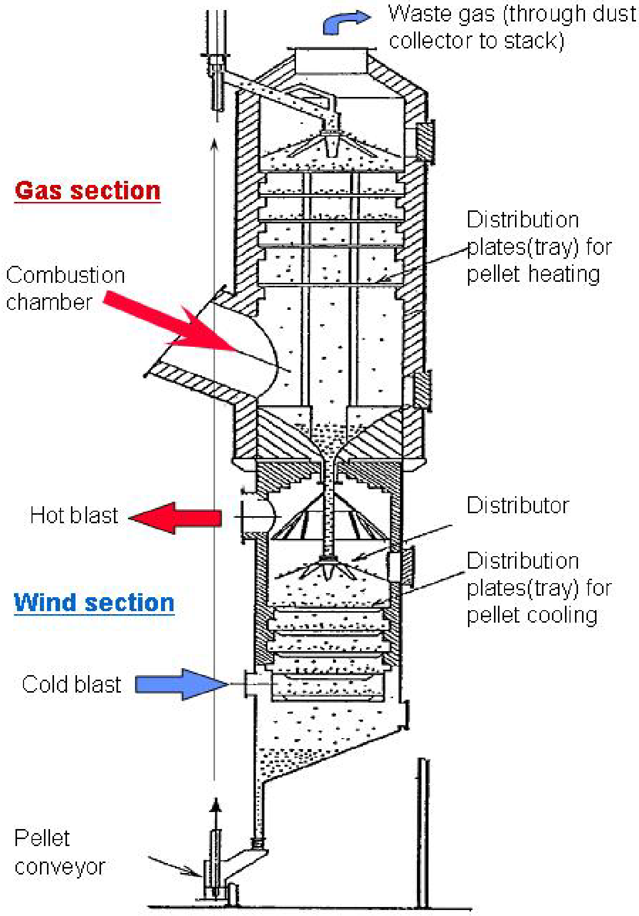


Fig.2 Structure of the recuperator using ceramic pellets as the heat exchange medium

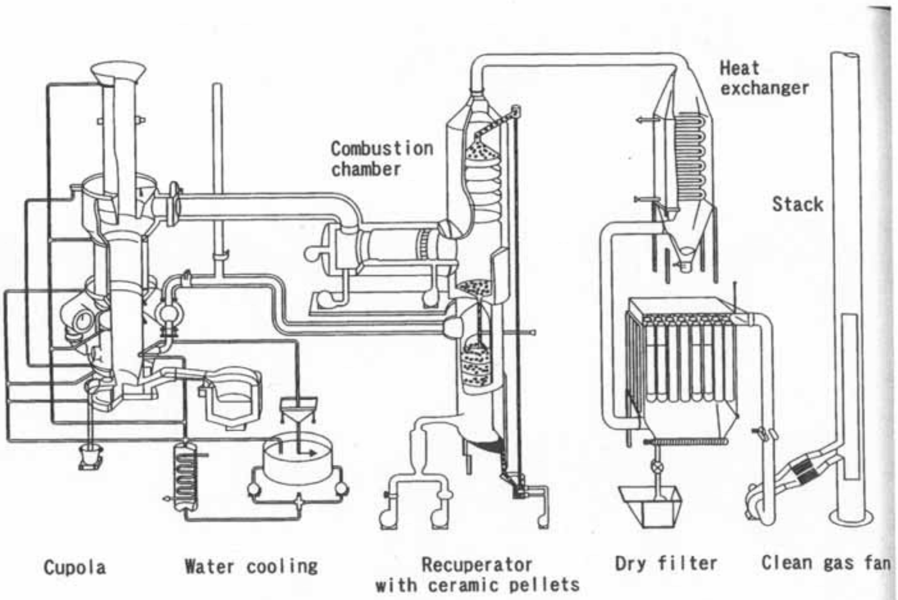
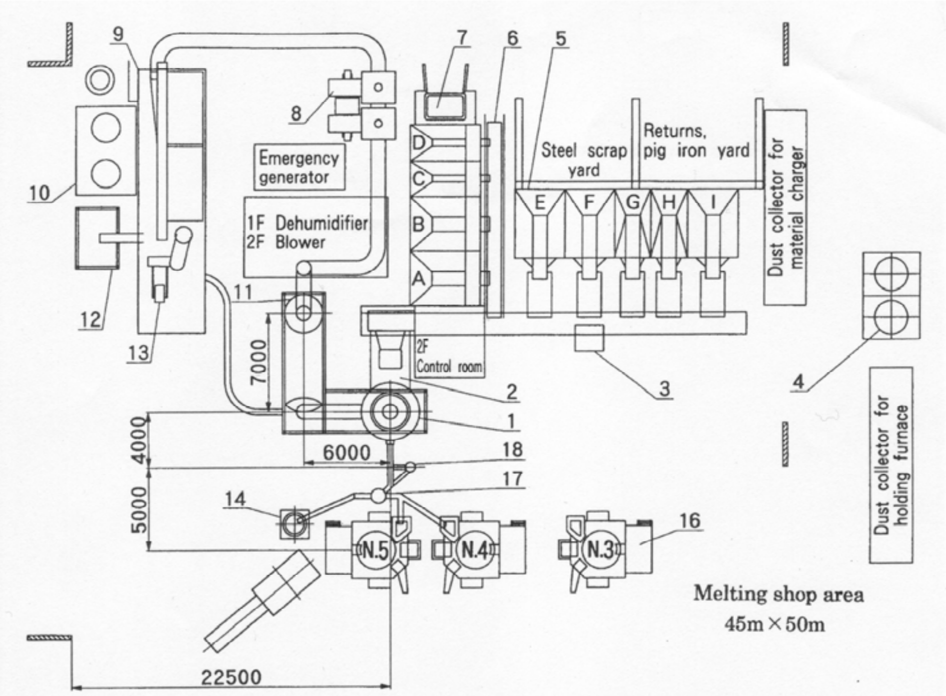
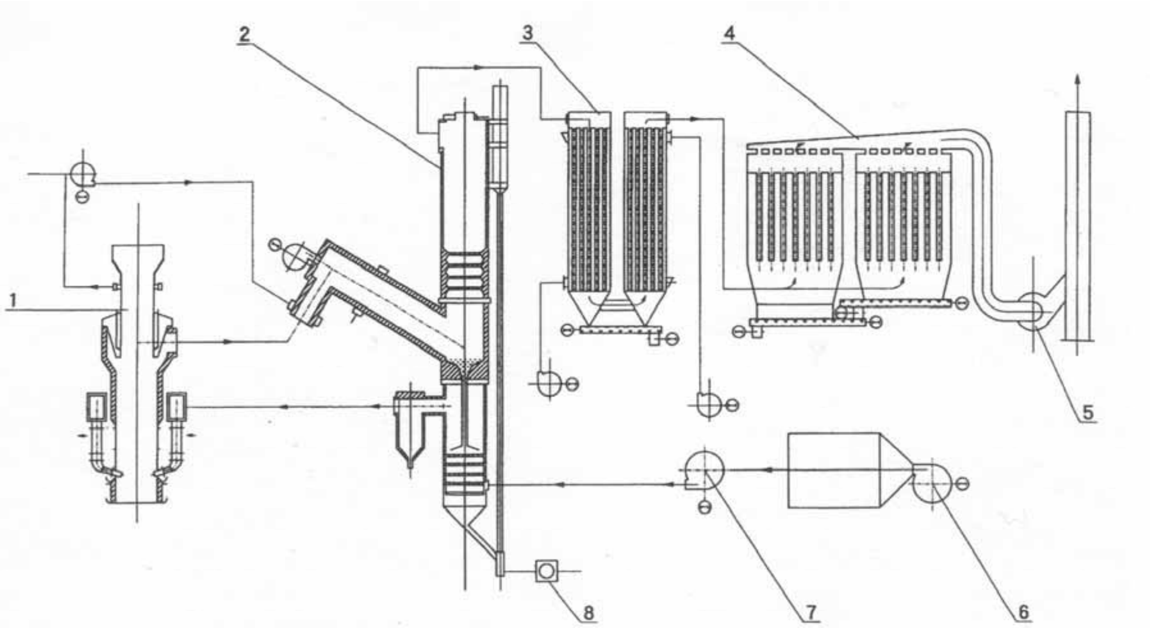


***Figure 3** Cupola melting system with a recuperator using ceramic pellets incorporated.*



1. Cupola 2. Charger 3. Weighing truck 4. Liquid nitrogen evaporator 5. Iron storage tank 6. Conveyor belt 7. Charger for supplementary materials 8. Exhaust gas cooler 9. Dust collector 10. Circulating water cooling tower 11. Recuperator 12. Slag reservoir 13. Slag granulating line 14. 10 tons ladle 15. Molten iron transfer truck 16. Holding furnace 17. Distributing spout 18. Continuous desulphurizing device

Figure 4 Plan of cupola melting system (company A)



1. Cupola 2. Recuperator 3. Gas cooler 4. Dust collector 5. Exhauster 6. Dehumidifier 7. Blower 8. Pellet transfer blower

Figure 5 Process flow of cupola melting.(company A)

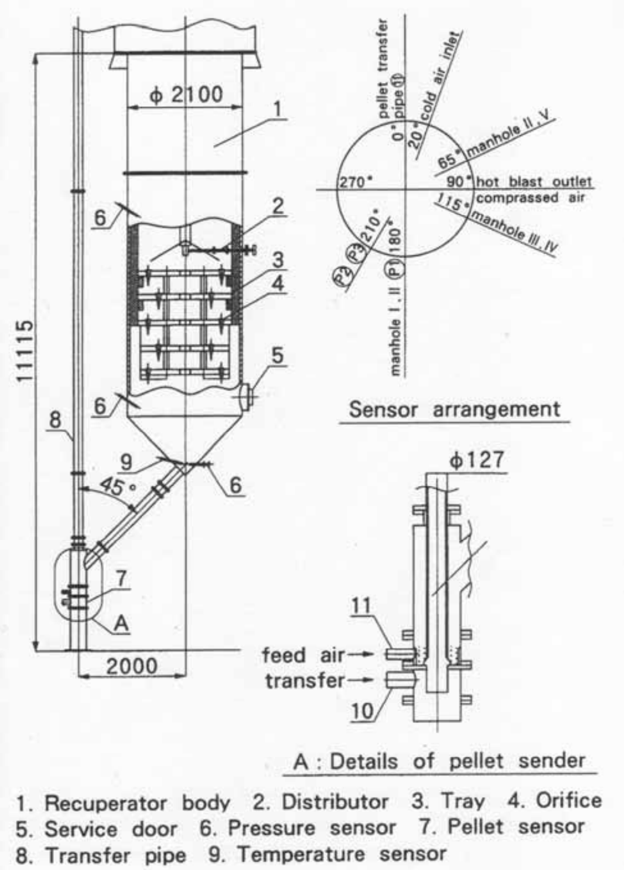


Figure 6 Construction of the recuperator (company A)

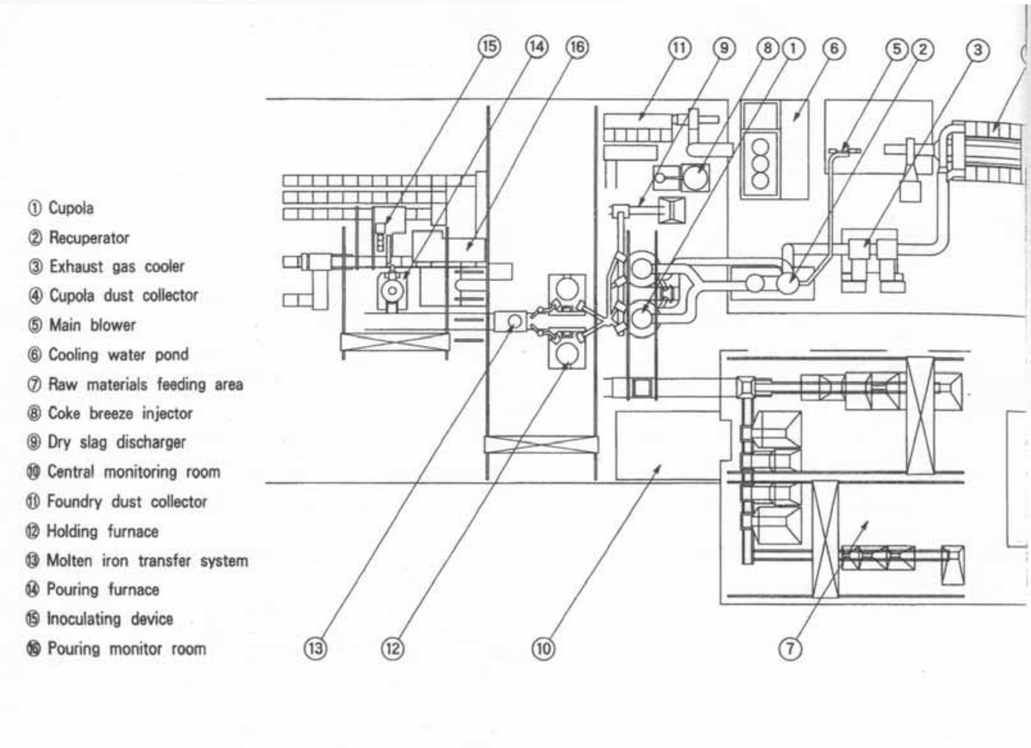


Figure 7 Plan of melting equipment (company B)

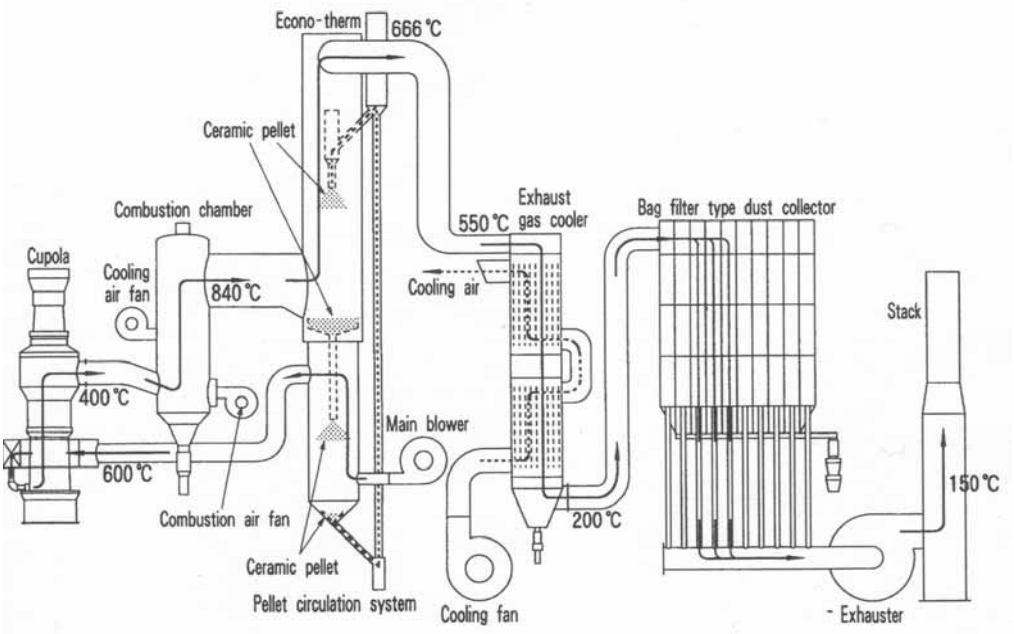


Figure 8 Process flow of melting (company B)

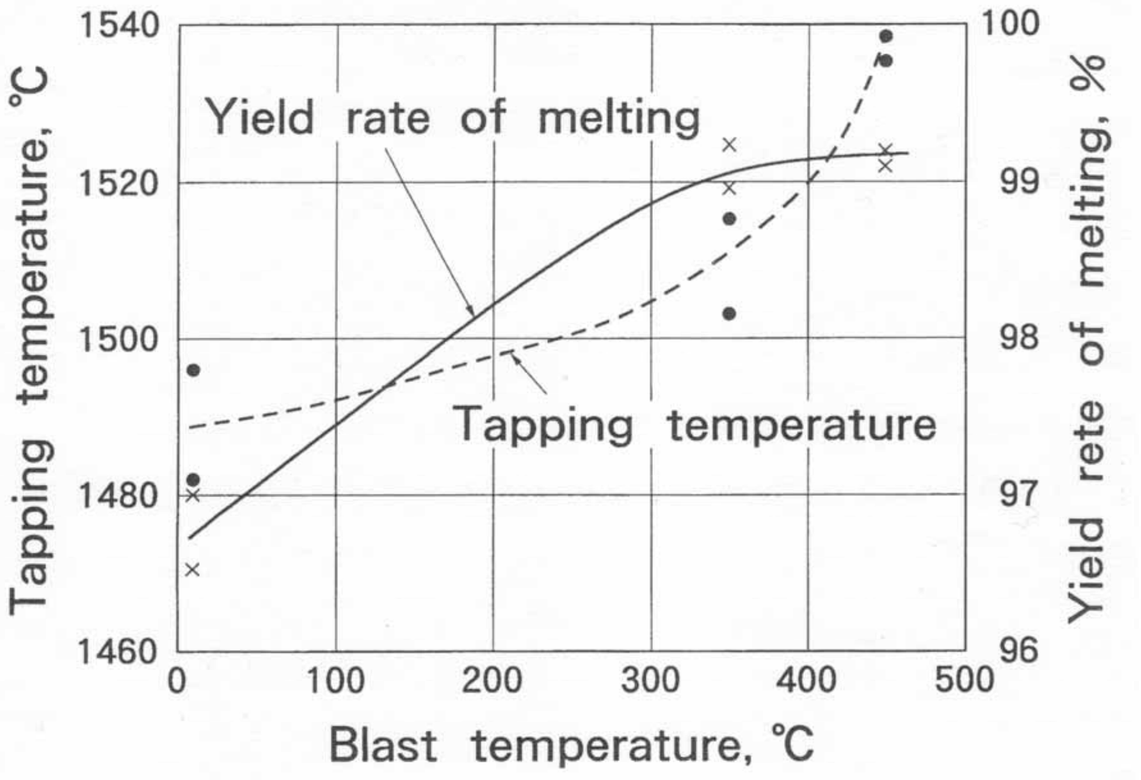


Figure 9 The effect of blast temperature on tapping temperature and yield rate of melting. (cupola inner diameter 500mm, coke ash 8.2%, coke ratio 14~9%)

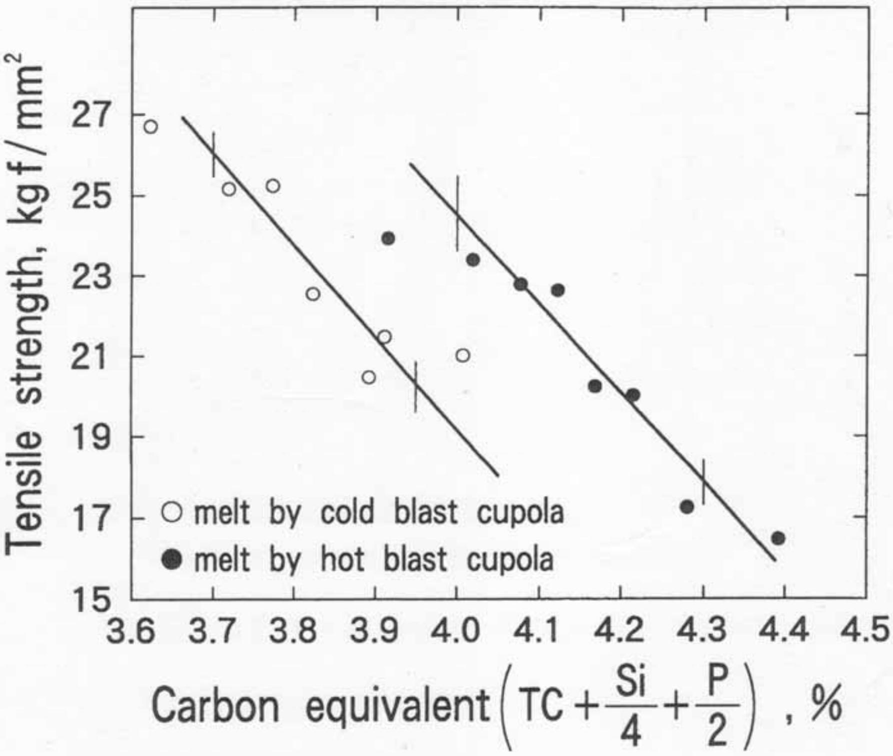


Figure 13 The difference between cold blast and hot blast operation affecting iron tensile strength and CE value

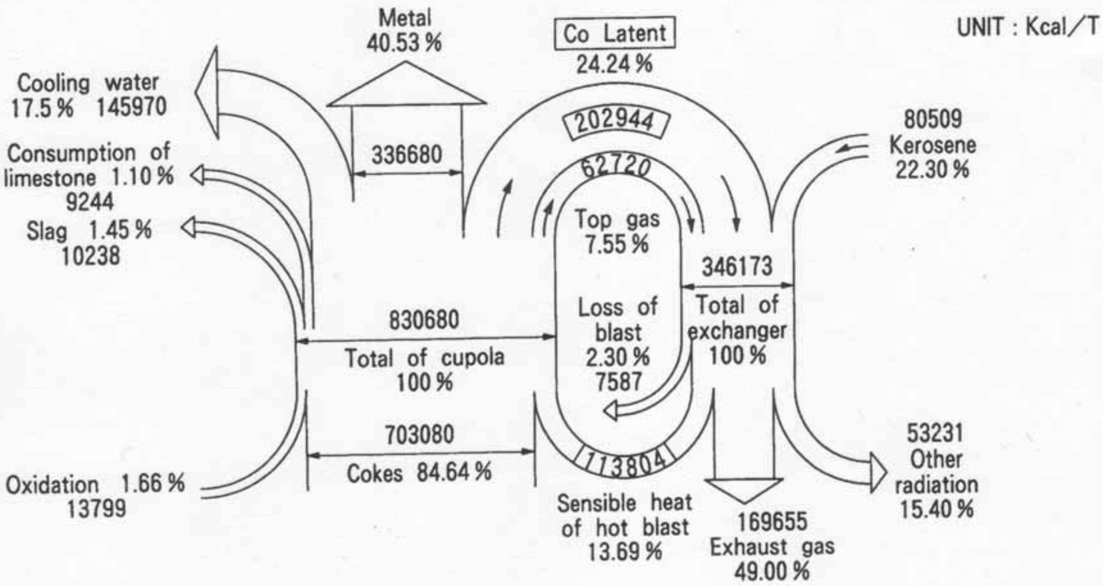


Figure 14 Thermal balance of cupola-recuperator system (company A)