Analysis of Scale-up of a Shaft Furnace by Process Engineering - From the Iron-manufacturing Experiment by Using Bei-tetsu in Hippo Tatara -

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="Iron technology and history forum" obtained the opportunity to participate in the 38th iron-manufacture experiment by using Bei-tetsu (lump iron ore with rice cake shape) conducted like in 1859 (Ansei era 6) by "the committee of restoring iron manufacture of “Hippo” (Village of Marumori-Town, Igu-County, Miyagi-Prefecture, Japan)” as early reconstruction assistance from the Great East Japan Earthquake in 2011. This experimental result was analyzed by process engineering and discovered the bird’s eye view on the conversion from the Japanese-style indirect iron-making into the shaft furnace historically and technically.

KEY WORDS: Tatara; shaft furnace; Blast Furnace; similarity rule; golden ratio.

1. Introduction

It is said that “Technology is sublimated to learning as it grows on a large scale. This is certain by theoretic common evolution.” In manufacturing technique, the blast furnace is the maximum scale serves as the comprehensive engineering1) of many learning fields as well as rolling. A blast furnace method has two faces, “Takumi’s” (Japanese craftmanship) work and comprehensive engineering, which continue maintaining the unchanging value like a spark-test method also in a big wave of high-technology.

Although the curtain of this Japan’s modern iron manufacture became and was cut and dropped to the Meiji term, it is prompt at the time of the end of Edo Period before it, and is supposed that the iron-manufacture experiment2–5) which is a lump ore stone was conducted by Bei-tetsu (lump iron ore with rice cake shape) instead of iron sand. This time, iron technology and history forum obtained the opportunity to take part in the planning of “the 38th iron-manufacture experiment by using Bei-tetsu”7) by “the meeting which restores iron manufacture of “Hippo” (Village of Marumori-Town, Igu-County, Miyagi-Prefecture, Japan; Hereinafter, it is called Hippo for short.)” as early reconstruction assistance from the Great East Japan Earthquake.

This time, Bei-tetsu was produced from plateau of Taneyama where is located in northernmost part of old Sendai-feudal domain and the place of an experiment, Hippo, Marumori-tawn is located in the maximum southern part of the old Sendai-feudal domain.

By restoring northeastern industrial history by carrying out using the Bei-tetsu from Taneyama plateau of the northernmost tip of old Sendai-feudal domain as the tatara material of the Marumori-tawn renaissance at the southernmost tip of the old Sendai-feudal domain as traditional craftsmanship, it was the prayer of all concerned of if it becomes supports of THE NORTHEST JAPAN REVIVAL from the Great East Japan Earthquake in 2011.

Tate described in the book of iron sand refining method, “Tatara method in ancient times of reprinted edition”7), that as the weak point of the Japanese-style indirect method above all was the lost more than 50% of the iron of materials iron sand in slag at iron-making process, so it was natural to have asked conversion in a hot wind blast furnace, such as square or a round furnace type process for the policy of the radical improvement.

And although the trial showed the improvement in an operating efficiency and an operational result remarkably, inconsistency of the iron sand refining method is also made actualized simultaneously. (Omission) For the end of transition, the high iron yield which is a premise of economical efficiency was not expectable by the refining method which uses only iron sand as materials pessimistically.”

The iron-manufacture experiment by Bei-tetsu is only an example of a Nippon Steel Corporation, Kamaishi works in the past.8) Bei-tetsu which is a kind of magnetite presents metallic luster or submetallic luster with color of black and a brown-black and also a black rifle mark on a bullet, and it is defined as iron contents of more than 70% being almost close to 72.4% of the theoretical iron value. Therefore, this

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Bei-tetsu supposed that an important point is grasped on the history elucidation of Japanese-made iron. In iron technology and history forum, the iron-manufacture experimental result by the 38th Bei-tetsu was analyzed in chemical reaction engineering, and it aimed at searching for the seeds of new iron-manufacture process technology by Bird’s-eye view historically and technically about conversion in the blast furnace type process of a Japanese-style indirect method, especially by the comparison with Iron-Manufacture between Tatara and Blast Furnace Operation of iron yield and furnace profile.

2. Iron-Manufacture Experimental Result by Bei-tetsu

2.1. Experiment General Condition

On April 15, 2012 in Hippo, Marumori-tawn, the member of “the meeting which restores iron manufacture of Hippo” which puts in iron ore and charcoal from on the furnace made from clay, and makes iron had the conversation of “this is large. the good thing was made”. Chairman Yoshinori Yamaki of that and the meeting looked at the lump of the iron in which heat still remains satisfactorily with members.

In 2002, the meeting is started in seven members with of Chairman Yamaki and others to revive the iron-manufacture method of the ancient times currently performed by Hippo at the Edo period and it is tackling iron manufacture 4 times per year.

Trial and error, such as using a fan instead of bellows, improvement of the magnetic ore dressing machine which takes out only iron sand have been repeated. “The temperature of a furnace also reaches 1400°C. Chairman Yamaki explains that a high heat like this can be given off by sending the combustion power and the wind of charcoal.”

Although iron sand of Abukuma River was always used, Nakagawa who acted as the superintendent of the “iron history hall” of Kamaishi-shi, Iwate and others were invited this time, and the new trial which breaks iron ore from this prefecture and it uses for materials was challenged. Members charge 1 kg of iron and 2 kg of charcoal into the furnace made from clay according to Nakagawa's directions. Above a 1.3-meter-high furnace, a flame goes up by no less than 50 cm. 30 kg of iron ore and 60 kg of charcoal became a lump of 12.8 kg in weight black iron in about 3 hours.

It is described in the literature which remains in Hippo for about ten years after 1615 that iron of 7 tons per year was dedicated to the Sendai-feudal domain instead of rice collected as land tax. The old Hippo which disappeared by the merger in 1954, have gotten rich with the sales of firewood or charcoal once. A member, Mr. Ichiro Shoji, stretches a breast, saying, “Iron manufacture was completed just because there was charcoal abundantly.”

2.2. Experimental Result

About the iron-making method of Tatara operation, it is supposed that it is generally classified into following the 4 term.

The 1st term (period of start-up, so-called ‘Komori Tsugi’) is that is filled of easy to be reduction nature in low melting first and throw in iron sand, next, throw in charcoal, burn it, and make Noro (slag). In that case, keeping warm in a furnace becomes good by an exothermic reaction.

On the 2nd term (next period of start-up, so-called ‘Komori Tsugi’), by increasing furnace temperature further, not only Noro (slag) but also Zuk (pig-iron) can be produced.

On the 3rd term (uphill period, so-called Nobori), by increasing ‘Masa’ (High grade) iron sand is increased gradually, a kind of ‘Kera’ (steel) will be made. The furnace condition will become active and a flame will shine with bright yellow highly. And while a furnace is eroded gradually, ‘Kera’ (steel) grows.

On the 4th term (blow-down period so-called ‘Kudari’), although by increasing ‘Masa’ (High grade) iron sand to grow up ‘Kera’ (steel) further, but at this time, a furnace wall will become thin and it will become impossible to continue the operation beyond this, and it will end of Tatara. The above is 1 operation made into one generation (so-called ‘Hitoyo’).

Figure 1 shows the furnace structure and Fig. 2 shows and the furnace condition of Hippo Tatara. As the furnace condition is the same as that of the above in general mentions, and this operation record and analysis research also followed the above-mentioned 4 period classification.

![Fig. 1. Furnace structure of Hippo Tatara.](image)

![Fig. 2. Furnace condition of Hippo Tatara.](image)
3. Analysis of Iron-Manufacture Experiment by Using Beitetsu by Process Engineering

3.1. Change of Temperature in Furnace

Figure 3 shows the change of the temperature distribution in a furnace of Hippo tatara. By the change from 1st period of start-up to so-called ‘Komori’, 2nd next period of start-up, so-called ‘Komori Tsugi’, 3rd uphill period, so-called Nobori, and 4th blow-down period so-called ‘Kudari’, the temperature in a furnace is falling down. This is assumed that the direct (or smelting) reduction is proceeded in by the rise in furnace temperature instead of discharge of Beitetsu as FeO at the beginning as shown in operation transition (Fig. 2) to shift to generation of ‘Kera’ (steel).

In addition, it is remarkable that the temperature gradient of the height direction is almost constant through 4 terms being observed and this means a slight change of gas volume, i.e., a slight change of gas utilization ratio described in following section.

3.2. Mass Balance

Table 1 shows the material balance of Hippo Tatara. In addition, the components of Bei-tetsu is referred to T-12 components (%t-Fe:68.91, %M-Fe:0.02, %FeO:21.27, %Fe2O3:74.86) of the reports of Terashima on “the characterization of Beitetsu extracted from Taneyama plateau” and carbon content of charcoal was premised on 91.4% of hinoki hard charcoal.

As the amount of extracted iron from bottom after blow-off was 12.8 kg under the total amount of charged iron of 20.7 kg, so the iron yield was 61.8% and the remaining 38.2% was discharged as FeO in slag.

It considered that the temperature distribution in a furnace over 4 terms (Fig. 2) was the counter-current flow moving bed, and since it was easy, the heat flux ratio was calculated by disregarding the heat loss from a wall and the tem-

| Operational term | Komori 09:00-09:51 | Komori Tsugi 09:52-11:04 | Nobori 11:05-11:39 | Kudari 11:40-12:12 |
|------------------|---------------------|--------------------------|------------------|------------------|
| Charging Condition |                     |                          |                  |                  |
| Coal rate (kg/kg-HM) | 2.177               | 2.177                    | 2.177            | 2.177            |
| Ore rate (kg/kg-HM)   | 1.451               | 1.451                    | 1.451            | 1.451            |
| Heat transfer |                     |                          |                  |                  |
| Furnace height (cm)   | 130                 | 130                      | 130              | 130              |
| Top gas temperature (°C) | 512                | 512                      | 430              | 157              |
| Top solid temperature (°C) | 50                 | 50                       | 50               | 50               |
| Reserve temperature (°C) | 1770               | 1760                     | 1455             | 435              |
| Heat flux ratio (–)   | 0.73                | 0.73                     | 0.73             | 0.72             |
| Top gas rate (Nm³/kg-HM) | 3.776              | 3.784                    | 3.787            | 3.823            |
| Oxygen balance |                     |                          |                  |                  |
| blast gas rate (Nm³/kg-HM) | 0.079             | 0.089                    | 0.092            | 0.139            |
| Blast volume (cal.) (Nm³/min) | 0.009             | 0.010                    | 0.011            | 0.016            |
| (cc/min) | 9.017               | 10.199                   | 10.569           | 15.943           |
| Blast volume (act.) (cc/min) | 9.077             | 10.411                   | 10.667           | 15.541           |
| Oxygen in blast (kg/kg-HM) | 0.024             | 0.027                    | 0.028            | 0.042            |
| Total oxygen (kg/kg-HM) | 2.698               | 2.701                    | 2.702            | 2.716            |
| Carbon balance |                     |                          |                  |                  |
| ηCO (%) | 1.7                 | 1.8                      | 1.9              | 2.4              |
| Solution loss C (kg/kg-HM) | 1.972             | 1.970                    | 1.969            | 1.958            |
| Direct reduction ratio (%) | 99.1              | 99.0                     | 99.0             | 98.4             |
| Indirect reduction (%) | 0.9                | 1.0                      | 1.0              | 1.6              |
perature distribution in particles. About the reserved temperature which is needed in calculation, since the temperature in a furnace of 1200°C or more was not able to be measured, reserved temperature was made into the parameter fitting was performed so that the amount of calculated blast volume might be in agreement with the amount of actual blast volume, and the heat flux ratio was determined.

Gasification oxygen according the top gas volume can be determined by heat flux ratio and the carbon and oxygen balance in a furnace can be determined by gasification of carbon uniquely. The gas utilization ratio shows displacement from 1.0 of the molar ratio of gasification oxygen to the gasification carbon in a furnace.

Through 4 term of this Hippo tatara, the gas utilization ratio is as low as 2.0% order, the molar ratio of gasification oxygen to the gasification carbon in a furnace is about 1.0, and it turns out that reduction reaction is predominant of direct (or smelting) with endothermic reaction. In the 4th blow-down period so-called ‘Kudari’, the gas utilization ratio increased slightly accepted to be 2.4%, this tendency is corresponds with the report by Nagata on the exhaust gas of the Iron and Steel Institute of Japan Steel project on restoration of Tuatara that 2nd campaign had 12.5% in ‘Kudari’ and 3rd campaign had 12.5% in ‘Komori’.

### 3.3. Heat Balance

Table 2 shows the heat balance of Hippo Tatara. In addition, the components of Bei-tetsu is referred to T-12 components (%SiO₂:2.34, %Al₂O₃:0.58, %CaO:0.1, %MgO:0.04) of the reports of Terashima on “the characterization of Beietsu extracted from Taneyama plateau” and ash content of charcoal was premised on 1.3% of hinoki hard charcoal. Although that reduction reaction is predominant of direct (or smelting) with endothermic reaction in the mass balance (Table 1), as a result, top gas sensible heat is falling rapidly and, as for this, change (Fig. 3) of the temperature distribution in a furnace corresponds.

On the other hand, the heat loss meaning the heat efficiency in a furnace is kept almost constant. From this point, it is estimated that the heat loss or heat capacity in the lower

|                  | Komori 09:00~09:50 | Komori Tsugi 09:52~11:04 | Nobori 11:05~11:40 | Kudari 11:40~12:12 |
|------------------|--------------------|--------------------------|-------------------|-------------------|
| **Input**        |                    |                          |                   |                   |
| Coal rate (kg/kg-HM) | 2.177             | 2.177                    | 2.177             | 2.177             |
| Combustion heat (kcal/kg) | 7,000           | 7,000                    | 7,000             | 7,000             |
| Ash in coal (%)   | 1.3                | 1.3                      | 1.3               | 1.3               |
| Oxidation in FeO slag (kg/kg-HM) | 2.255          | 2.255                    | 2.255             | 2.255             |
| Slag producing heat (kcal/kg-Fe) | 1,150          | 1,150                    | 1,150             | 1,150             |
| Slag producing heat (kcal/kg-HM) | 9,052           | 9,052                    | 9,052             | 9,052             |
| Oxygen in ore (kg/kg-HM) | 0.419           | 0.419                    | 0.419             | 0.419             |
| Reduction heat (kcal/kg-Fe) | 680            | 680                      | 680               | 680               |
| Ore rate (kg/kg-HM) | 1.451            | 1.451                    | 1.451             | 1.451             |
| Slag components (%) | 3.08             | 3.08                     | 3.08              | 3.08              |
| Slag ratio (kg/kg-HM) | 10.2            | 10.2                     | 10.2              | 10.2              |
| Slag specific heat (kcal/kg) | 0.26           | 0.26                     | 0.26              | 0.26              |
| Slag temperature (°C) | 1,350            | 1,350                    | 1,350             | 1,350             |
| **Output**       |                    |                          |                   |                   |
| Slag sensible heat (kcal/kg-HM) | 3,580          | 3,580                    | 3,580             | 3,580             |
| Metal sensible heat (kcal/kg) | 0.201           | 0.201                    | 0.201             | 0.201             |
| Metal temperature (°C) | 1,350           | 1,350                    | 1,350             | 1,350             |
| Metal sensible heat (kcal/kg-HM) | 271             | 271                      | 271               | 271               |
| Top gas temperature (°C) | 512              | 512                      | 289               | 157               |
| Top gas volume rate (Nm³/kg-HM) | 3.776          | 3.784                    | 3.787             | 3.823             |
| Top gas specific heat (kcal/Nm³/°C) | 0.325          | 0.325                    | 0.325             | 0.325             |
| Top gas sensible heat (kcal/kg-HM) | 628             | 630                      | 356               | 195               |
| Heat loss (kcal/kg-HM) | 10,866          | 10,865                   | 11,138            | 11,299            |

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part increased in the latter half of this operation.

Especially this is equivalent to furnace condition in 3rd uphill period, so-called Nobori.

Although in present-day blast furnace operation is operated with high temperature blast, but In the Tatara that normal temperature blast is premises since only the charcoal combustion by blast is the amount of heat inputs and the increase and decrease of a wind over 4 terms are very important. From the meeting which restores iron manufacture of Hippo in this 38th time and Nakagawa, It can catch a glimpse of the work of skill.

3.4. Observation on Kera Formation

A charcoal log is inserted in tap hole at 12:03, and burden supply was stopped with blasting to descend the stock line. After blowing off, the salamander of bottom exposure on the dissection on 13:12. The appearance which beats like signs of the mother’s body surely was like the Chinese character of 'Kera'.

Harvested ‘Kera’ is weight of 12.8 kg with height of 11.7 cm, length of 30.0 cm, and width of 21.0 cm. Although some specialty products of ‘Tamahagane’ made in Tatara has the color in rainbow color like a ‘Youhen’ tea bowl and a color changes with the angle to see, coloring of 5 colors (rainbow color) is accepted moderately faintly this time. It is said that which does not have the paper analyzed scientifically, i.e., iron oxide.

**Table 3.** Metal and slag components of Hippo tatara.

| Metal component | C | Si | Mn | P | S | Ti | Cu |
|-----------------|---|----|----|---|---|----|----|
| %wt             | 0.15 | 0.03 | <0.01 | 0.074 | 0.002 | <0.01 | 0.03 |

| Slag component | t-Fe | M-Fe | FeO | Fe2O3 | SiO2 | Al2O3 | CaO | MgO | MnO | TiO2 |
|----------------|------|------|-----|-------|------|-------|-----|-----|-----|------|
| %wt            | 25.98 | 0.19 | 29.29 | 4.33 | 19.11 | 5.22 | 2.00 | 3.81 | 0.96 | 32.59 |

4. Comparison with Iron-Manufacture Experiment by Using Beitetsu and Blast Furnace Operation

4.1. Relation between Total Iron Content and Iron Yield

**Figure 4.** Total iron content (T-Fe%) in iron ore and the iron yield (%).

Although in this figure, the case of iron sand (Fukushima shinchi iron sand with %t-Fe of 42.0, Fukushima magnetic separated iron sand with %t-Fe of 54.3) was plotted together as comparison.

Although the yield increases linearly with the increase in the total iron content in iron ore, even if Beitetsu has near a theoretical iron value, the yield is only 61.8%.

In addition, this yield is near the reduction rate (65.0%) of the lump ore stone in the cohesive zone in investigation of Hirohata No. 1 blast furnace. In Hirohata No. 1 blast furnace, the agglomerated or sintered material of the reduction ore is investigated carefully, also in case of a lump ore stone, it is the same as that of sintered ore, the slag generated in particles consists of fayalite and silicate glass, and it is estimated that FeO in melt was high. Therefore, it is thought that the iron yield of Tatara operation is connected with the reduction degree in dropping from cohesive zone in blast furnace.

As the results, it is found out that the iron yield of Tatara, low height furnace operation corresponds to the reduction degree in dropping from cohesive zone in blast furnace, high height furnace operation.

4.2. Contrast of Tatara Operation with Blast Furnace Blow-in Operation

**Table 4.** The comparison of Hippo tatara with the Iron and Steel Institute of Japan and the Society for Preservation of Japanese Art Swords on furnace volume and blast volume ratio. Here, the blast volume ratio is define as the ratio of blast volume to the furnace inner volume and the blast increase rate is defined as the ratio of blast volume in the latter half to that in the first half of operation.

Compared with the Iron and Steel Institute of Japan and the Society for Preservation of Japanese Art Swords, the blast volume ratio is define as the ratio of blast volume to the furnace inner volume and the blast increase rate is defined as the ratio of blast volume in the latter half to that in the first half of operation.

On the other hand about the blast increase rate, the blast increase rate of Hippo is 2.0, and it is the same as that of the Iron and Steel Institute of Japan almost. It is considered to originate in that the blast of the Iron and Steel Institute...
of Japan is continuous blast with an electric blower, and this is that Hippo is the same and one side, the Society for Preservation of Japanese Art Swords being the intermittent blast by the electric motor drive of four piston type. Furthermore, there is a close resemblance between the blast increase rate of this Hippo (round furnace) and the blast increase rate at the time of blow on of blast furnace until first tapping. Namely, the intermittent tapping operation of Tatara is corresponding to the operation at the time of blow on of blast furnace until first tapping and under just the difference in furnace volume that and its unsteady operation are carrying out the closely same work as connection to both processes and it can be observe that it is very common blasting operation.

4.3. Contrast of Tatara Ironmaking with Present Age Blast Furnace

Kihara (‘Murage’) described that on the growth of ‘Tamahagane’, Tatara is said to be a blast furnace on top and converter on bottom in the modern ironing system.18,19) Moreover, Okimori on translation of Tile Coat work of “A History of Metallurgy”20) described that the changes of the profile a furnace have the history that the composition changed from the independent furnace bodies of a reverse cone or belly part and hearth part to the composition of connected a chimney part and hearth part by connected by belly. Nagata described that with increasing the furnace height, oxygen partial pressure will become low.12)

It is considered that the expansion to the upper ward as scale-up of furnace volume21) introducing the decrease of oxygen partial pressure and strengthening the reduction function, especially desulphurization reaction of the furnace lower part and on the other hand, it became impossible to inhibit an excessive carburizing reaction.

Figure 5 shows the operational comparison of Hippo tatara with cupola test reactor22) the commercial cupola furnace23) and a present age blast furnace on the heat loss and CO gas utilization with furnace volume. About in 1 000–3 000 m³ of furnace volume, and the furnace volume expansion effect is saturated. On the other hand, although the blast furnace of Japan is carrying out blast furnace expansion repair on the world’s largest level, this is the purposes with main improvement in the labor productivity by concentration and enlargement of a blast furnace, and as a result, labor productivity is the present and about 1 600 ton/person/year has reached.24)

5. Development of Theory on Scale-up of Shaft Furnace

5.1. Similarity Rule of Shaft Furnace

The principle of scale-up is a similarity rule. The foundations are set to be five factors as geometric similarity, static similarity, hydrodynamic similarity, dynamical similarity, and thermal similarity.25) The upper part expansion as scale-up of furnace volume needs to take into consideration the shift from a fixed bed to a moving bed with considering static similarity and hydrodynamic similarity in common sense under geometric similarity.
Hydrodynamic similarity, *i.e.*, the motion study similarity in the system accompanied by a flow, is that fluid or a solid particulate flows in time to correspond in accordance with a stream geometrically, *i.e.*, the pattern of a streamline is similarity geometrically.

In a blast-furnace shaft part, a solid descent streamline is defined as being a straight line drawn as “which it was underlined radiately from cross-point of the extension of a furnace wall and axis along the straight line”.\(^26\)

**Figure 6** shows the geometric similarity figure in a furnace shaft part. In this figure, by defining \(X\) as a belly radius and ‘a’ of vertical distance from top to cross-point of the extension of a furnace wall and axis of furnace center, the following formula will be obtained from hydrodynamic similarity.

\[
aX : a = a : a(X - 1) \\
\therefore X^2 - X - 1 = 0
\]

The solution of this equation is \(X = (1 + \sqrt{5})/2 = 1.61803398\) which is exactly the “golden ratio”.\(^27\) Therefore, in a blast-furnace shaft part, when a solid descent streamline presupposes “which it was underlined radiately from cross-point of the extension of a furnace wall and axis along the straight line”, it is assumed that the ratio of the diameter of the belly to throat is maintained by the golden ratio.

### 5.2. Change of Furnace Profile Accompanying Furnace Volume Expansion

It is currently examined in detail by Inada about the relation between blast furnace volume and furnace profiles form including evaluation of the influence blast furnace.\(^28\)

**Figure 7** shows the change of the furnace profiles form accompanying the furnace volume expansion by Inada and the ratio of the diameter of the belly to throat plotted in addition the curve (dashed line) of \(\text{Throat} \times 1.61803398\) assumed are maintained by the golden ratio.

By taking into consideration that the diameter of the belly is an initial-setting value on blow in, it is in agreement with the diameter of the belly about. Therefore, it can be presumed that the geometric relation between throat of a blast furnace and the diameter of the belly is a thing according to a hydrodynamic similarity rule. Although there is a report\(^29\) about the proper range of the shaft angle of a shaft furnace until now, since there is no report about the relation between throat of a blast furnace and the diameter of the belly, this result can be said to be discovery.

### 6. Conclusion

In this report, the technology and the history and iron forum have been working for the purpose of “while studying world-historic and scientifically the technology and history of the method of ironing Japanese ancient times, and the processing method and aiming at the elucidation of an academic subject and searching for the seeds of new steel technology” and analyzed the iron-manufacture experimental result by the 38th Beitetsu was in chemical process engineering and the following conclusions were obtained.

1. In tatara ironmaking process, even if it is Beitesu near a theoretical iron value, the yield is only 61.8%, and the iron yield of Tatara operation is connected with the dropping reduction rate of the lump ore stone in blast furnace cohesive zone.
2. Namely, the intermittent tapping operation of Tatara is corresponding to the operation he time of blow on of blast furnace until first tapping.
3. Under just the difference in furnace volume that and its unsteady operation are carrying out the closely same work as connection to both processes and it can be observe that it is very common blasting operation.
4. The geometric relation between throat of a blast furnace and the diameter of the belly is maintained by scale-up according to a “hydrodynamic similarity rule” at the “golden ratio.”
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