CURRENT DEVELOPMENT OF SLAG VALORISATION IN CHINA

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Introduction to Wuhan University of Sci. and Tech.

Wuhan Univ. of Sci. and Tech.:

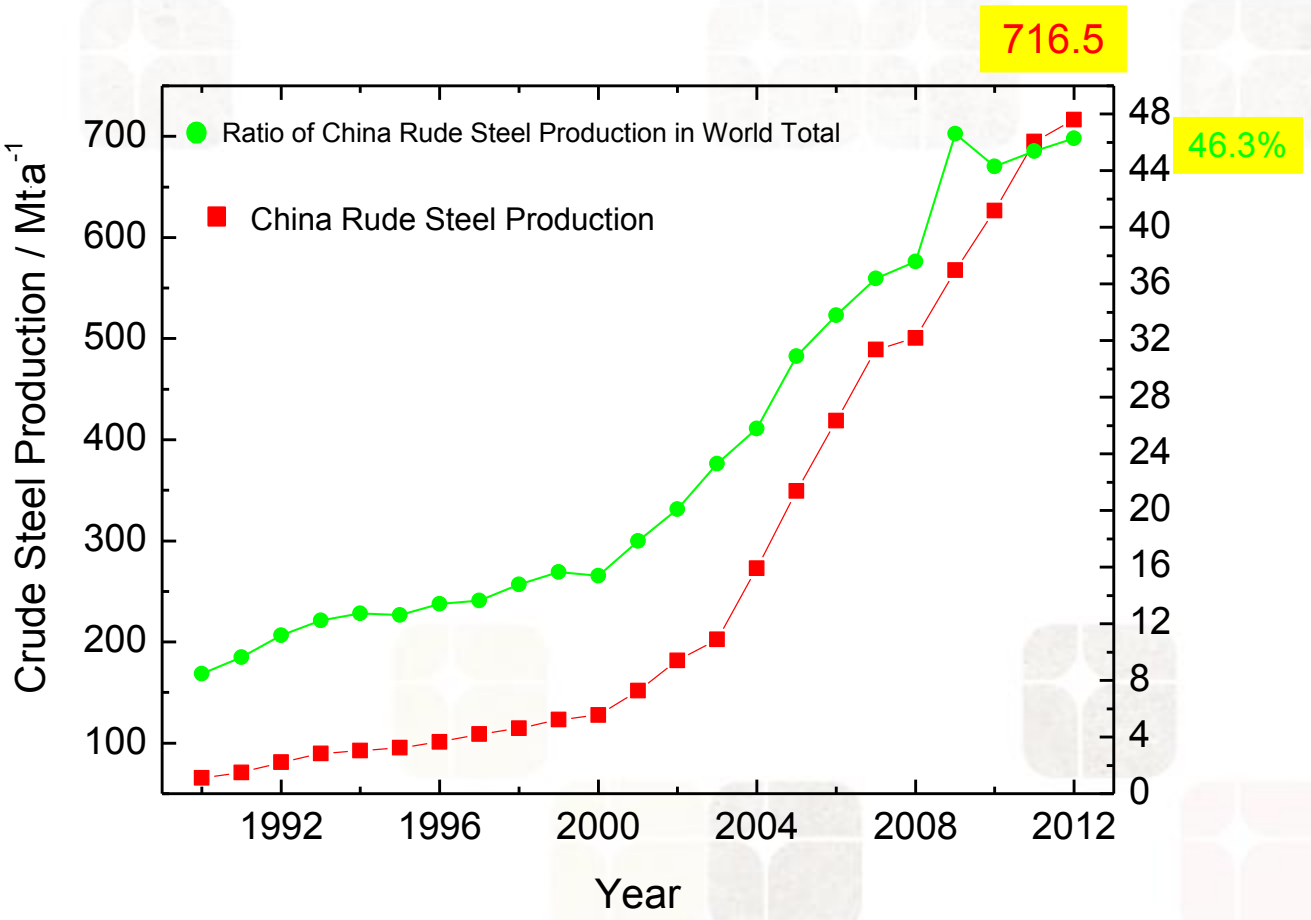
A key public
higher learning institution
in Hubei Province

Traditional strengths:
metallurgy-related engineering
and technology

Contents

- Introduction
- Current State of Ironmaking and Steelmaking Slags Valorisation in China
- Current development and fundamental research activities in China
- Conclusions

Introduction

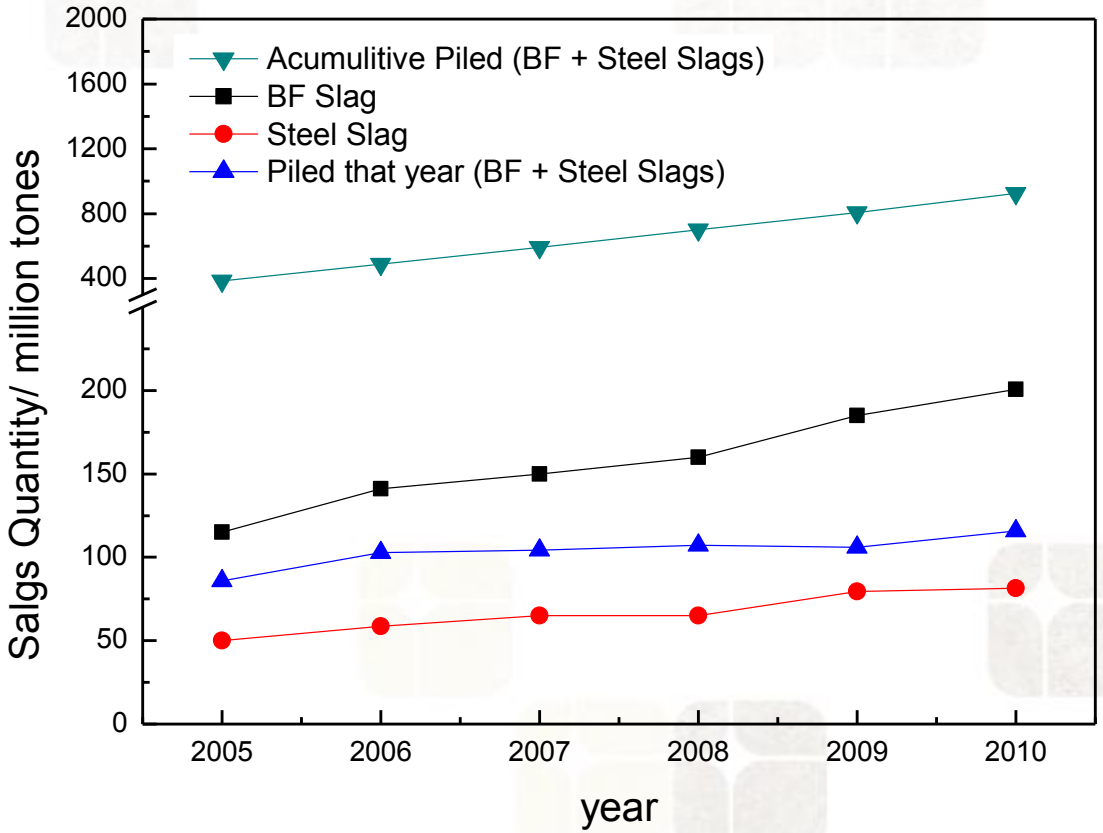


- Crude steel production of china and its ration in world total

Introduction

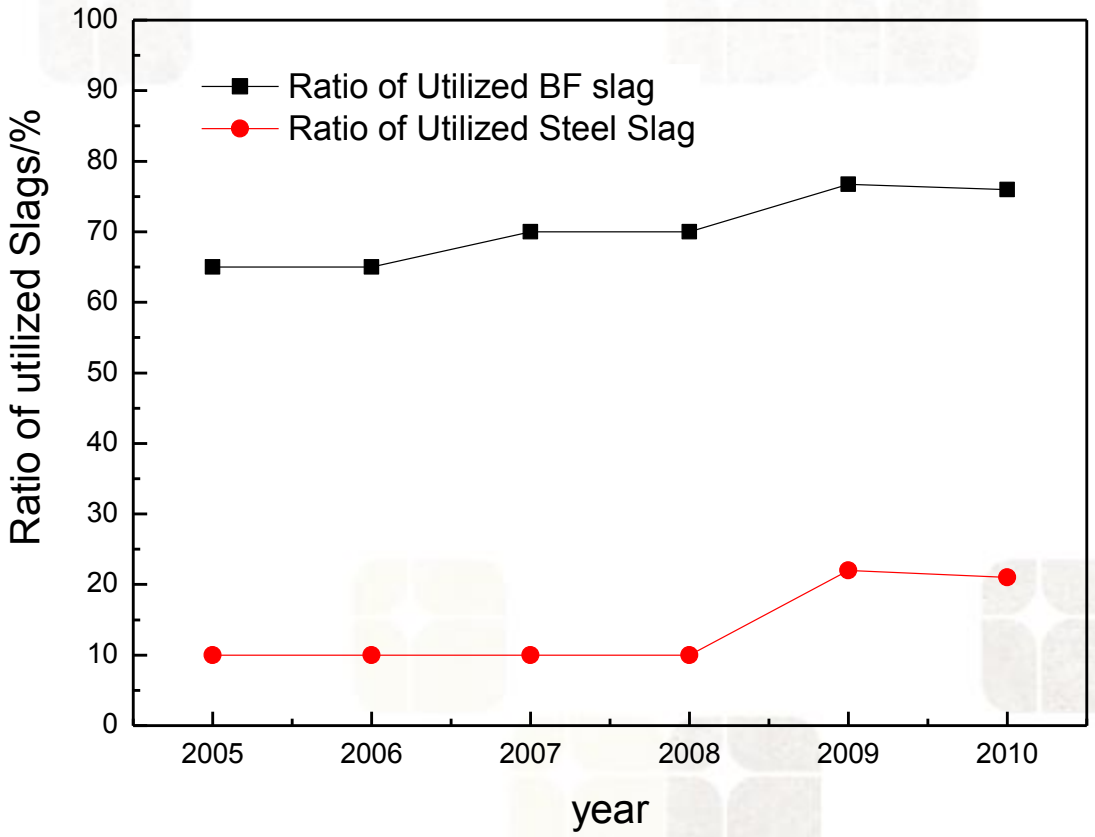
- in 2010, the steel slags and blast furnace slags have reached 81.47 and 200.67 million tonnes, respectively.
- The ratios of utilisation or valorisation are 21% for steel slags and 76% for blast furnace slags.
- Realizing “zero” dumping of iron and steelmaking slag has been an urgent task to save energy, to reduce the emission, to protect the environment and to develop a recycling economy in the steel industry.
- A series of technical routes, management modes, valorisation standards and environmental regulations for the utilisation of iron and steelmaking slags were established in China.

Current State of Ironmaking and Steelmaking Slags Valorisation in China



- Changes in the quantity of iron and steelmaking slags during 2005 to 2010 in China

Current State of Ironmaking and Steelmaking Slags Valorisation in China



- Changes in the ratio of the utilised slag to total slag during 2005 to 2010 in China

Current State of Ironmaking and Steelmaking Slags Valorisation in China

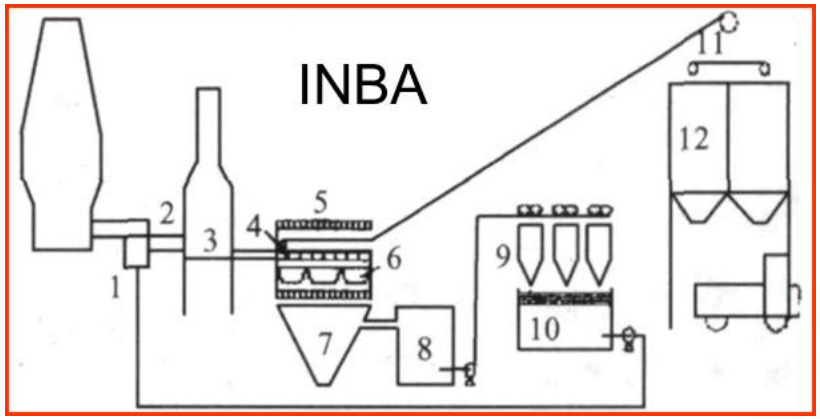
Table 1: Slag valorisation routes and their ratio

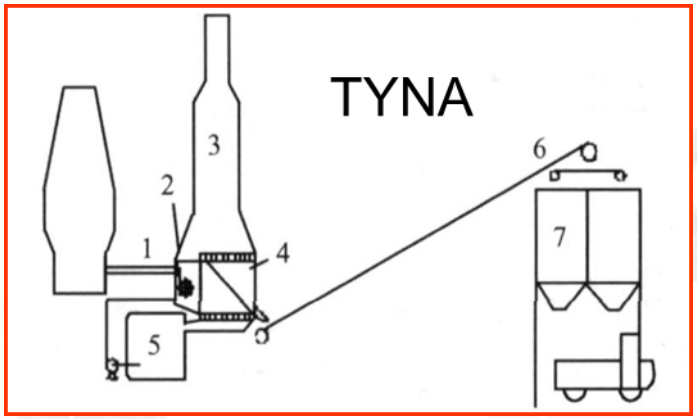
Type of slags		Main valorisation routes	Ratio(%)
BF slag	Water granulated	Ground granulated BF slag powder as cement and concrete material	48.5
		Cement mortar material	46.5
	Air cooled	Blinding	5.0
Steel slags		Ground granulated steel slag powder as cement and concrete material	5.4
		A series of Portland cements grades	30.1
		Bricks	1.1
		Road construction and backfilling	63.4

Current State of Ironmaking and Steelmaking Slags Valorisation in China

- Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China
  - The hot stage processing for BF slags mainly include

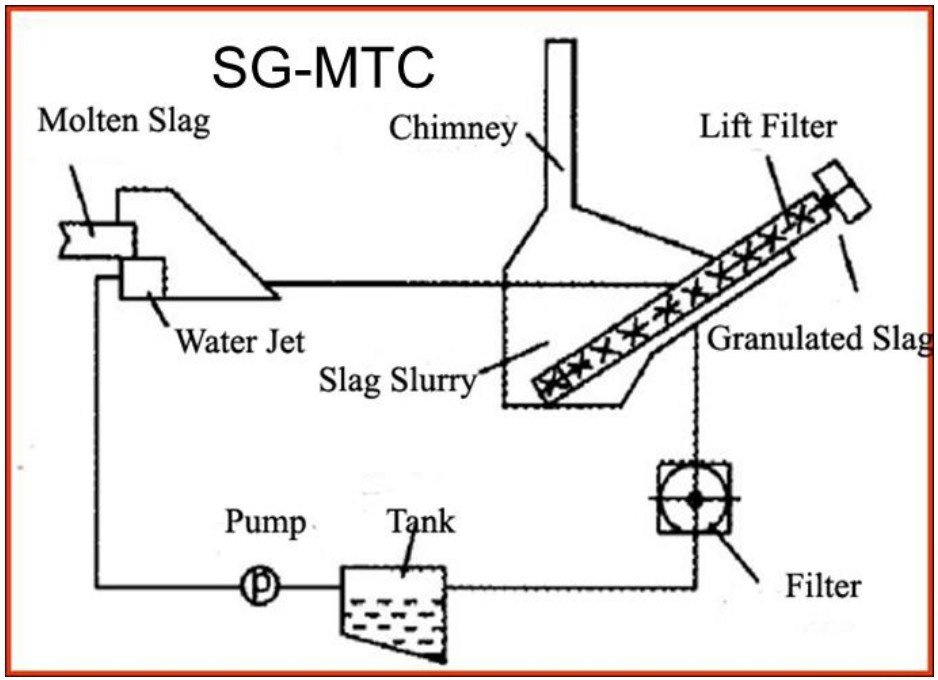
INBA, TYNA, SG-MTC, and HK processes

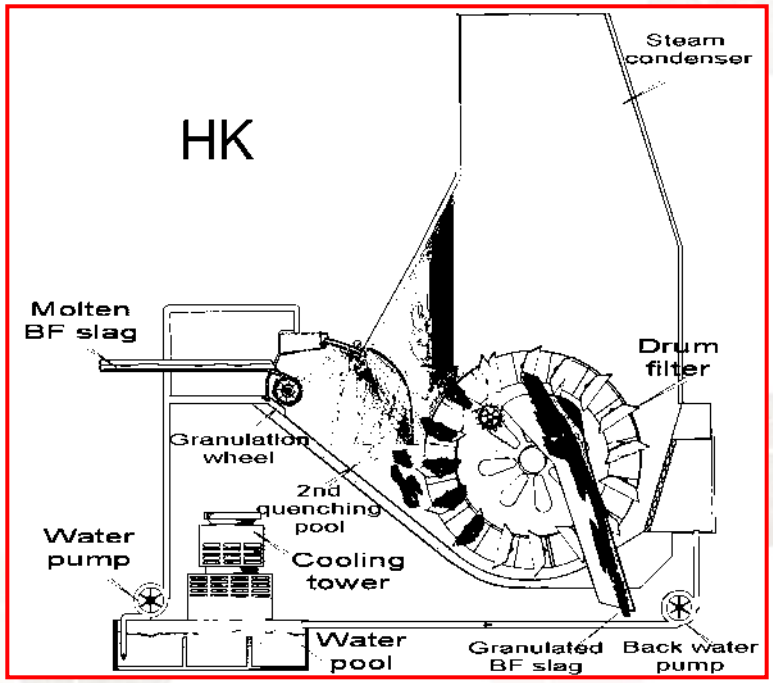




Current State of Ironmaking and Steelmaking Slags Valorisation in China

- Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China





Current State of Ironmaking and Steelmaking Slags Valorisation in China

- **WISDRI** Engineering & Research Incorporation Limited Company developed a modified INBA process called **IDE** (Impact, Drum improved and Environmental friendly)
- Granulated BF slag contains more than 95% vitreous phases and less than 15% water.
- Up till June 2012, 9 sets of IDE units were employed in practice, thereby operating in 6 blast furnaces ranging from 1800 m^3 to 5800 m^3, and 6 sets are under construction.

Current State of Ironmaking and Steelmaking Slags Valorisation in China

IDE drum filter for water granulated BF slag

Current State of Ironmaking and Steelmaking Slags Valorisation in China

- Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China
- **The current hot stage processing of BOF slags**
  - ***Pyrolytic Self-slaking proces***
  - ***Baosteel's Slag Short Flow (BSSF)***
  - ***Instantaneous slag chill process (ISC)***
  - ***Water-granulation process***
  - ***Wheel-granulation process*** (HK)
  - ……

Current State of Ironmaking and Steelmaking Slags Valorisation in China

- The pyrolytic Self-slaking process was designed by China Jingye Eng. Corporation Ltd.
- The hot molten slag is poured into a tank with a cover, while water is sprayed into the tank, resulting in steam generation. This water steam reacts with the free lime and magnesia in the slag to obtain a stabilised BOF slag. This stabilised slag is subjected to size reduction for different utilisations.
- Due to the good stability, the wide suitability of the treated slag and the high recovery yield of steel grains from the residual slag, the pyrolytic self-slaking process is generally used in China.

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Pyrolytic Self-slaking proces

Current State of Ironmaking and Steelmaking Slags Valorisation in China

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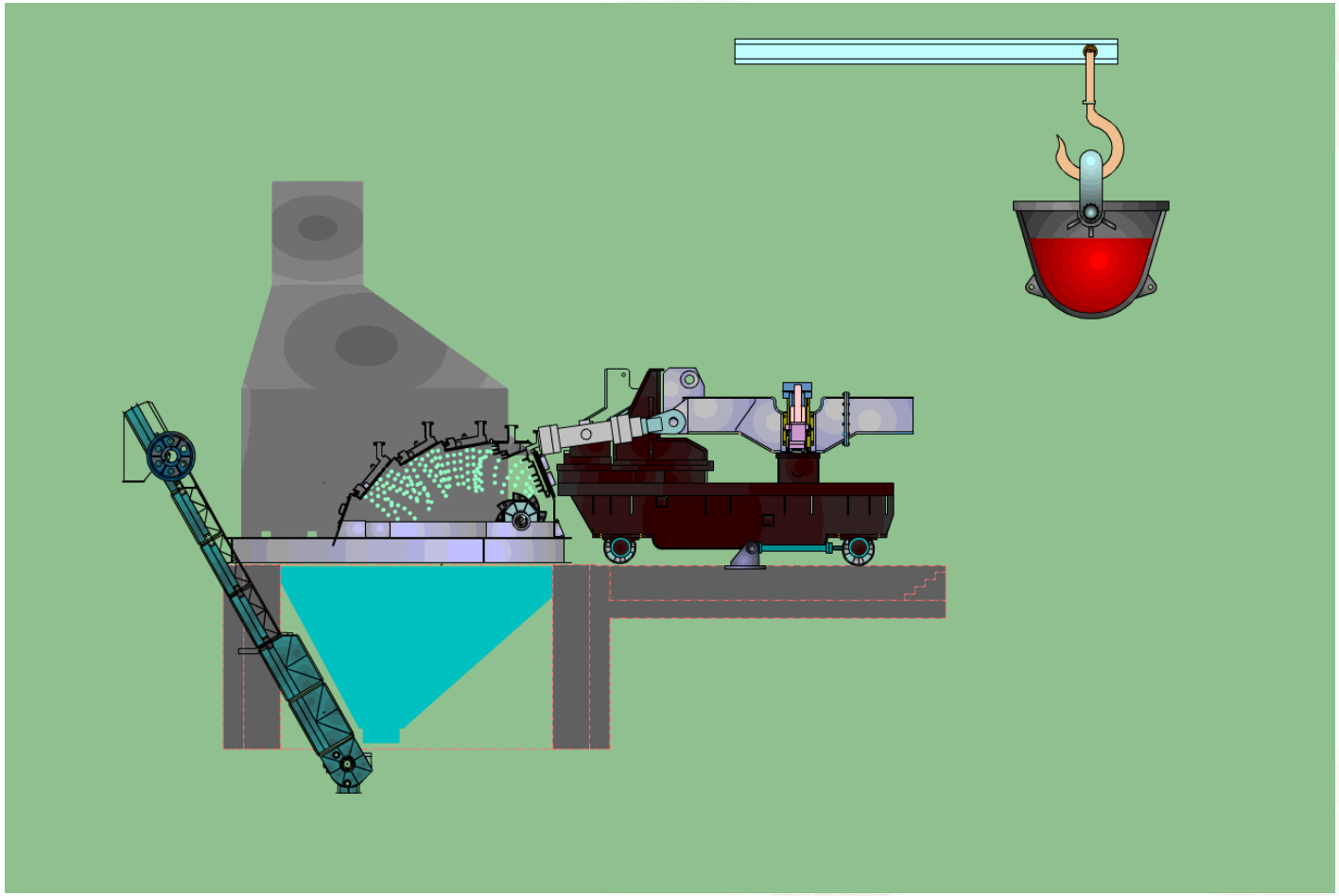
Current State of Ironmaking and Steelmaking Slags Valorisation in China

- From 2007 to 2010, this process has been adopted by more than 30 steel companies.
- The treatment ability of these installations ranges from 0.25 to 1.7 million tonnes slag/year.
- During 2008 to 2010, 31 million tonnes steel slags were treated and recovered iron increased 496 thousand tonnes by the newly installed Pyrolytic Self-slaking processing units which increased the valorisation ratio of steel slags from 10% to 21%.

Current State of Ironmaking and Steelmaking Slags Valorisation in China



Demonstration of Wheel-granulation process (HK)

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Layout of Wheel-granulation installation (HK)

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Table: Operation parameters of the HK steel slag granulation process

An example of slag composition (%)	CaO	SiO_2	Al_2O_3	FeO	T. Fe	R
	40.6	11.1	3.0	21.0	23.8	3.2~3.5
Temperature of taping slag (° C)	1550~1650					
Water supply (in circulation, t/h)	430~485					
Water pressure (MPa)	0.32~0.38					
Rate of granulation for total slag (%)	80~85%					
Water consumption (t/t slag)	0.657					
Granulation speed (t slag/min)	1.5~3					
Size (mm) distribution of granulated slag	<1	1~3	3~7	7~12.5	>12.5	
	5%	41%	36%	13%	5%	
Water ratio in granulated slag (%)	<10					

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Granulated BOF slag by Wheel-granulation process (HK)

Current State of Ironmaking and Steelmaking Slags Valorisation in China

- A temporary standard system has been constructed, which includes 18 product standards, 7 analysis and test method standards, and 4 technical specifications related with slag valorisation

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Table : Standards for ironmaking and steelmaking slag valorisation

Category	No.	Title	Serial No.
Product standard	1	Portland steel slag cement	GB 13590-2006
	2	Steel slag powder used for cement and concrete	GB/T20491-2006
	3	Low heat Portland steel slag cement	JC/T1082-2008
	4	Steel slag cement for road	JC/T1087-2008
	5	Steel slag masonry cement	JC/T1090-2008
	6	Steel slag cement for road	GB 25029-2010
	7	Low heat BF slag and steel slag cement	report for approval
	8	BF slag and steel slag powder	report for approval
	9	steel slag sand for road	YB/T 4187-2009
	10	Ground granulated blast furnace slag powder used for cement and concrete	GB/T 18046-2008
	11	Crushed air-cooled blast furnace slag for concrete	YB/T 4178-2008
	12	Ground Silicon-manganese slag used for cement and concrete	YB/T 4229-2010
	13	Ground lithium slag used for cement and concrete	YB/T 4230-2010
	14	Steel slag used for cement	YB/T 022-2008

Current State of Ironmaking and Steelmaking Slags Valorisation in China

Table : Standards for ironmaking and steelmaking slag valorisation(continued)

Category	No.	Title	Serial No.
Product standard	15	Steel slag for engineering backfill	YB/T 801-2008
	16	Steel slag for metallurgical burden	YB/T 802-2009
	17	Steel slag for roads	GB/T 25824-2010
	18	Steel slag for concrete perforated brick and concrete pavior brick	YB/T 4228-2010
Basic standard	19	Terminology for iron and steel slag & treatment and utilisation	YB/T 804-2009
Methodology standard	20	Test method for stability of steel slag	GB/T 24175-2009
	21	Methods for chemical analysis of steel slag	YB/T 140-2009
	22	Method for the determination of content of magnetic metallic iron in steel slag	YB/T 4188-2009
	23	Methods for the determination of total iron content in steel slag	YB/T 148-2009
	24	Test method for grindability of smelting slag	YB/T 4186-2009
	25	Method for the determination of particle size of smelting slag by using powder laser diffraction	YB/T 4183-2009
	26	Method for estimation of the metal content in stainless steel slag	YB/T 4227-2010
Technical specification	27	Technical specification for iron and steel slag concrete application	Under working
	28	Code for construction of the mass concrete	GB 50496-2009
	29	Technical specification for the construction of steel slag mixture used as base course	YB/T 4184-2009
	30	Technical specification of the tailings mortar	YB/T 4185-2009

Current development and fundamental research activities

- Even though a certain part of ironmaking and steelmaking slags could be valorised as resources, the sensible heat in all kinds of molten slags was not recovered.
- The waste sensible heat of the molten BF slag at 1500° C and that of the molten steel slag at 1550 ° C reached respectively 18.5 and 5.1 kgCE per tonne of steel production.
- Based on the industrial Data, the total waste heat energy of Chinese steel industry to be 243.8 kgCE (kilogram of coal equivalent) per tonne of steel production. The recovery ratio was less than 15.1%.

Current development and fundamental research activities

- Furthermore, the recovery ratio of sensible heat for the molten BF slags was only 2.16% and that for steel slag was zero.
- A simple estimation shows 2.7×10^8 GJ heat energy, i.e. 9.2 million tonne CE (coal equivalent) was wasted in 2010 by BF slag in China.
- The energy consumption ratio of steel industry is about 10 to 15% of the total energy consumption in China. Therefore, the heat recovery of the BF slag is of significant importance for energy saving and emission reduction of Chinese steel industry.

Current development and fundamental research activities

- The current widely used process for BF slag treatment is the water granulation method, such as INBA which can obtain vitreous slag product as cement chamotte. This method shows high added value and environmental benefit.
- However, the water granulation transforms the high temperature sensible heat in the molten BF slag into the low temperature heat of the granulating water. The high quality heat in molten BF slag cannot be well utilised.

Current development and fundamental research activities

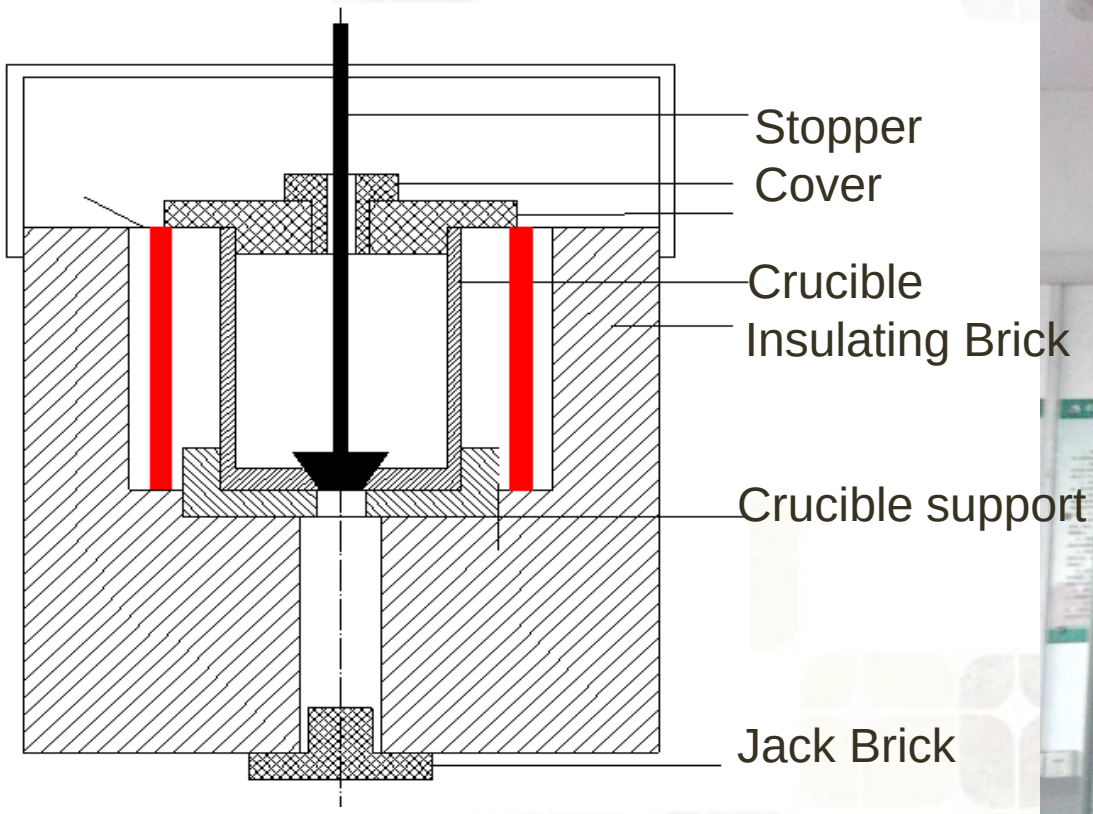
- The problem of heat recovery from molten slag is the lower exergy (Availability or Work Potential)recovery efficiency.
- Most of the heat recovery efficiency in various industrial scale tests was higher than 60%, even to 80%, but the exergy recovery efficiency was only about 40%.
- To realise the commercial operation of heat recovery from molten slag, the exergy recovery efficiency must be improved.
- The key issue is to recover heat in a closed system with simultaneously the valorisation of the slag products.

Current development and fundamental research activities

- Recently, Chinese researchers are interested in using the Rotary Cup atomisation process to recover heat from BF slag.
- Several projects have been conducted respectively by the Central Iron and Steel Research Institute (CISRI), Shougang Group, Ansteel, Northeastern University, Qingdao University, Chongqing University and Wuhan University of Science and Technology.

Current development and fundamental research activities

Fundamental woks in Wuhan University of Sci. and Tech.



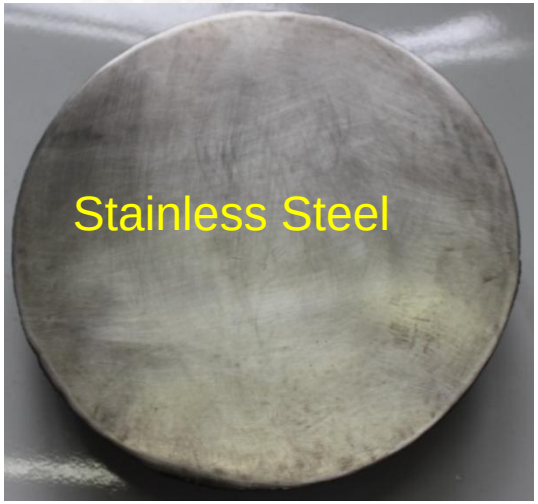
Furnace for Slag remelting

Current development and fundamental research activities

5 kg Rotary Cup atomisation unit for molten BF slag dry granulation experiments

Current development and fundamental research activities

- Discs



Current development and fundamental research activities

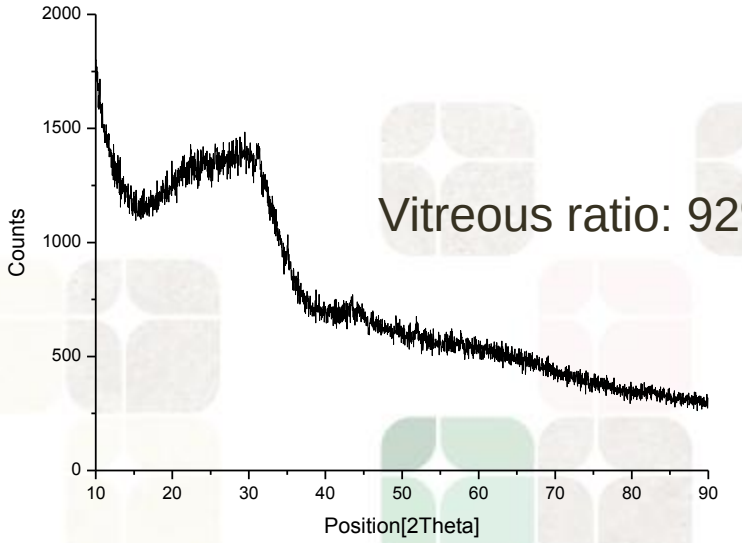
- Layout of experimental equipments

Current development and fundamental research activities

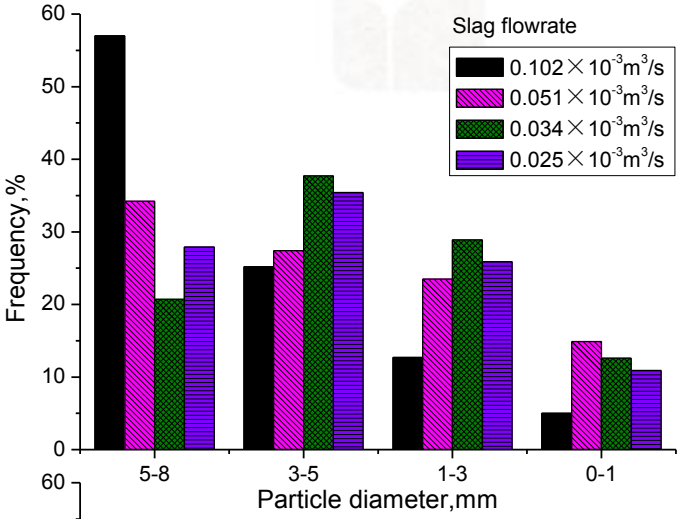
（a）0~2mm

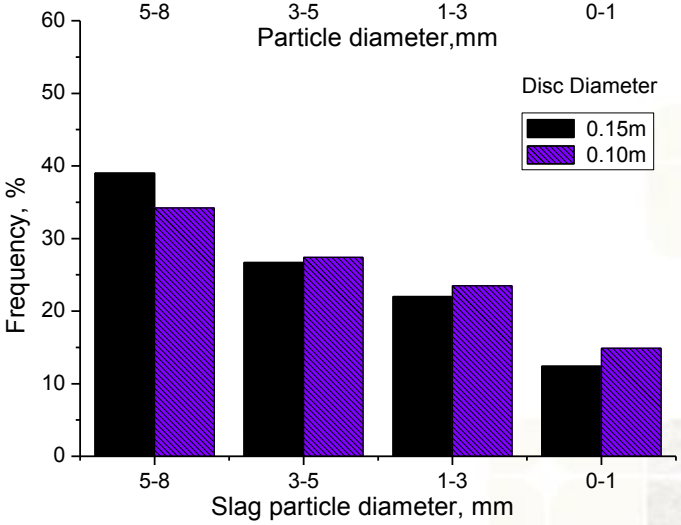
（b）2~5mm

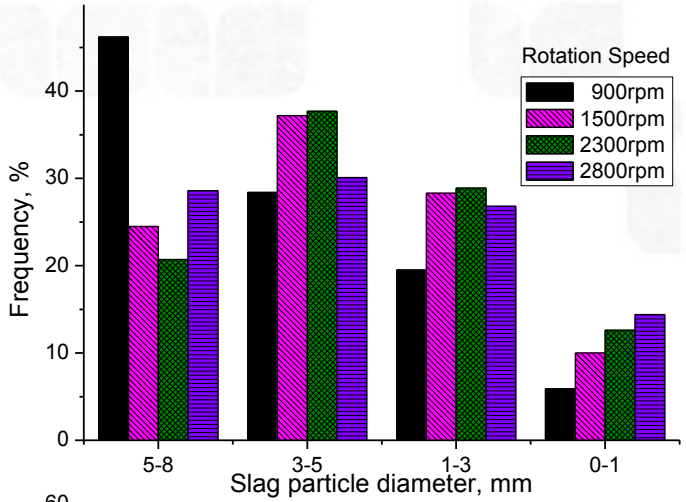
（c）5~8mm

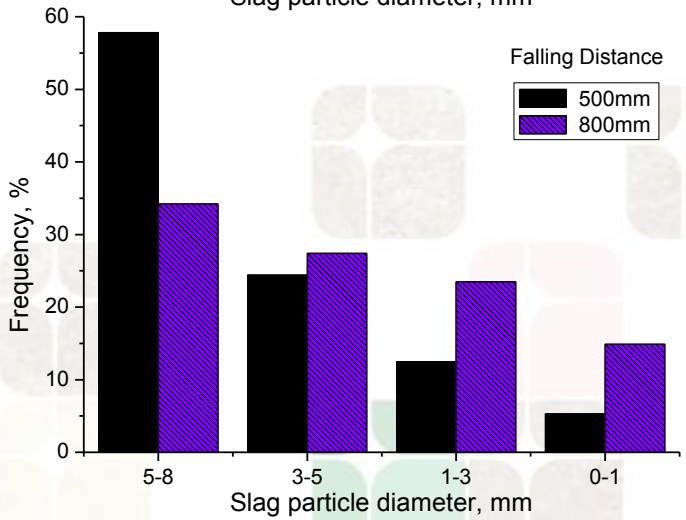


Current development and fundamental research activities



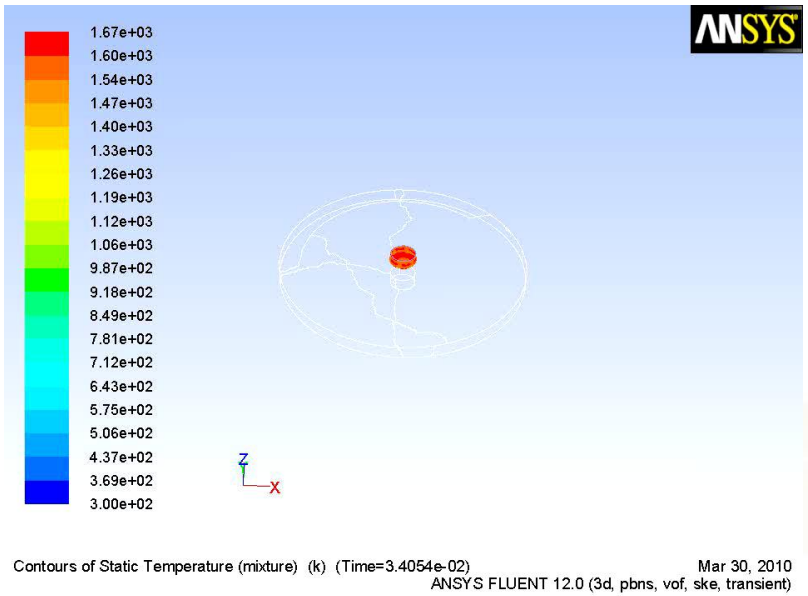


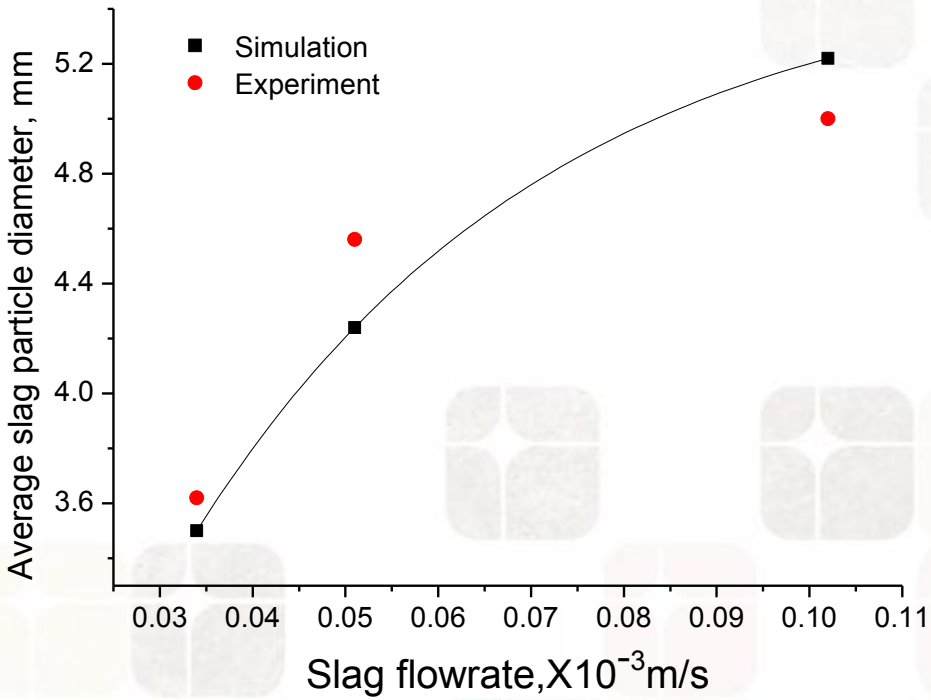




Current development and fundamental research activities

Mathematical Simulation with FLUENT





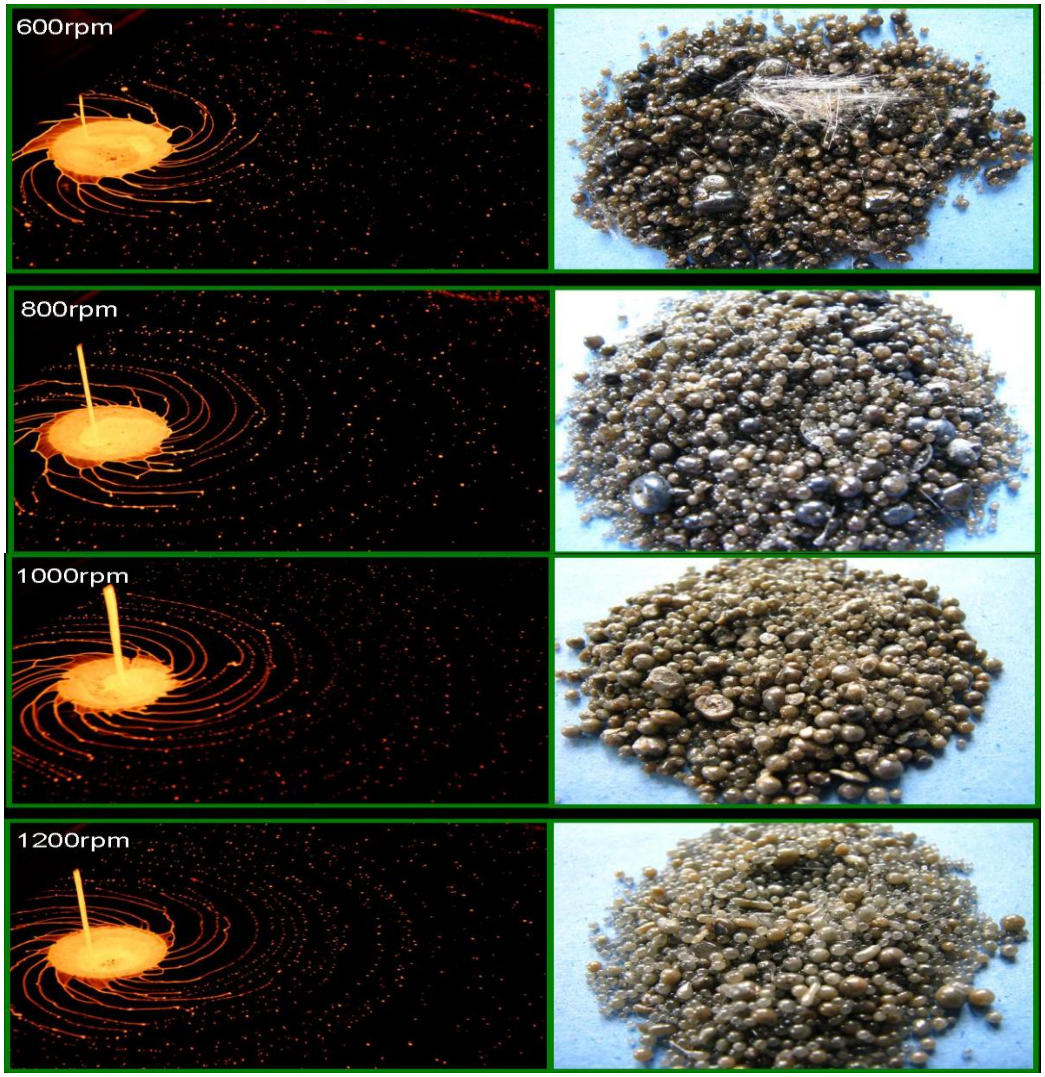
Current development and fundamental research activities

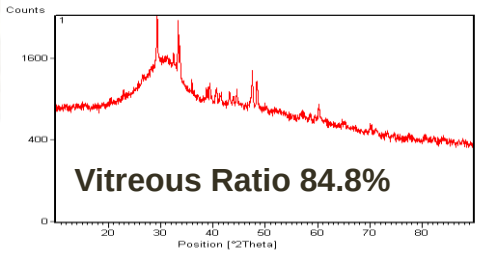
- The experimental results show that the best disc material was graphite and the most suitable rotation speed was in the range of 1500 to 2300 rpm;
- the vitreous content of granulated slag was more than 88%, which was comparable to that of water granulated BF slag.
- The higher the molten slag temperature and the rougher the surface of the rotation disc, the better the results in the slag wool formation. The slag composition has also influence on the slag wool formation.

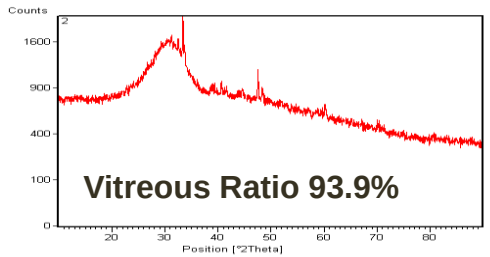
Current development and fundamental research activities

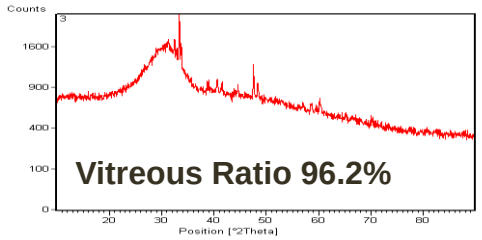
- Based on model simulations and laboratory experiments, the SKLP (State Key Laboratory of Advanced Steel Process and Products of the CISRI in China) developed a Dry Slag Granulation Technology.

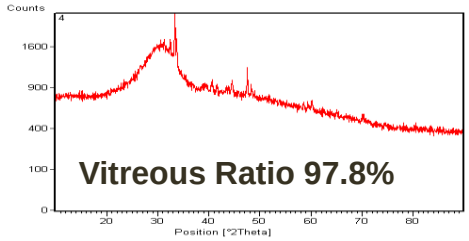
Current development and fundamental research activities

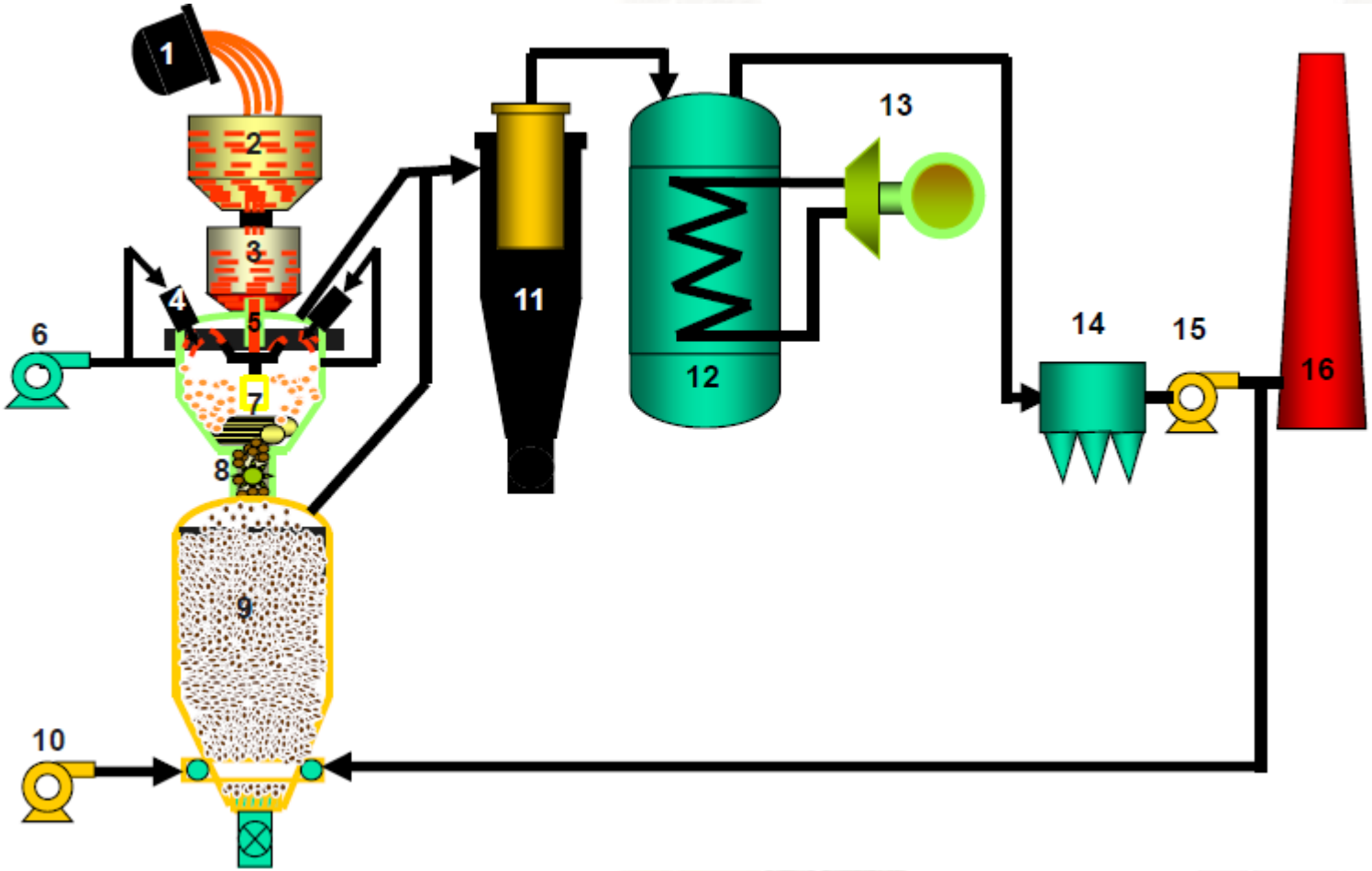












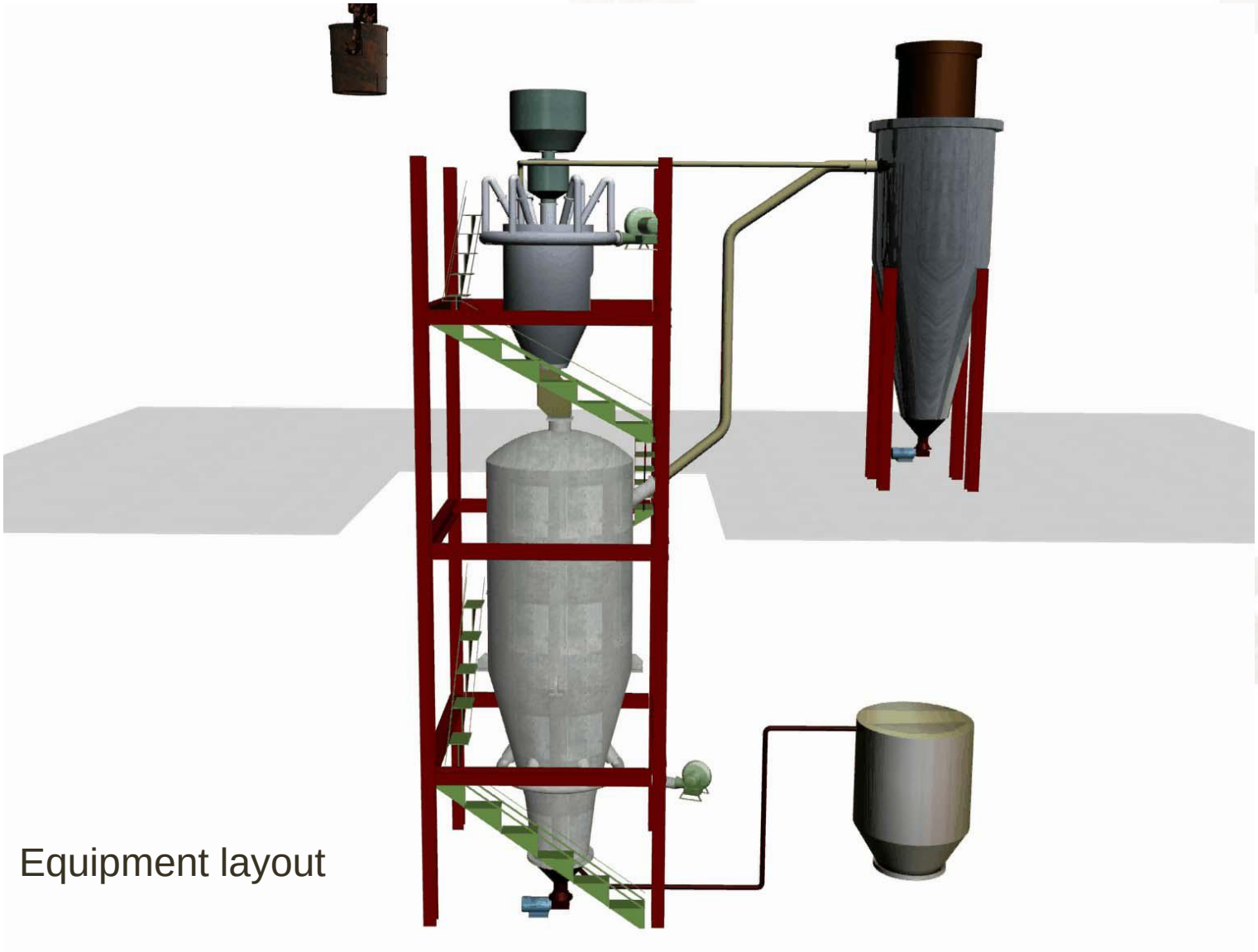
(1) Slag pot, (2) Slag tank, (3) Slag tundish, (4) High speed jet, (5) Nozzle, (6) Primary cooling blower, (7) Roller crusher, (8) Star discharger, (9) Vertical fluid bed, (10) Secondary cooling blower, (11) Hot cyclone dust collector, (12) Boiler, (13) Power generator, (14) refined dust cleaner, (15) Chimney

Process flowsheet of BF slag dry granulation and heat recovery developed by the Central Iron and Steel Research Institute (CISRI), China

Current development and fundamental research activities

- The size of the slag tank was 1 meter in diameter and 1.3 meter in height with a volume of 1 m^3. The slag tundish size was 0.56 meter in diameter and 1.5 meter in height with a volume of 0.05 m^3. The inner diameter of the slag outlet nozzle (in the bottom of the slag tundish) was 30 mm.
- During the test, the slag tank and tundish were heated to a constant temperature. The diameter of the steel rotary cup was 250 mm and the rotating power of the rotary cup was 1.5 kW. The diameter of steel rollers was 150 mm, and the rotating power of roller was 2.2 kW. Rotary cup and rollers were inner cooled by water.

Current development and fundamental research activities

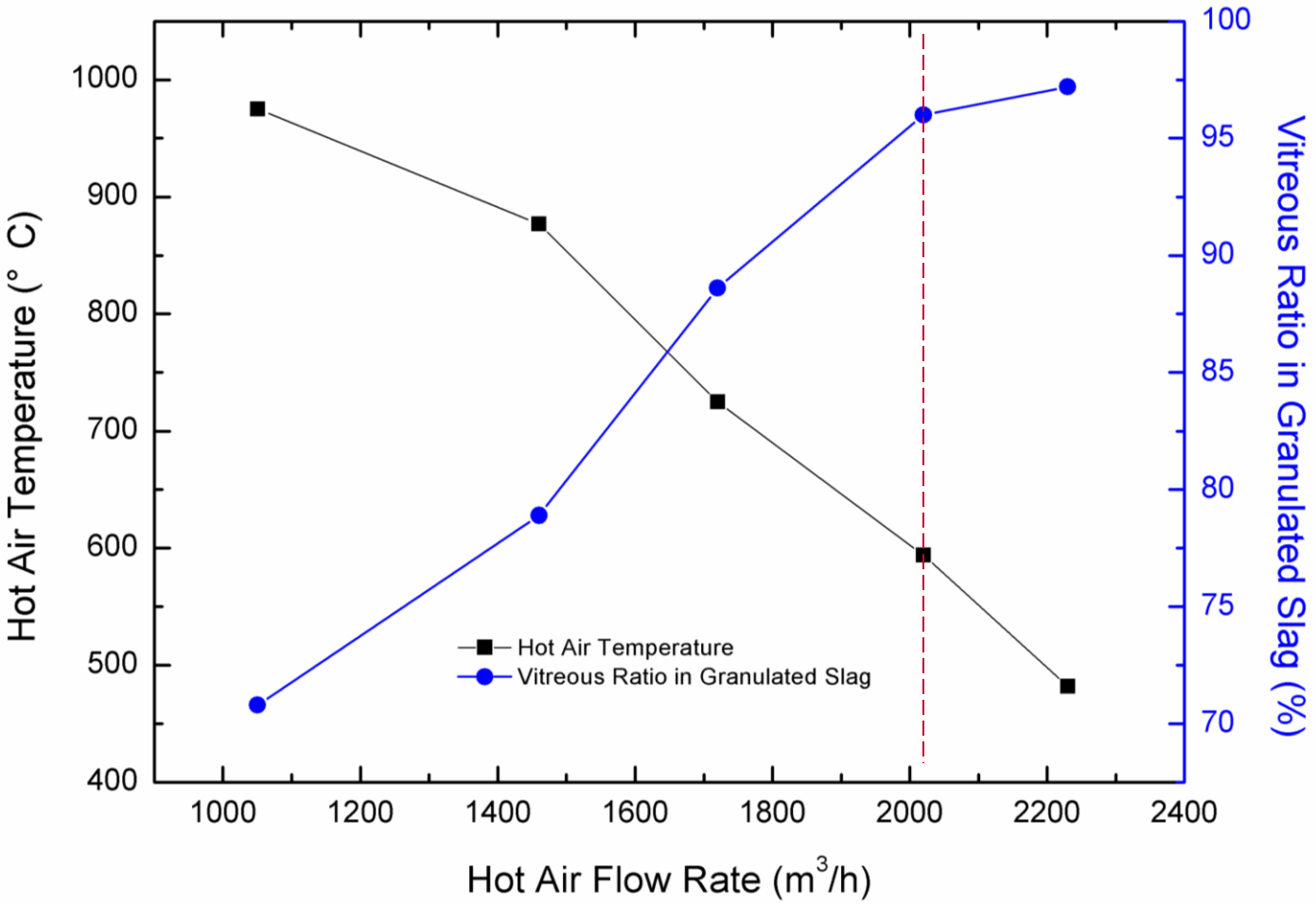


Equipment layout

Current development and fundamental research activities

- The BF slag quantity treated was 1.2 tonne;
- The line speed of slag flow was 0.2m/s; slag flowed 1 hour in the experiment.
- 2020 m^3 hot air with temperature of 594° C was recovered from 1.2 tonne molten slag theoretically containing 2.1 GJ heat. The recovered heat was 1.6 GJ and the electricity consumed in this process was 38.5 MJ, accounting for 2.4% of the recovered heat. The heat recovery efficiency by the heat exchange between molten slag and cooling air was 77%.

Current development and fundamental research activities



Figure：The recovered hot air temperature and vitreous ratio of the granulated BF slag as a function of the air flow rate in the experiment.

Current development and fundamental research activities

- About 96% vitreous components in the dry granulated BF slag could be obtained when the cooling air flow rate was higher than 2200 m^3 per hour. This is similar to the level of water granulated BF slag.
- The maximum particle size of the dry granulated BF slag was 3.1 mm.
- Further studies, however, are needed concerning to the issues of slag crusting and heterogeneous size distribution, and to the phenomenon of glass wool formation in the process.

Conclusions

- The slag valorisation in China improved gradually during the recent past years. This was not only in quantity but also in quality, thereby increasing the economical and environmental benefits.
- The hot stage processing processes with respect to BF slag granulation and steel slag pyrolytic self-slaking have made progress and are applied in a number of large steelmaking companies in China.
- The fundamental researches and process developments are mainly focusing on the dry granulation of molten BF slag with both heat recovery and improvement of the slag product quality.


Thank you for your attention!