MAGMA Smelting Unit for coke-free production of cast iron, using iron ore fines & Indian / Indonesian thermal coal

INTRODUCTION –

MAGMA is a cost–effective continuous melting unit that can process & convert any grade of iron ore & any grade of coal into cast iron & steel, using waste-free & environmentally clean technologies. The multi-purpose smelting unit MAGMA is primarily intended for efficient processing of ores & energy carriers.

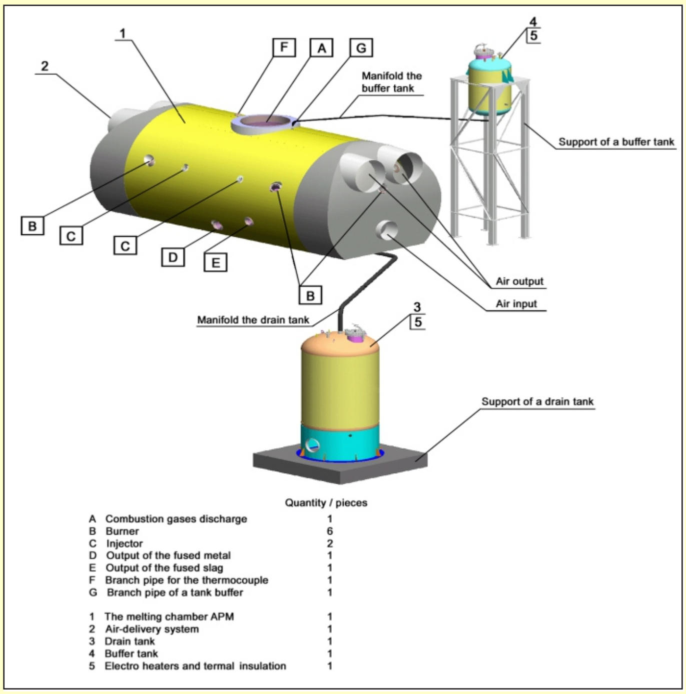
The main modules of the unit are the smelting chamber & its original cooling system. The other components of the unit are driers, heaters, charge feeders, feeders of additives to the molten metal, the release system of smelting products i.e., slag & metal, the process automated control system, the system for purification & use of off gases for thermal power– these are all selected depending on the application purpose of MAGMA.

MAGMA Smelter can be used for coke-free production of cast iron & steel in mini steel plants (up to 1 million tons per year) that do not require high expenses for the preparation of iron ore & coal.

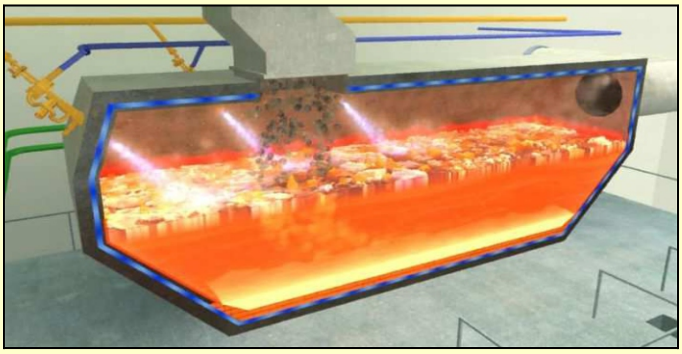
Natural gas or thermal coal is used as fuel; they are burned in oxygen. This engineering solution allows reaching high temperatures up to 1,900°C in the working space of the smelting chamber of the unit and up to 1,650°C in the molten slag zone.

MAGMA produces cast Iron from iron ore by the method of liquid-phase reduction of iron. Coal is used as a fuel & reducing agent of iron in the ore. Limestone is used a flux. For combustion of coal, gaseous oxygen is blown into the working space of the smelting chamber by water-cooled lances with Laval nozzles. The reduced iron is carbonized & settles down from the ore-limestone melt into the metal bath. Gases generated in the working space of the smelting chamber, as a result of oxidation (burning) of coal & reduction of iron from the ore-limestone melt, come to the pre-heater of the charge materials. From the pre-heater, gases are sent to the power boiler at 950-1,000°C, which further go to the gas treatment facilities.

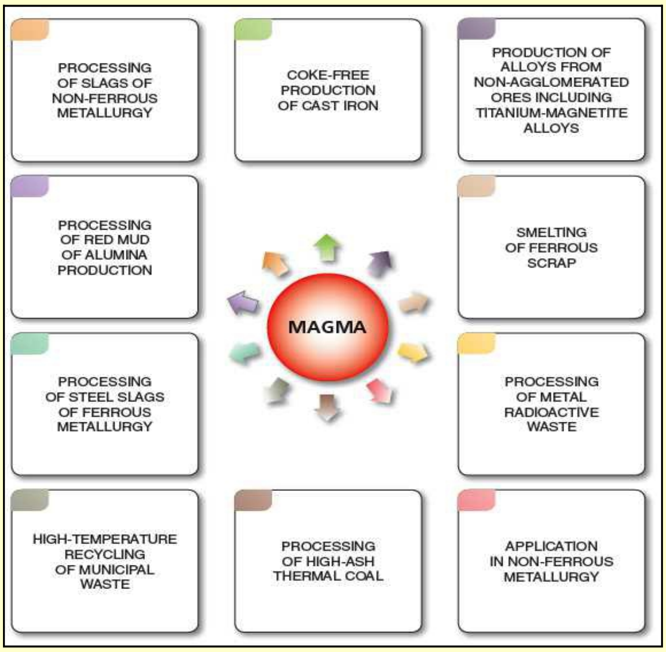
Schematic view of the MAGMA unit



Isometric view of the working of MAGMA unit



APPLICATIONS OF MAGMA



COMPANY PROFILE –

Industrial company "Technologiya Metallov", Russia, is an engineering company that develops and implements innovative technologies of environmentally clean and waste-free processing. The company offers MAGMA technology to the Russian and international markets.

Technologiya Metallov co-operates with leading scientific research and design bureaus of Russia for modern designs of MAGMA smelting units.

MAGMA will comply with all the requirements of metallurgical equipment, and its warrantee period is 2 years from the date of commercial production.

The MAGMA project successfully passed expert review at the Urals Institute of Metals, the validation authority at Ekaterinburg, Russia and at the National University of Science & Technology (MISIS), Russia (the creators of Romelt).

Assembly design of MAGMA and the created technologies for its application are protected by both Russian and international patents.

Main Partners for MAGMA Project –

- Technologiya Metallov LLC – owner and leader of the project;
- A.I. Leipunsky Institute of Physics and Power Engineering - justification of innovative cooling method (creators of the world's first nuclear power plant in 1954; developers of more than 120 nuclear reactor systems; creators of the world's first fast breeder nuclear reactor in 1973) ;
- South Ural State University – theoretical and practical justification of technology;
- Gidropress Science & Production Company – MAGMA unit engineering (designers of fast breeder nuclear reactors in Russia);
- CKBA Research and Production Company – engineering of cooling system (manufacturers of cooling systems for nuclear reactors & nuclear submarines in Russia);
- Akont group of Companies – engineering of other equipments (manufacturers of electric arc furnace, ladle furnace & ferro alloy furnace in Russia).

Elements of Technologies used in MAGMA –

Technology	Common usage
Liquid phase iron reduction	Electric arc furnace, Romelt technology
Kish formation on the walls of body/housing	Electric arc furnace with water cooling, Vanukov furnace, Ferro alloy furnace
Fuel-oxygen burners	Modern iron - melting Electric arc furnace
Liquid-metal coolant	Nuclear-power industry (fast neutron power reactor, submarine power reactor)
Pre-heating of charge with waste gas	Electric arc furnace with pit pre - heater, Consteel furnace, Pit melting unit

Adoptability of MAGMA in Indian Iron & Steel Industry

1) MAGMA in Pellet Plants – Red hot pellets can be charged into MAGMA along with Indonesian / Indian coal to make pig iron. Off gases coming out of MAGMA at high temperatures can be used in the pellet plant, thus making the best use of available facilities.

2) MAGMA in Sponge Iron Kilns – Rotary kiln-based sponge iron plants are not able to get high grades of lumpy ores at present & many of them stopped operations. MAGMA can convert the sponge iron plants into pig iron plants, for using low grades of iron ore fines & cheaper Indonesian / Indian thermal coal to make pig iron.

3) MAGMA in Beneficiation Plants – The tailings of the iron ore beneficiation plants (containing 40-50% Fe) can be directly used in MAGMA to make pig iron. In coal beneficiation plants, MAGMA can use the waste coal (middlings & rejects).

4) MAGMA in Blast Furnaces & Steel Mills - MAGMA can convert the blast furnace dust, electric arc furnace dust, breeze coke, billet scale & rolling mill scales into pig iron & slag products.

5) MAGMA in Electric Arc Furnace/Converter Plants– MAGMA can re-melt the oxidized slag from electric arc furnace / converter, to recover the Fe from FeO (oxidized slag has 24-30% FeO) and to convert the remaining slag into clinker, for cement making.

MAGMA PROCESS FOR COKE-FREE PRODUCTION OF CAST IRON –

In MAGMA process, the charge (non-agglomerated iron ore & lime stone) is preliminarily heated by off-gases of the smelting chamber in a rotary kiln to a temperature of 900-1,000^{0}C. At such temperatures, partial de-carbonization of lime stone & partial reduction of iron oxides take place. The heated charge is subsequently fed into the surface of the molten mass of MAGMA unit for smelting & reduction of iron oxides into iron in the liquid bath.

Coal required for reduction of iron oxides & for adjustment of carbon content in cast iron is fed into the smelting chamber on the surface of the ore & lime molten mass and also additionally injected inside by the injectors.

These injectors are located in the body of the smelting chamber at the level of the upper limit of the molten metal mass, that is formed as a result of reduction of iron contained in the slag.

The dust captured by the gas treatment system is recuperated by injectors of the smelting chamber into the molten slag. Heat, which is necessary for smelting the charge, heating the molten mass, endothermic reactions of reduction of metal oxides and compensation of thermal losses of the unit, is generated by gas-oxygen burners or by oxidizing of coal fed into the working space of MAGMA with oxygen burners.

An original primary cooling system design of the smelting chamber uses a liquid-metal (liquid-sodium) heat carrier for cooling and maintaining the temperature of the body of smelting chamber to less than 500°C. The secondary cooling system is made by cool air or nitrogen.

Under such conditions, a skull is formed in the free space and in the molten slag zone on the working surface of the smelting chamber & this skull is used instead of conventional refractories. The molten metal zone (bottom of the smelting chamber) is lined with refractories that are cooled through the body by the liquid-metal coolant, which ensures high resistance and high service life of refractory.

As a result, MAGMA can operate for a long time without interruption for maintenance.

Liquid Sodium cooling in MAGMA

Sodium is a metal, with a melting temperature of 98^{0} C & a boiling temperature of 883^{0}C. Liquid sodium cooling system in MAGMA is not a copy of nuclear reactor cooling; but there is a common principle of intensive heat removal. In MAGMA process, heat is removed in the following way –

- Heat from the working space is transferred through the layer of skull on the working surface of the body wall, which as a result of cooling, has a temperature of 500^{0}C;
- Then the heat is transferred through the body wall to the liquid-metal coolant, i.e., sodium, which fills in the cavity. Temperature of sodium at the internal surface of the working wall is around 450^{0}C;
- Heat is then supplied through the liquid-metal coolant to the internal surface of the second body wall & further through this wall to its external surface, which is in contact with gas coolant (air or nitrogen) ; &
- Due to the high speed of movement & high flow of gas coolant, temperature of the external surface of the second body wall is maintained at 300^{0}-350^{0}C.

Advantages of liquid sodium cooling –

- The heat transfer co-efficiency of liquid sodium is about 90 times higher than water;
- There is no need to circulate liquid sodium at high pressures, as in water. There is nearly no loss in circulation;
- Compatibility with traditional structural materials;
- Corrosion inertness;
- Excellent thermo-hydraulic characteristics, assuring effective heat removal;
- Safety of application under any possibility of thermal interaction with molten metal;
- Sodium is relatively cheap & its resource is vast.

Liquid sodium cooling is the proprietary technology of Russia, which is proven in the nuclear reactors & nuclear submarines for the last 30 years.

Metal and slag are released from the smelting chamber of the MAGMA unit continuously or non-continuously, depending on the design of further processing equipment for production of final products.

The heat of the off-gases from the smelting chamber can be used in a boiler unit for generation of electric power or for preliminary heating up of the charge fed to the unit. Process gases are treated by modern gas purification systems.

Principal specifications of a large - size MAGMA

Thermal power, MW	70 to 140
Fuel types	natural gas or thermal coal
Oxidizing agent	technical oxygen (95% O_2)
Metal temperature in liquid bath, °C	1,350-1,600
Temperature of molten slag, °C	1,400-1,650
Temperature of gas phase in the free space (above molten slag), °C	1,800-1,900
Smelting chamber dimensions:	
outside diameter, m	4
length, m	9
Smelting chamber steel	Stainless alloy steel
Cooling of smelting chamber body	liquid-metal coolant
Bath lining	periclase-carbonaceous or high alumina bricks
Lining in slag zone of smelting chamber	slag skull

The temperature of molten slag in the smelting chamber is 1,400-1,650^{0}C. This allows adjusting the composition of the slag being smelted, by adding fluxes.

Slag produced in the MAGMA chamber can be treated in several ways:

a. Crushed to produce break stone (the cheapest solution);

b. Granulated;

c. Used for production of slag molds (this solution requires additional space for installation of teeming conveyor, casting molds and heat-treatment furnaces for slow cooling of molds);

d. Used for the production of rock wool fibre mats & boards (molten lava can be directly poured into a centrifugal machine to draw rock wool or mineral wool fibres, which can be subsequently formed into mats, boards or sandwich panels).

If slag is used for the production of cast-slag crushed stones, their quality is not inferior to natural granite-crushed stones.

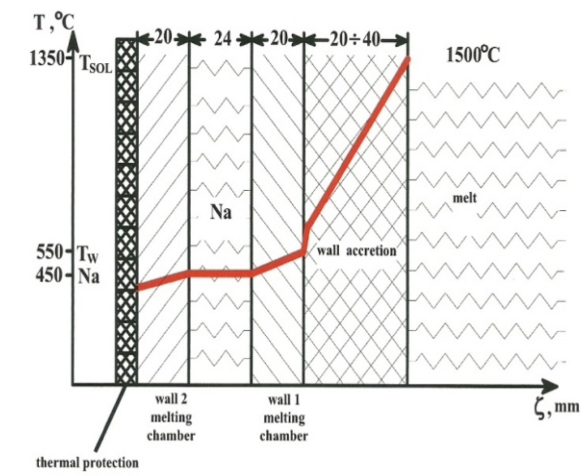
Application of MAGMA is based on environmentally clean waste-free technologies. Capital costs for implementation of technologies using MAGMA are lower than the capital costs of existing plants that produce similar products.

DINCOR-CODES

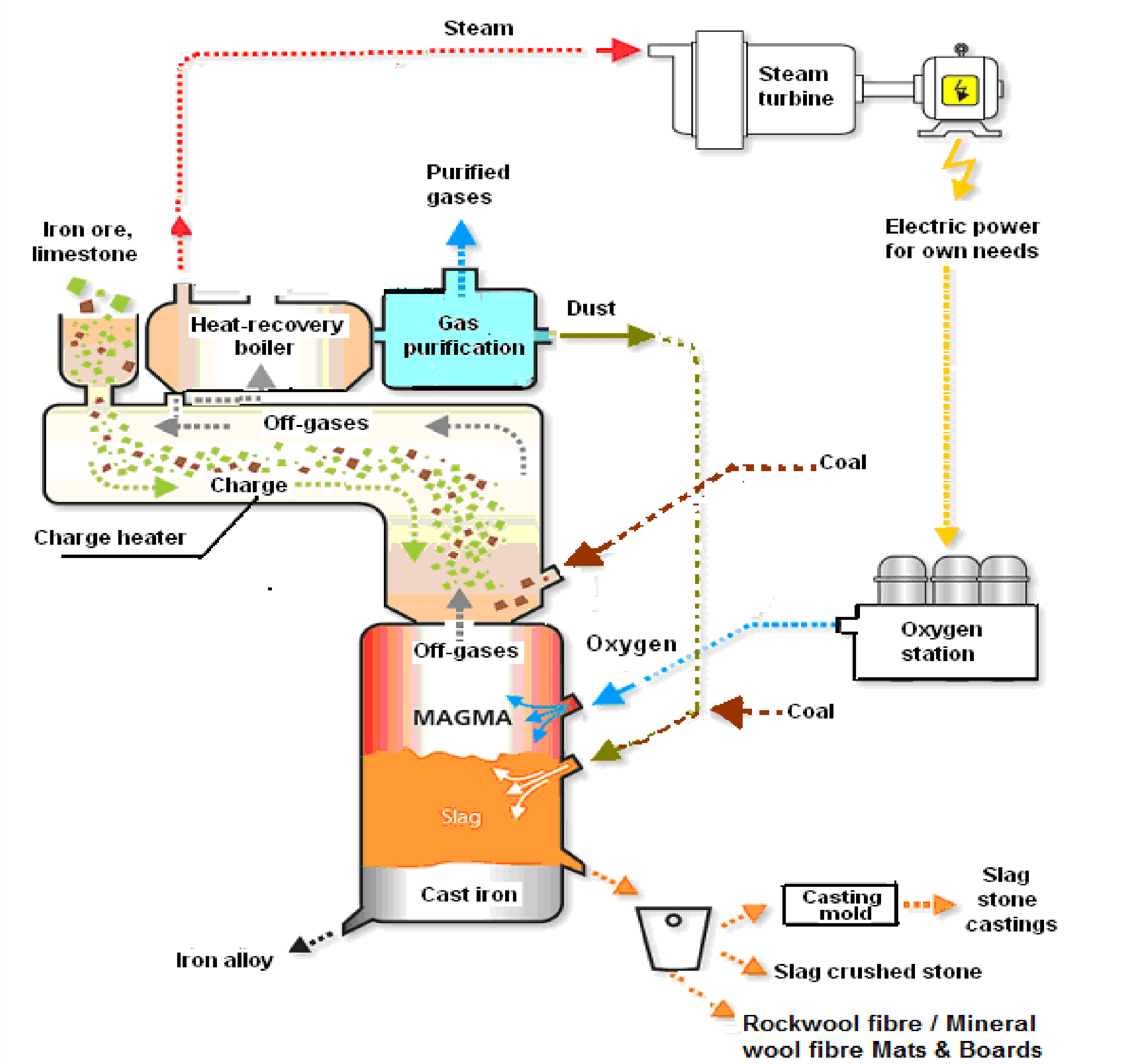
All calculations of the MAGMA unit and processes (physical-chemical, thermo physical and hydrodynamic) taking place in it, are made by means of special mathematical models and the DINCOR-Codes model in particular, assigned for numerical solution of non-stationery two dimension equations of hydrodynamics and heat transfer of in-compressible multi-component medium, taking into account the processes of components' melting/hardening due to heat-transfer processes.

The DINCOR-Codes were appropriately modified and then applied for calculation of thermal-hydraulic processes taking place in the MAGMA unit, particularly for defining time, place and size of the generating skull, space materials distribution, slag, metal and gas phases in the melting chamber, their quantity and temperature. DINCOR-Codes are used in Nuclear Physics & the results of some calculations are presented below –

Temperature distribution near the wall of melting chamber by the normal to the surface



Flow diagram of MAGMA technology for coke-free production of cast iron



Reactions in MAGMA for liquid-phase reduction of iron ore

Reactions (Fe_2O_3) + 3C ® 2Fe + 3CO

and (Fe_3O_4) + 4C ® 3Fe + 4CO

(round brackets mean that iron oxide is in the slag)

The above are overall reactions and reflect the result of a complex multi-stage process of iron reduction. Back in the first half of the 20[th] century, it was found that reduction of Fe would run according to the following scheme:

Fe_2O_3®Fe_3O_4® FeO ® Fe

The most complex and energy-intensive is the final stage FeO ® Fe. It can run according to the following reactions-

(FeO)+C ® Fe+CO

(FeO)+[C] ® Fe+CO

Square brackets mean that C is in the metal.

(FeO) + CO ® Fe+CO_2 may be one of the stages of such process, but in this case it requires the reaction CO_2+C ® 2CO or CO_2+[C] ® 2CO.

What prevails in the overall process – reduction by C or reduction by CO, which depends on the type of the process and the design of the unit. For example, in the blast furnace process, reduction of Fe by CO prevails. In the liquid-phase reduction of Fe, both variants of Fe reduction can develop (MAGMA, Romelt).

When coal is used for the heating of the unit, all carbon of coal neither practically nor theoretically can be oxidized according to the scheme C+O_2 ® CO_2 that gives the biggest amount of heat and requires operation with excess of oxygen, because reducing conditions are required for the reduction of Fe, i.e. part of C must be oxidized to CO according to the scheme C+1/2O_2® CO that gives a far less amount of heat, but creates a reducing composition of the atmosphere of the working space. The entire CO is later burnt to CO_2 for the generation of additional heat outside MAGMA.

Typical Input-Output figures of MAGMA (for annual production, based on 300 days of working) –

	Parameters	Large MAGMA	Medium MAGMA	Small MAGMA
	Input -			
-	Iron ore fines of 0-10 mm size (Fe - 60%)	2,32,000 tons	1,16,000 tons	54,000 tons
-	Indonesian thermal coal of 0-50 mm size (GCV-6,000 kcal/kg)	1,39,100 tons	71,200 tons	33,500 tons
-	Lime stone of 0-50 mm size (CaO – 45 to 48%)	32,500 tons	16,300 tons	7,600 tons
-	Oxygen – 95% O_2	1,23,000 tons (602 Nm^3 per ton of cast iron)	63,000 tons (616 Nm^3 per ton of cast iron)	29,500 tons (621 Nm^3 per ton of cast iron)
	Output -			
-	Molten iron	1,44,000 tons	72,000 tons	33,500 tons
-	Slag	64,000 tons	32,000 tons	15,000 tons
-	Power generation after pre-heating the ore	14-15.5 MWh	7-8 MWh	3-4 MWh

Composition of cast iron (%) –		Composition of slag (%) –	
C	3.5 - 4.2	CaO	29 - 31
Mn	0.1 - 0.2	SiO_2	30 - 32
Si	0.05 - 0.10	MgO	2 - 5
Fe	95.4 - 96.3	Al_2O_3	20 - 25
		FeO	3 - 4
		Others (MnO, TiO_2, etc.)	remaining

Notes:

1. Sulphur-phosphorus in the cast iron can be reduced to acceptable levels by increasing the basicity of the slag and also by maintaining 3-5% FeO in the slag.

2. Technically, MAGMA can use any grade of iron ore & any grade of coal in the smelting chamber. However, it is desirable to use fairly good grades of iron ore & coal, as a matter of economics.

INVESTMENTS & PROFITABILITY ON MAGMA PROJECTS –

	Parameters	Large MAGMA	Medium MAGMA	Small MAGMA
-	Total charge capacity – tons per year (300 working days)	300,000	150,000	70,000
-	Pig iron production – tons per year (using 60% Fe grade iron ore & Indonesian coal)	144,000	72,000	33,500
-	Size of oxygen plant per hour (95% O_2)	12,000 Nm^3	6,200 Nm^3	2,900 Nm^3
-	Power generation potential	14-15.5 MWh	7-8 MWh	3-4 MWh
-	MAGMA price (1 USD = Rs. 63)	Rs. 60 crores	Rs. 47 crores	Rs. 30 crores
-	Estimated total investment including MAGMA unit, rotary kiln, oxygen plant, power plant & miscellaneous equipments in a green-field project	Rs. 250 crores	Rs. 150 crores	Rs. 75 crores
-	Cost of production of pig iron per ton	Rs. 13,500 – 15,000		
-	Pay-back periods - For making pig iron & crushed stones from the slag - For making pig iron & rock wool fibres, mats & boards from the slag	 2 – 3 years 1 – 2 years		
-	Total implementation period	24 months	21 months	18 months

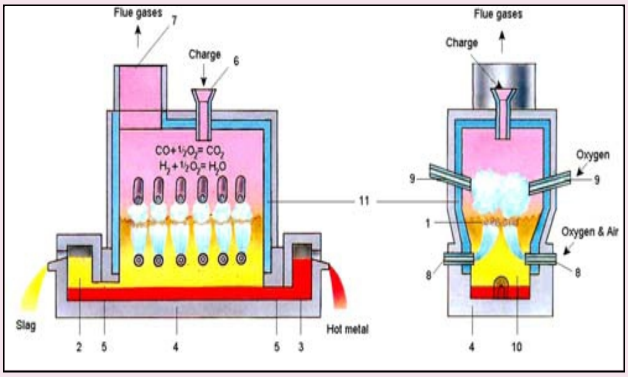
MAGMA – The Improved Romelt Process

MAGMA has obtained positive Technical review from the National University of Science & Technology (MISIS), Russia, where Romelt was developed.

The pilot-commercial plant of Romelt was built at the Novolipetsky Steel Works in Russia. During the years from 1985 to 1998, forty one campaigns were performed & more than 40,000 tons of cast iron were melted & used in the basic oxygen furnace for steel making.

The Romelt furnace under operation

Romelt process is the technique of continuous iron making from various iron-bearing materials, using inexpensive non-coking coal. The general diagrams of Romelt are given below–



The Romelt furnace scheme:
1.agitated slag, 2.sump for slag, 3.sump for hot metal, 4.hearth with refractory lining, 5.channels for slag and hot metal, 6.feed tunnel, 7.gas-escape branch pipe, 8.lower tuyeres, 9.upper tuyeres, 10.calm slag, 11.water-cooled panels.

MAGMA is the improved version of Romelt, retaining all its advantages & overcoming its limitations as under–

1) In Romelt, the melting bath is blown with oxygen-air mixture (in 100:40 ratio) from the lower tuyeres. Similarly, post combustion of CO, H_2 & coal volatiles is done by oxygen through the lower tuyeres to return the heat into the slag bath. The density of oxygen blowing from these two places and the absence of charge pre-heating in Romelt resulted in higher oxygen consumption of 700-800 Nm^3 per ton of molten metal.

   In MAGMA, liquid sodium maintains the wall temperatures at 450^0C & hence the energy requirements are lower. Oxygen injectors are provided from the top at high pressures, to reduce slag-foaming & to increase the heat intensity. As a result, oxygen consumption in MAGMA can be reduced to 500-600 Nm^3 per ton of molten metal.

2) In Romelt, the hearth, the lower part of the furnace bath & the bottom of the smelter are lined with refractory bricks. After the slag bath, walls are made of steel panels with water cooling.

   In Romelt, the formation of slag skull lining was observed, which is now scientifically calculated using DINCOR-Codes. Hence MAGMA does not use any refractory, except in the bottom. Sodium cooling also eliminates the need for water-cooled panels in MAGMA.

3) In Romelt, off- gases directly flow into the waste heat recovery boiler; in MAGMA, off gases are used for pre-heating & partial reduction of the charge. Subsequently, these gases enter the waste heat recovery boiler, where they are after-burned by the hot air available (at 300^0C) from the secondary cooling system of MAGMA unit.

4) Unlike in blast furnace, the slag basicity can be chosen both in Romelt & MAGMA and the sulphur-phosphorus can be reduced. Higher basicity makes the sulphur come into the slag, while higher content of FeO (3-5%) in the slag makes phosphorus come into the slag.

5) Experiments in Romelt have proven that volatile matter in the coal can participate in the reduction process. The same is applicable to MAGMA.

6) The estimated investment on 200,000 tons/year Romelt project was worked out as 100 million USD. Similar capacity of MAGMA needs an investment of only 60 million USD in India.

7) In Romelt process, there is no need to co-ordinate in terms of technology, power & operations of several units in multi-stage processes, which form an integral part of the traditional iron making plant. In Romelt, iron making operation can be a single process & in a single building. It was observed that there are no fundamental restrictions on the Romelt process & it can accept wide range of raw materials; limited only by economic factors. In Romelt, all the experiments were finished & the process was ready for commercial use.

MAGMA is the improved Romelt, in the following ways -

a) Use of liquid metal coolant;

b) Pre-heating of charge, to increase the unit capacity;

c) Lower oxygen & energy consumption, due to
   - Charge pre-heating by waste gases,
   - Rational scheme of oxygen input to the melt,
   - Sodium cooled body;

d) Lower overall investment;

e) Lower height of the smelter achieved through rational direction of high power oxygen jets to the melt, along with intense mixing of the melt;

f) More advanced metal & slag tapping equipments;

g) In Romelt, the walls are constructed with water-cooled copper panels above the slag bath & water-cooled steel parts in the slag bath, to reduce heat losses. They burn through quickly, despite high water consumption. The liquid-metal cooled body of MAGMA can operate for more than 7 years without overhaul.

h) The amount of dust generated during the operation of MAGMA is much less compared to Romelt (up to 1% of the weight of charge materials, as against 3% in Romelt), due to a more rational scheme of oxygen & charge input into the melt. Moreover, dust from MAGMA is injected back to the working space of the unit & there is no need for ground disposal. Hence, MAGMA conforms to the European Norms for environmental protection.

Advantages of MAGMA, as compared to Blast Furnace

1) Blast furnace needs high grades of lumpy iron ore / pellet, sinter feed and also coke as the energy carrier. MAGMA can use any grade & size of iron ore and also any grade & size of high-volatile coal. In MAGMA, coal + oxygen or natural gas + oxygen is used as the energy carrier. For this reason, the cost of production of pig iron is 30-50% lower in MAGMA, as compared to blast furnace.

2) Thermal efficiency of a large blast furnace is around 80%, as against 93-94% in MAGMA, when the heat from off gas is used for power generation. The overall thermal efficiency of the entire iron making process using blast furnace, pellet, sinter & coke making plants is less than 50%.

3) Blast furnace generates a lot of dust, creating problems for its disposal. In MAGMA, dust coming with the off-gases is collected in the de-dusting system & injected back into its chamber again, so that the entire plant becomes waste-free.

   Slag from the blast furnace is used for low-value construction materials. Slag from MAGMA can be converted into stone aggregates or mineral-cast products such as railway sleepers, cast pipes or heavy machine frames. It can also be used for the production of rock wool or mineral wool fibres, mats, boards or sandwich panels.

4) Possibility of power generation from MAGMA is much higher than blast furnace. MAGMA is a self-sufficient process of iron making.

5) Emissions of NOx are much lower in MAGMA when compared to blast furnace, as coal is burnt in oxygen. Emissions of CO_2 are also lower in MAGMA as it does not need iron ore preparation (such as pelletisation & sintering) and coke production.

6) Iron ore consumption is lower in MAGMA, for the following reasons –

   a) Blast furnace needs pellets / sinter feed from iron ore concentrates. A part of the iron ore is lost in the enrichment process. For example, Indian iron ore is predominantly Fe_2O_3 (hematite) & in the process of beneficiating the same from 55% Fe to 64% Fe, around 30% of the Fe is lost by way of tailings (in the form of associated limonite & goethite), which cannot be recovered by the hydro-metallurgical processes. In MAGMA, 50-55% Fe grade of iron ore can be directly used.

   b) A part of the iron ore is lost by way of dust from the pre-heating zone of the blast furnace. On the other hand, this dust is captured by the gas treatment system & put back into MAGMA. Some carbon is also carried over with the dust in the blast furnace.

   c) The coal requirement is lower in MAGMA, as Romelt has proven that even volatiles in the coal participate in the liquid-phase reduction process.

7) MAGMA is an environmentally clean & energy-efficient process when compared to the blast furnace & hence eligible for carbon credit.

8) Investments on blast furnace along with beneficiation, pelletisation, sintering & coke-making facilities are much higher, as compared to MAGMA.

9) Blast furnace can be used for making cast iron / pig iron only. MAGMA can be used for making cast iron / pig iron as a continuous unit and also for making steel, as a batch unit in place of the basic oxygen furnace. By using natural gas / pyrolysis gas + oxygen for melting, it can replace the induction furnace / electric arc furnace with many advantages.

10) Blast furnace occupies a larger area of land for creating facilities such as beneficiation, pelletisation, sintering & coke-making, which are environmentally pollutant processes & also need more water, air, power, thermal heat and labour. MAGMA is a single-step process for making pig iron & occupies a smaller area with less water, air, power, thermal heat & labour.

MAGMA can meet the objectives of the 21st Century, as a clean & efficient iron making process. GoodRich is authorized to promote MAGMA and its wide range of applications in India.

Manufacturer in Russia	Representative in India
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