RECYCLING OF IRON-CONTAINING WASTE OF METALLURGICAL WORKS IN THE COUNTRIES OF BLACK SEA ECONOMIC COOPERATION (BSEC)

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Abstract: *Some aspects of recycling of iron-containing waste products which are situated in territories of the countries of members BSEC are considered. The opportunity of their processing using Romelt technology with make of hot metal and by-products is shown. Technical and economic parameters of Romelt process on the example of recycling of Kremikovtzi Steel Work waste are calculated. Economic appeal of the project is shown.*

Keywords: IRON-CONTAINING WASTE, ROMELT PROCESS, HOT METAL, CAPITAL INVESTMENTS

1. Introduction

Mining and smelting industry is the source of large amounts of solid wastes which has a negative effect on the environment. Their ecological hazard is determined by many factors, above all, by their physical conditions and chemical composition. The most dangerous are dusts and sludges, because they are dissipated by wind during storage. Their particles being very fine favoures the leaching of some components. In this way ions of non-ferrous metals get into water and soil, thus poisoning them.

Many countries of BSEC and borders have a well developed metallurgical industry with a lot of enterprises who form iron-containing waste. The accumulated and current wastes of the metallurgical works are in Ukraine, Turkey, Russia, Hungary and others pollute the Black Sea pool. Even when works are stopped or are converted, waste will continue to occupy the areas and worsening ecological conditions.

Most of these waste products are stored, and only a small part of them is used. Increase of metallurgy production demands urgent solution of the ecological problem of the accumulated waste utilization. This is especially important as the mineral and ore recourses of the Earth are diminishing gradually, while the content of valuable components in waste often exceeds their contents in raw materials.

For example, zinc content is 3–7% in brass works slags and 6–10% in lead works slags. Dump slags contain copper, cobalt, nickel, and silver. But the most abundant component of all waste, including non-ferrous metallurgy slags and sludges, is iron. Iron oxides content in the red mud of the alumina production is up to 40–45% — the same as in high-grade iron ores. Iron content in non-ferrous metallurgy slags is 25% or more, and in dusts and sludges in ferrous metallurgy it may reach 60%; is exceeds iron content in crude ores. Hence, waste may be good "potential" raw materials for ferrous metallurgy. Taking into account enormous amounts of the accumulated waste, they may be named man-made mineral deposits.

The possibility of waste utilization depends on the availability of proper technologies, but cost efficiency and ecological prospects are also taken into account. Various metallurgical waste may be processed to recover their valuable components. However, their composition, different from that of usual raw materials, and their aggregative state do not allow to process waste in metallurgical units of today. There are still no industrial technologies that would allow large-scale processing of waste.

Complex utilization of many kinds of waste products demands creation of new processes, which satisfy the following requirements: processing of finely dispersed materials, iron reduction, and recovery of other valuable components. There is a need to avoid usage of shaft furnaces and coke because of high cost of coke and pollutant emissions in coke production. That is why smelting reduction processes, which do not use shaft furnace, are actively developing nowadays, including Romelt technology.

2 Romelt Process Description

Single-stage smelting reduction process for ironmaking has been developed at the National University of Science and Technology "MISIS" [1]. Later it was registered under trade mark "Romelt". To test the process feasibility a pilot commercial plant with the hearth area of 20 m^2 was built at the Novolipetsky Steel Works in Lipetsk (Russia). The photo of the plant in operation is given in Fig. 1. During 1985–1998 forty-one campaigns were performed, each of which included startup and slowdown, with full tapping of metal and slag from the furnace. More than 40 thousand tonnes of hot metal were melted and used further in BOF for steel melting.

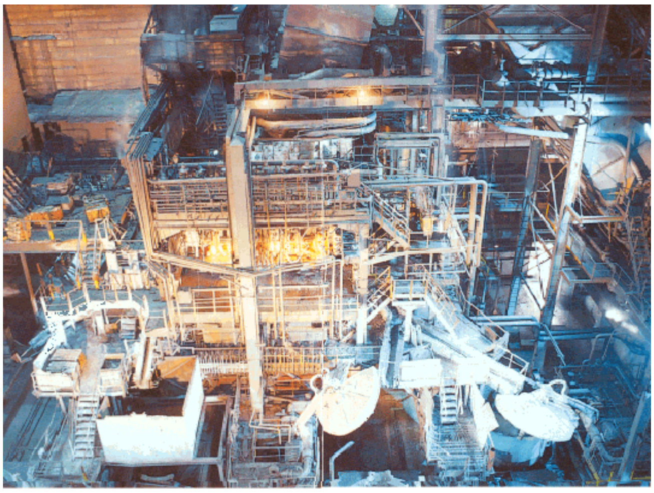

Fig. 1 *TheRomelt furnace under operation*

Romelt process is technique of continuous ironmaking from various iron-bearing materials using inexpensive noncoking coal. The general diagram of the Romelt furnace is shown in Fig. 2. Iron-containing materials, coal and flux, are fed, using weigh-hoppers, from relevant bins to the common conveyer. The charging into the furnace is performed through the aperture in the furnace roof. No preliminary mixing of charge materials is needed: it takes place directly in the slag bath due to its intensive agitating. The working space of the Romelt furnace is under negative pressure of 1 to 5 mm w.c. which is ensured by induced draft fan.

The bath of melting slag is blown with an oxygen-air (100–40%) mixture through the lower tuyeres positioned below the slag layer. The tuyeres have simple desine and proved to be reliable in operation. They ensure the required agitating power of the slag bath.

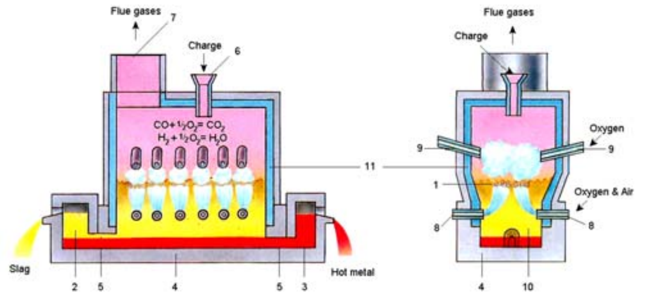

***Fig. 2** The Romelt furnace scheme: 1 - agitated slag, 2 - sump for slag, 3 - sump for hot metal, 4 - hearth with refractory lining, 5 - channels for slag and hot metal, 6 - feed tunnel, 7 - gas-escape branch pipe, 8 - lower tuyeres, 9 - upper tuyeres, 10 - calm slag, 11 - water-cooled panels*

Getting into the agitated slag that contains coal, iron-bearing materials are reduced. Iron produced by the reduction becomes enriched in carbon. Drops of melted metal precipitate under gravity on the furnace hearth. Thus, three melted layers are formed in the furnace: the layer of metal on the furnace hearth, the layer of calm slag between the metal and the lower tuyeres, and the layer of agitated slag (the reaction zone). Two lined siphon sumps are situated each at one of the end sides of the furnace. They are used for separate tapping of metal and slag. The sumps are connected with the working space by channels of different heights. This ensures separate transportation of metal and slag into the metal and slag sumps. There are holes for tapping metal and slag, which are located at different heights. That ensures continuous free tapping of the melting products at the speed that matches the unit capacity. If the furnace has little capacity tapping may be arranged periodically.

In the slag bath the heat expense on melting and reduction of the burden materials is greater than the heat received from the burning of carbon into CO near the lower tuyeres. Thus, the main peculiarity of the process is the post-combustion of CO, H_2 and coal-volatile matter evolving from the bath by the oxygen blown through the upper tuyeres. Post-combustion of gas up to CO_2 and H_2O allows to return the heat into the slag bath and to maintain processing of raw materials.

The hearth and the lower part of the furnace bath, which contains permanently metal and calm slag, are lined with refractory bricks. In this zone the refractory lining is under favorable conditions: at the suitable temperature and out of the oxidizing effect of the atmosphere. In the zone of agitated slag the furnace walls are constructed of copper water-cooled panels. Formation of the slag scull lining on them reduces the heat losses and rules out their wear. That allows to avoid destruction of the lining in the places of the most aggressive attack of gas-slag-metal emulsion. Above the slag bath walls are made of steel panels with water cooling.

After post-combustion gases flow through the water-cooled gas-eskape branch pipe at a temperature up to 1700^0C into the waste-heat boiler for steam generation. There they are burned completely with natural air inflow and cool to $250–300^0$C. Off gases are transferred to the gas-cleaning system and discharged into the atmosphere through the chimney. Steam with power standard is received on heat recovery power station for electricity generation. Thus, Romelt furnace not only metallurgical, but also energy-production unit.

3. Pilot-industrial trials

The Romelt process extends significantly the capabilities of the direct usage of wastes. During the operation of the Romelt unit significant experience of processing various materials (Table 1), including ecologically dangerous, while being in storage fine grained and dusty sludges, was obtained [2]. Hot metal for using in BOF steelmaking was melted from all kinds of waste.

***Table 1:** Iron-bearing materials composition (wt.%)*

Component	Iron Ore	Blast and BOF Dust Mixture	BOF Dust	Mill Scale	Scale from the Billet Continuous Casting	Lead-and-Zinc Works Slag	Vanadium Sludge
Fe_{tot}	58-59	51-56	60-64	71.2	81	24.0	25-30
Fe_{mel}	-	<3	<1	1.6	42.7	–	–
FeO	11.6-12.0	30-43	41-43	33.3	35.9	29	–
Fe_2O_3	71.0 - 72.5	26-37	40-42	62.5	14.7	2.1	–
SiO_2	4.5 - 4.7	4-5	1.4-1.5	1.5	2.4	32.9	16-20
Al_2O_3	2.5 - 2.7	1-1.5	0.1-0.3	0.2	0.7	11.45	2.5-3.5
CaO	2.0 - 2.1	8-10	8.5-9	0.2	2.2	5.31	7-9
MgO	0.3 - 0.35	1.2-2.2	0.7-0.9	0.69	0.47	3.69	1.5-2.5
MnO	0.06 - 0.07	0.1-0.4	0.6	–	–	–	5-7
TiO_2	0.14 - 0.15	0.07	0.03	–	0.04	0.41	6-9
K_2O	0.07 - 0.08	0.1	0.16	–	–	1.08	–
Na_2O	0.03 - 0.04	0.1-0.3	0.15-0.2	–	–	2.73	–
ZnO	0.1	1.6-2.5	0.9-2.5	0.01	–	7.63	–
PbO	-	0.4	0.2-0.4	0.01	–	0.85	–
Cu_2O	-	0.04	–	–	–	0.82	–
Cr_2O_3	-	–	–	–	–	–	2-5
V_2O_5	-	–	–	–	–	–	2-4.5
S	0.06 - 0.10	0.1-0.4	0.02-0.1	0.05	0.02	1.0	4-6
P_2O_5	0.11 - 0.12	0.2	0.1	0.01	0.03	0.28	–
As_2O_3	-	0.003	–	–	–	0.09	–
C	-	<2	1.2-1.6	–	0.25	–	–
Ag (g/t)	-	<10	–	–	–	18	–
Au (g/t)	-	-	-	-	-	0.57	-

As per the carbon content the hot metal from the Romelt furnace is similar to the one produced in the blast furnace. The distinctive feature of the hot metal produced by Romelt process is low content of silicon and manganese at the level not exceeding 0.1% due to the peculiarities of iron and additives reduction.

The slag produced during Romelt process differs from blast furnace slag in higher content of iron oxides and lower content of sulfur. For modification of slag basicity fluxes are utilized. The slag basicity is to be chosen for every particular kind of raw materials.

4. Application fields of Romelt technology

The Romelt process does not claim to be competitive with blast furnaces in the world hot metal production. But it can fill a definite niche in the metallurgical industry. Firstly, in the nearest future, the Romelt unit can be constructed at the integrated metallurgical works in addition to the blast furnaces, rather than in lieu of the same, first of all, for processing the iron-containing waste, generated at the works. This will allow to bring zinc and alkali metals out of a metallurgical cycle, with the respective saving of the coke rate.

Secondly, a smelting reduction unit, the Romelt furnace, for example, is more preferable in the structure of a mini-mill in its head part. Its liquid iron can be more economically used in converters or electric furnaces. The Romelt unit requires less capital investment. It produces cheaper hot metal, owing to the usage of low-grade iron ore and iron-containing waste in the burden, to the absence of need in pellets in the burden, to the application of coal without preparation and the complete lack of need in coke. For most mini-mills, capital investments on the construction of a blast furnace or of any other unit with a shaft are excessively high.

Now in Republic the Union of Myanma the plant is under construction which will produced 200 thou. tonnes of pig-iron per one year using Romelt technology (Fig. 3). Pig-iron will be used at a mini-mils making steel and rolling. Local low-grade quality ore and brown coal will be used for melt of pig-iron.

Fig. 3 *General view on the site of the Romelt plant in Myanmar*

5. Processing of steel waste of Kremikovtzi Steel Works

The significant amount of iron-containing steel waste of the following composition (Table 2) is accumulated at Kremikovtzi Steel Works. We offer to use the Romelt technology for their processing. For this purpose it is necessary to construct a complex consisting of Romelt shop, and additional shops & units, serving it.

Table 2: *Kremikovtzi steel waste composition (wt.%)*

Fe_{tot}	70.23
Fe_{mel}	40.71
FeO	20.39
Fe_2O_3	19.50
SiO_2	5.80
Al_2O_3	1.71
CaO	5.79
MgO	0.51
MnO	1.54
TiO_2	0.317
K_2O	0.149
Na_2O	0.217
ZnO	0.045
PbO	0.026
Cr_2O_3	0.048
S	0.14
P_2O_5	0.046
C	1.517

The results of calculations of technical-commercial indices of the recycling of iron-containing waste are shown below. Ordinary steam coal is used as the reducing agent and heat source. Though basicity of wastes is close to unity, presence in coal's ash acid components results in necessity to add lime.

It was assumed that the annual productivity of the Romelt furnace is 150 thou. tons of hot metal. For a furnace with an area of 14 m^2 at the level of the lower tuyeres, this corresponds to a unit productivity of 1.32 tons/(m^2·hour) or 18.5 tons/hour. Hot metal can either be used in liquid form to steelmaking or can be cast into pigs for subsequent shipment to customers.

Recycling of the waste generates roughly 50 thou. tons of slag a year. This slag is granulated and it is realized as passing production. Except for that it is formed about 50 thou. m^3 per hour of hot (1600-1700^{0}C) gases, containing roughly 35% CO and H_2. The gas can be burned in a waste-heat boiler to obtain steam that will allow receiving about 115 million MW-hour of the electric power per year at construction heat recovery power station.

Specific consumptions of the main charge materials and utilities per ton of hot metal in Kremikovtzi steel waste are as follows: steel waste – 1.48 tons/ton, coal – 0.74 tons/ton, lime – 0.04 tons/ton, oxygen - 640 m^3/ton, compressed air - 230 m^3/ton, natural gas - 30 m^3/ton. These data can be used to design a Romelt complex and calculate the economic indices of the process. Taking into account the operational costs, the cost value of Romelt hot metal minus the value of the by-products (granulated slag, and electricity) will be significantly below the cost of blast furnace hot metal. Using of liquid hot metal in steel-making will allow to reduce a scrap deficit a and to decrease the cost price of steel.

6. An estimation of capital investments and economic efficiency of the project

Complex Ромелт consists of the following basic objects:

- receiving and storage facility;
- charge material building;
- the main building including the Romelt furnace, slag granulation unit, ladle heating unit, waste-heat boiler, gas-cleaning unit, casting bay (crane, hot-metal transfercar, ladles, et cetera), a system to circulate chemically treated water;
- a heat recovery power station including chemically water treatment plant;
- an oxygen plant;
- air compressor unit.

The capital investments for Romelt complex on integrated steel-making plant including design, equipment, construction and construction, and other types of work, is roughly 73 million euro. Of this amount, the Romelt shop accounts for 36%, the heat recovery power station 16%, the oxygen plant 14%, and the receiving-storage facility 8%. Exclusion from the Romelt complex a heat recovery power station greatly reduce the cost of the project.

The above calculated were used to determine the main indices that characterize the return on investment:

- internal profitability norm – 27%,
- investment pay-back period – 3 years,
- net discounted profit – 55 millions euro,
- profitability index - 37%.

These indices allow estimating Romelt project as economically attractive. However, given the current instability in the world economics, it is very important to determine the effects of different factors on the economic characteristics of a Romelt project. We calculated the economic indices while varying the prices for the commercial products, costs production, and the capital investment. Fig. 4 shows the dynamics of the investment pay-back period with a change in these indices. Sensitivity analysis to variations of external factors indicates a good stability and reliability of the project in case of unfavorable changes (within 30%).

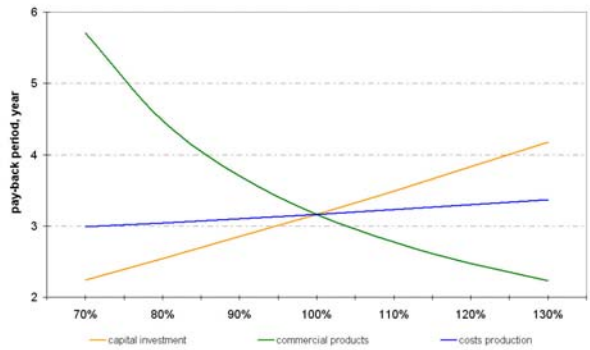

Fig. 4 *Economic stability of the project. Effect various factors on pay-back period*

7. Conclusion

The construction of Romelt complexes will make it possible to solve the problem of utilizing iron-containing waste, improve the environmental situation in different regions. The products of the Romelt process: inexpensive hot-metal (liquid iron), granulated slag and the electric power make this technology economically efficient.

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