Analysis of methods for processing oily mill scale and oily sludge for iron and steel production

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Abstract. The paper considers the main methods of processing oily mill scale and oily sludge for iron and steel production. At present, the issue of processing such waste is highly relevant for iron and steel works. The iron content allows regards them as a valuable technogenic raw material. But direct processing is complicated by the high oil content. The authors describe thermal processing variants with and without regeneration of oil products, physicochemical methods and briquetting. A desludging method with the help of Rotor Impulse Machines (RIM) is described in sufficient detail; its main advantages are presented. A very promising direction in the development of new technologies for the processing of oily sludge is the combination of physicochemical, mechanical, magnetic and other methods of desludging with the regeneration of oils.

1. Introduction

In ferrous iron and steel production annually a considerable amount of technological waste, while the raw materials processing, is generated in the form of scale, dust and sludge. A part of the iron, about 45-50%, contained in the waste, comes into production through agglomeration and converter production. The remaining 50-55% are accumulated in dumps and sedimentation tanks. It has a negative impact on the environment or is irrevocably lost outside enterprises [1–3]. They include waste that contains harmful substances such as zinc, lead or oil. Recycling these wastes, as well as extracting valuable components from them, is of great importance due to official regulations and the lack of storage space.

A particular attention is paid to the iron-containing oily sludge of bottom sediments of sludge storage systems of ferrous iron and steel works [4].

The iron content there remains in the range of 30–63%. So, they can be regarded as valuable technogenic raw materials [5]. But their direct processing in sinter-blast furnace and steel-making industries is complicated due to the increased oil content (up to 4%). It is associated with violation of fire safety standards, the likelihood of failure of the devices serving production and unpredictable disruptions in the course of the established technological process. Also, disposal in sinter production will necessarily be accompanied by emissions of strong toxins, i.e., dioxins and furans into the atmosphere, which causes the application of expensive gas desludging systems or technologies that prevent their formation at sinter plants [6, 7].

The problem of processing oily scale is solved by de-oiling with the subsequent disposal. But chemical (washing with chemical reagents) and thermal (burning off oil) de-oiling is quite expensive
processes that create additional environmental complications in the form of the regeneration difficulty of wash water, purification of waste gases, and others. Therefore, the development of a more efficient processing technology and complex application of these sludges remains relevant for ferrous iron and steel production.

At the beginning of 2020, more than 10.8 million tons of oily sludge of bottom sediments were accumulated in the existing and stored maps. At present, from an economic and technological point of view, it is considered reasonable to process oily sludge from the Levoberezhny industrial storm water sedimentation tank.

The formation of oily bottom sediment sludge is due to the presence of fine scale in the wastewater of iron and steel production. Figure 1 shows the gross discharges of pollutants by the plant into water bodies.

![Figure 1. Gross discharges of pollutants into water bodies at Magnitogorsk Iron and Steel Works for the period 1996–2020.](image)

2. Methods and materials

Nowadays, several directions for the disposal of oily sludge have been formed (figure 2). They are based on the physicochemical properties of the raw used materials [5-7].

These include:
- de-oiling to obtain a clean, easily recyclable product;
- pelletizing fine-grained and fine-dispersed materials applying various briquetting technologies;
- various mixtures development based on oily sludge for injection into blast furnaces and electric arc furnaces.

The JSC “SverdNIKHIIMMASH”, Yekaterinburg [8] designed a machine for thermal processing of oil-containing waste (greasy dirty scale), formed in pipe-rolling production of iron and steel works.

The main unit of the machine is a fluidized bed (FB) machine. The dirty oily scale (or any other technological waste) is fed there for processing. In the FB machine iron oxides are dehydrated and oily organic components are burned out at a temperature of 800–900°C. Dry iron oxide is carried away through the gas distribution grid and captured in two subsequent cyclones.

The machine can be applied for thermal processing of waste from other industries, including medical ones. The capacity of the plant can vary from 3 to 100 thousand tons per year. The technology has been tested in the processing of sludge scale from the Seversky and Pervouralsky pipe plants.

A group of research and design organizations developed a machine for processing oily mill scale for the JSC “PNTZ” (Pervouralsk).
Figure 2. Classification of methods for disposal of oily sludge and mill scale.

The machine is designed for low-temperature treatment of mill scale in order to sublimate oils with subsequent complete afterburning of sublimates. It consists of a reactor, where heat treatment of oily scale takes place in a high-speed vortex flow of combustion products, and a cyclone furnace, where after cleaning in cyclones, oil fumes contained in the exhaust gases are burned. The heat of gases leaving the cyclone furnace, within 0.7–1.0 Gcal/t of oily scale, is used in the waste heat boiler.

The resulting de-oiled scale is a valuable metallurgical raw material for sintering or, after briquetting, can be used in blast-furnace smelting.

The JSC Severstal together with FSBEI HPE “ChGU” have developed a machine for complete separation into separate components of thick sludge, consisting of water, oil and fine scale [9]. It includes systems for sludge preparation, component separation and used drying agent treatment.

The firm “Preussaganlagenbau Salzgitter” (Germany) has developed a technology for cleaning oil-containing mill scale by the method of wet mechanical washing [10].
In the process of descaling from oil, the following final products are formed: mill scale, cleaned from oil and containing not more than 0.2% oil and not more than 12% water, which can be reused in the sintering machine; waste oil that can be used in a plant for its regeneration or incineration; residual substances (less than 2%); distilled water.

One of the rational directions for solving the problem under consideration can be the agglomeration of fine-grained and fine-dispersed materials using the briquetting technology. It is widespread in many countries of the world for the production of multi-purpose briquettes [6]. All briquetting technologies can be roughly divided into two groups such as thermobriquetting and cold briquetting.

The LLC STC “Trubmetprom” [6] on the basis of the long-term research proposed a technology for briquettes manufacturing from a mixture of pure and oily scale with liquid glass as a binder. This technology was applied to produce a pilot batch of briquettes from oily scale produced by the Pervouralsk New Pipe Plant and passed pilot tests on the basis of Certizen-Truba LLC and the Scientific and Technical Center of “Mechel OJSC”. The test results for chemical, granulometric composition and mechanical properties fully meet the requirements for raw materials for the production of cast iron. Briquettes from oily scale, obtained by a new technology, in terms of consumer properties correspond, and in some respects even surpass, analogues of a raw material product of blast-furnace production in domestic and foreign practice.

SSC RF JSC “Ural Institute of Metals” together with JSC “Seversky Pipe Plant” [11] organized a pilot production of briquettes based on fine production waste - oily scale, dust from gas cleaning of open-hearth furnaces and a crushing and sorting complex for slag processing. The optimal composition of the briquettes had a total iron concentration of 40%, carbon 5% and a basicity of 1.2. Also, coke and lime screenings were added to the briquettes. Experimental melts have shown that the use of briquettes does not have a negative effect on the furnaces, there was a slight increase in the steel yield and a decrease in the amount of limestone additive.

The technology is developed to process the most sophisticated to recycle sludge products formed as a result of abrasive processing of steel workpieces, as well as sludge generated at metallurgical enterprises and is fully suitable for processing metal shavings formed during blade processing of parts.

The IMET UB RAS [12], on the order of the Chelyabinsk Pipe-Rolling Plant, developed a technology for the production of a product sintered with nontronite. Also, a department for the disposal of scale-oil-containing sludge from sedimentation tanks of a dirty production cycle was designed. The resulting sintered product has a high iron content (Fe_total is 68.15%), an admissible content of sulfur and phosphorus, as well as small amounts of alloying elements, i.e., nickel, chromium, vanadium. It has been established that the content of oils is 0.12–0.15% at a temperature of 650–700°C during three hours and it is 0.1% at 1100–1200°C in briquettes after sintering.

A research firm "EKO-PROJECT", Yekaterinburg [13], has developed a technology for the utilization of scale-oil-containing sediments (OMO).

The chemical composition of the resulting pellets is not inferior to the fired iron and steel pellets for blast furnace production. The combination of their mechanical and thermal characteristics also qualifies the non-fired agglomerated product as not inferior in quality to the best fired pellets. It should be noted that all the equipment necessary for the technology implementation is serially produced by the industry. The developed technology meets environmental requirements.

The PJSC “MMK” developed a technology for the production of briquettes from the mill scale [14]. Quartz sand, ground clay and technical lignosulfonate powder (LST) were taken as supplement components of the charge for scale briquetting.

At the technological scheme development to manufacture an iron-containing briquette, the equipment available in the refractory production of the PJSC “MMK” was taken into account. It included the following operations: raw material pressing, drying, storage and transportation to the blast furnace shop.

According to the new technology, a briquette based on mill scale with a compressive strength of at least 15 MPa was obtained. An experienced briquette was tested in the blast-furnace shop of the PJSC “MMK”.
The Rotary Impulse Machines are applied to process systems such as "liquid-liquid", "liquid-solid" and "gas-liquid" due to a wide range of influencing factors:

- mechanical effect on particles of the heterogeneous medium, disposed in shock loads, shear and abrasive loads and contacts with the working parts of the Rotary Impulse Machines;
- hydrodynamic effect, expressed in high shear stresses in the fluid, developed turbulence, pressure fluctuations and fluid flow velocity;
- hydroacoustic effect on the liquid is carried out due to small-scale pressure pulsations, intense cavitation, shock waves of nonlinear acoustic effects.

The rational application of these effects and phenomena opens up the possibility of creating new energy-saving technologies for processing man-made waste from mining, iron and steel as well as other industries.

The Rotary Impulse Machines refer to the equipment that provide intensification of technological processes. They are promising due to the relative simplicity of the design and high energy efficiency. The RIM at the stage of de-oiling provides the impact on the pulp of hydrodynamic pulsations, acoustic waves, resonance, as well as cavitation effects. We obtain mineral iron particles separated from oils with cleaned surfaces as a result of such a complex effect on contaminated sludge particles in the treated pulp.

One of factors providing efficient de-oiling of sludge from oil products in the RIM is the ratio of solid to liquid. From the analysis of technologies for washing sands [15,16] and sludge [10], the ratio of solid to liquid is 1: (1–4). To ensure the above effects in the studies, the ratio of solid to liquid was taken to be 1: 3.

The oily sludge from storage sites, as well as flowing in the form of slurry through pipelines, are pumped to the RIM with a solid to liquid ratio of 1: 3. After de-oiling, the sludge enters the classifier, where the solid and liquid phases are separated. The chamber product is subjected to another de-oiling stage in the RIM. This process is necessary for the maximum destruction of hydrocarbon contaminants on the surface of the slime particles and their most complete removal, because oily sludge is finely dispersed and therefore one-stage treatment does not give the desired effect. Then the sludge is fed to a magnetic separator with a constant magnetic field. We take out tailings and an iron-containing product ready for the further application.

The foam product from the classifier is also subjected to additional processing in the RIM, because part of the finely dispersed oily sludge leaves with the foam product, followed by classification and wet magnetic separation with the output of tailings and an iron-containing product ready for further application. [17, 18]

3. Conclusion

The analysis of the existing methods for processing oily sludge both in Russia and abroad has shown that a wide range of technological solutions in this area is currently being offered. The main technological processes for de-oiling are chemical and thermal. However, chemical (chemical reagents cleaning) and thermal (burning off oil) de-oiling are expensive processes that create additional environmental complications in the form of the problem of washing water regeneration, purification of waste gases, and others, because of this they have not found a wide application. Therefore, the development of new technologies that combine efficiency and simplicity, the application of standard equipment is relevant for ferrous iron and steel works continue to engage in it actively. On the one hand, they are prompted to do this by the growing deficit of iron ore raw materials and the increase in prices for it. On the other hand, the requirements of environmental legislation tighten up.

A promising direction in the development of new technologies for the processing of oily sludge is a combination of physicochemical, mechanical, magnetic and other methods of cleaning sludge with the regeneration of oils.

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