Solar technology for metallurgical waste processing

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Abstract. *The possibilities of solar installations based on mirror-concentrating systems for processing of waste materials in a stream of concentrated high-density solar radiation were analyzed. It was proposed to use mobile compact solar installations located near metallurgical plants for processing mining and metallurgical waste. The geometric and optical-energy parameters of the concentrator for processing were calculated in order to extract metals from mining wastes. It was shown that a system of mirrors consisting of a heliostat (100 m^2) and a paraboloid-shaped concentrator with a diameter of 10 m can focus a solar radiation flux with a density sufficient to melt metallurgical waste from the Almalyk Mining and Metallurgical Plant. It was shown that ultrasonic treatment of waste materials stimulates an increase in the amount of copper containing phase in the melt by 8 times compared to the initial state of the material.*

Keywords. Solar concentrators, mirror concentrating systems, high flux densities, material processing, metal extraction.

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Introduction

The usage of techniques (lasers, plasmatrons, cathode-beam or arc sources) that create high-density quantum or particle fluxes for surface modification and material processing lead to the formation of non-equilibrium microstructures that can be used to fabricate materials with higher corrosion resistance, high temperature oxidation and wear resistance. Solar installations based on mirror concentrating systems have unique capabilities for processing of metal (welding and surfacing, surface treatment and surface hardening), powders and non-metal (ceramics, fullerenes, carbon nanotubes) materials (Herranz, 2010; Fernández-González and Ruiz-Bustinza, 2018). A number of researchers (Fernández-González and Prazuch, 2018; Ruiz-Bustinza, 2013; Sibieude, 1982; Steinfeld, 1991; Akbarov, 2017; Faiziev, 2008) considered the possibility of using a stream of concentrated solar energy instead of burning hydrocarbons at high temperatures.

At present, the search for new energy sources is being intensively carried out along with the investigations on the efficient use of existing sources. Especially great attention is paid to renewable energy sources because of their ability to be regenerated by natural processes. In this regard, solar energy is one of the most promising renewable energy sources (Parpiev, 2021; Paizullakhanov, 2021). Various designs of melting units installed in the focal area of solar installations make it possible to implement technologies for energy-intensive processes in the ceramic, glass and metallurgical industries.

The melting unit in these installations usually contains a graphite cavity which absorbs the energy of concentrated high-density solar radiation and becomes a heat source, see for example, solar furnace (PSI Spain), for extracting metals from ore (Bader, 2017). Due to the high thermal conductivity of graphite, the material in the reaction chamber is heated and melted. However, it seems to us that the efficiency of such melting unit design will not be high in terms of the amount of melted material per unit of time, as well as the full melting of the loaded material. This work is aimed for the development of a solar installation and a melting unit for processing waste from metallurgical production in order to extract metal alloys from them. The influence of ultrasonic treatment of industrial waste from the metallurgical production of the Almalyk Mining and Metallurgical Plant (AMMP) on the process of metal recovery will also be studied.

Experimental

At the first stage, the chemical composition of metallurgical production waste of the AMMP was analyzed (Table 1).

Table 1. Chemical composition of waste from the metallurgical production of the AMMP.

Component	SiO_2	Fe_2O_3	CaO	K_2O	ZnO	MgO	CuO	PbO	MnO	MoO_3
Content, wt. %	52,29	38,58	3,28	2,57	1,07	1.13	0,40	0,24	0,22	0,22

As follows from Table 1, silicon and iron oxides were the predominant components in industrial waste. The analysis showed that for such a composition of AMMP wastes, a low melting point is characteristic, which was T = 1750 K with a material dispersion of no more than 100 μm.

At the second stage of the study, the flux density of concentrated solar radiation (Q) was calculated using the Stefan-Boltzmann equation, which describes the radiation of heated bodies:

$$Q = \sigma \varepsilon T^4,$$

where ε is the emissivity of the material, σ=5.67x10^{-8} W/(m^{2}K^4) is the Stefan-Boltzmann constant, T is the body temperature (K). When the value of the materials emissivity is 0.85, the required flux density for melting AMMP (T=1750 K) is Q=50 W/cm^2.

From the analysis of the previously shown estimations it follows that the energy density E = 100 W/cm^2 at the focus of the solar furnace will be more than sufficient for the melting of waste with the extraction of metal alloys from it. Obviously, the larger the focal spot size, the greater the amount of processed waste and the greater efficiency of this process. Let us estimate what optical-geometric (dimensional) parameters a solar concentrator should have in order to provide the required technological mode. For calculations, we use the following data: the flux density of concentrated solar radiation E = 100 W / cm^2, preferably with a flat distribution over the spot with the diameter d = 30 cm. To do this, we first determine what power will be in a circle with a diameter of 30 cm at a uniform density of 100 W/cm^2 in the focal zone:

$$W_f = \frac{E_f \pi d^2}{4} = 70\ 650\ W$$

On the other hand, such power should be provided by the concentrator midsection area. Let us consider a round concentrator. If we denote the diameter of the midsection of the concentrator as D_c , then:

$$\frac{E_0 R_g E_c \pi D^2}{4} = W_f,$$

where R_g, R_c are the reflection coefficients of the heliostat and concentrator mirrors, E_0 is direct solar radiation density. Thus:

$$\frac{E_f \pi d^2}{4} = \frac{E_o R_g R_c \pi D_c^2}{4}$$

From here, for the midsection of the concentrator, we get:

$$D_c = d_f \sqrt{\frac{E_f}{E_o R_c R_g}}$$

This equation makes it possible to calculate the diameter of the concentrator corresponding to the given values of optical and energy parameters, taking into account the conditions of technological processes.

The proposed scheme of the solar installation, which can be used for the processing of materials, is shown in Fig.1.

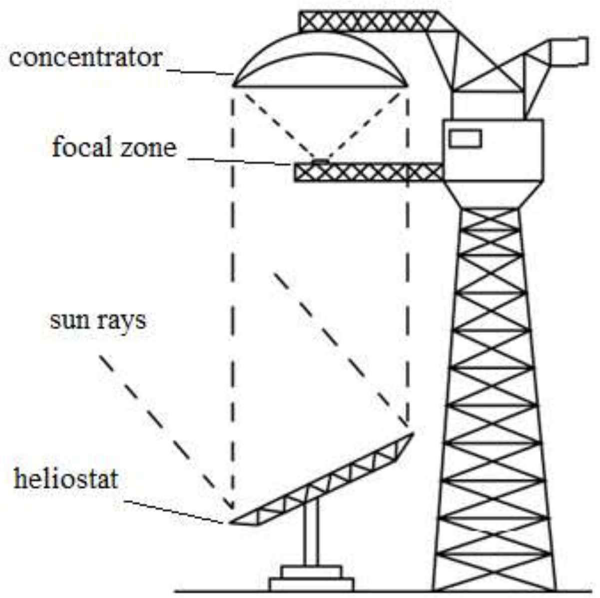

Fig.1. Scheme of the solar installation for materials recycling.

As can be seen from Fig. 1, the solar furnace is designed according to the bi-mirror scheme of mirror concentrating systems of the heliostat-concentrator type. Such a scheme of mutual arrangement of reflecting elements (mirrors) allows concentrating solar radiation into a focal region with a vertical flux vector that is more convenient for technological purposes of processing materials in the focal plane.

At the third stage of the experiments, technogenic wastes were irradiated with ultrasonic pulses in an ultrasonic bath of the DSA50-Ski-1.8L brand (manufactured in China) in order to identify the effect of preliminary ultrasonic exposure on the material before melting in a solar furnace.

Results and discussion

Assuming the flux density of solar radiation to be 0.07 W/cm^2 and the reflection coefficient of the mirrors to be 0.9 (the same for the concentrator and heliostat), we obtain D_c = 17.81 m. This value of the concentrator diameter is quite large. Therefore, it is necessary to clarify experimentally the smallest value of the concentrated radiation density sufficient to melt the material being processed. Figure 2 shows the dependence of the concentrator diameter on the concentrated radiation flux density. The calculations were performed for two values of the focal spot diameter, 30 cm and 20 cm.

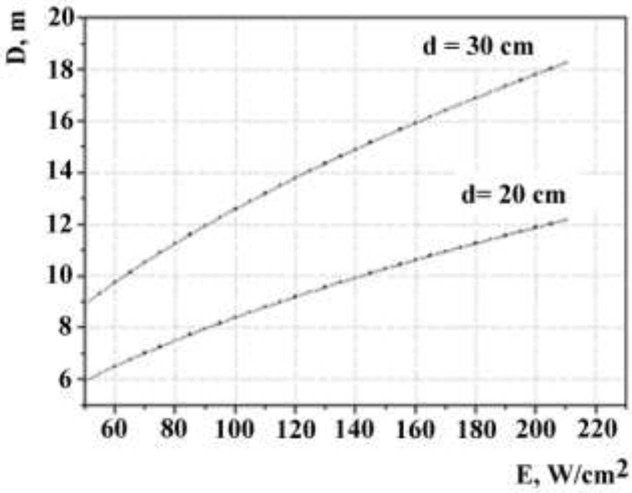

Fig.2. Dependence of the concentrator diameter on the concentrated radiation flux density

Figure 2 shows that if the diameter of the concentrator is 10 m, then it should provide a spot with a diameter of 30 cm with an average radiation flux of 65 W/cm^2 in the focal zone of such a concentrator. For the processing of materials in the focal region, we have developed a special design of a graphite melting unit in the form of a truncated cone (Fig. 3).

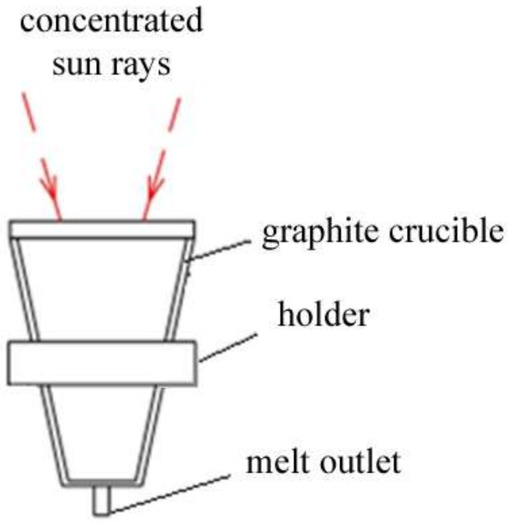

Figure 3. Graphite melting furnace.

The process of metallurgical waste processing from the AMMP in a solar furnace consisted of material melting and it quenching in the water. Analysis of the chemical composition of the fused material showed the presence of substances of metallic (approximately 22 wt.% Fe-Cu based alloy) and ceramic (approximately 71 wt.% $CaMaSi_2O_6$) compositions separately.

In a carbon medium, the process of metal reduction from their oxide states proceeded according to the reaction MeO + C = Me + CO. However, before the melt drops enter the water, the metals in the drop have time to oxidize in the air atmosphere, according to their chemical affinity for oxygen. For example, at a temperature of 1600 ° C, the chemical affinity of elements to oxygen decreases in the following line Be, Ca, Zr, Mg, Al, Ti, C, Si, V, B, Mn, Cr, Sb, Zn, Fe, W, Mo, Co, Ni , Cu, As. Due to the fact that the elements located to the left of iron, in comparison with it, have a higher chemical affinity for oxygen, they were quickly oxidized, that was observed in the experiment.

The chemical composition of the metallic part of the AMMP waste material melt subjected to preliminary ultrasonic action is given in Table 2.

Table 2. Chemical composition of the metallic part of the melted AMMP waste material subjected to preliminary ultrasonic treatment.

Component	Fe	Cu	Mo	SiO_2	CaO	Sb_2O_3	MgO	MnO	PbO	ZnO
Content, wt. %	88,04	3,28	0,63	2,81	3,32	0,12	1.13	0,22	0,24	0,21

An analysis of the composition of the metallic part of industrial waste melted in a solar furnace showed that their preliminary ultrasonic treatment led to an 8-fold increase in the amount of copper containing phase compared to the initial state of the material. This may be due to the acceleration of physical processes, based on the absorption of the energy of high-intensity ultrasonic frequency mechanical vibrations by the particles of the substance. In particular, as noted in (Khmelev, 2007), the use of high-intensity ultrasonic vibrations accelerates technological processes and increases the yield of useful products, and also makes it possible to obtain a material with new properties.

The capacity of the developed melting unit is 2 kg of material. Such an amount of substance can be melted out in 3 seconds of irradiation in the focal area of a solar installation. In case of providing a continuous supply of material to the melting unit a total weight of processed material for an 8-hour sunny day will be 2400 kg. Based on the fact that the minimum number of sunny days in the Republic of Uzbekistan is 220, then 500 tons of man-made waste can be processed in a working year. At the same time, the yield of iron will be 110 tons, and copper - about 16 tons.

Conclusions

The findings showed that a system of mirrors consisting of a heliostat (100 m^2) and a paraboloid-shaped concentrator with a diameter of 10 m could focus the solar radiation flux with a density sufficient to melt the metallurgical waste of the Almalyk Mining and Metallurgical Plant. It was revealed that in case of heating of the material in a carbon medium, the process of metal reduction from their oxide states proceeded according to the reaction MeO + C = Me + CO. Some metals oxidized when cooled in air according to their chemical affinity for oxygen. The continuous supply of material to the melting unit would make it possible to melt the material in the amount of 500 tons of industrial waste per 1 year with the extraction of 110 tons of iron and 16 tons of copper on one solar furnace. Solar extraction of metals can become an alternative in metallurgical processes. It was shown that preliminary ultrasonic treatment of waste materials stimulated an 8-fold increase in the amount of copper containing phase in the melt compared to the initial state of the material.

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References

Akbarov, R.Y., Paizullakhanov M.S., Characteristic features of the energy modes of a large solar furnace with a capacity of 1000 kW, *Applied Solar Energy*, vol. 54 (2), pp. 99-109, 2017.

Bader,R., Lipiński, W, Solar thermal processing, in *Advances in Concentrating Solar Thermal Research and Technology*, Blanco, M., Ramirez, L., Eds., Elsevier, pp.403-459, 2017.

Faiziev, S.A., Paizullakhanov, M.S., Nodirmatov, E.Z., Synthesis of pyroxene pyroceramics in large solar furnace with ZrO_2 crystallization nucleator, *Applied Solar Energy*, vol. 44 (2), pp.139-141, 2008.

Fernández-González, D., Prazuch, J., Ruiz-Bustinza, I., González-Gasca, C., Piñuela-Noval, J., Verdeja, L.F. Solar synthesis of calcium aluminates, *Sol. Energy*, vol. 171, pp.658–666, 2018.

Fernández-González, D., Ruiz-Bustinza, I., González-Gasca, C., Piñuela-Noval, J., Mochón-Castaños, J., Sancho-Gorostiaga, J., Verdeja, L.F. Concentrated solar energy applications in materials science and metallurgy, *Sol. Energy*, vol. 170, pp. 520-540, 2018.

Herranz, G., Rodríguez, G. P., Uses of Concentrated Solar Energy in Materials Science, Solar Energy, in *Solar Energy*, Radu D. Rugescu, Ed., Croatia: INTECH, pp. 145-170, 2010.

Khmelev, V.N., *Ul'trazvukovyye mnogofunktsional'nyye i spetsializirovannyye apparaty dlya intensifikatsii tekhnologicheskikh protsessov v promyshlennosti (Ultrasound multifunctional installations for intensification of technological processes in industry)*, Barnaul: AltGTU, 2007. (in Russian)

Paizullakhanov, M.S., Shermatov, Z.Z., Nodirmatov, E.Z., Synthesis of materials by concentrated solar radiation, *High Temperature Material Processes*, vol.25 (2), pp.25-34, 2021.

Parpiev, O.R., Paizullahanov, M.S., Nodirmatov, E.Z., Peculiarities of processing metallurgical waste in a large solar furnace, *Theory and technology of the metallurgical process*, vol.36. (1), pp. 15-20, 2021.

Ruiz-Bustinza, I., Cañadas, I., Rodríguez, J., Mochón, J., Verdeja, L.F., García-Carcedo, F, Magnetite Production from Steel Wastes with Concentrated Solar Energy, *Steel Res. Int.* vol. 84, pp. 207–217, 2013,

Sibieude, F., M., Tofighi, A., Ambriz, J., High temperature experiments with a solar furnace: The decomposition of Fe_3O_4, Mn_3O_4, CdO, *Int. J. Hydrogen Energy*, vol. 7, pp. 79-88, 1982.

Steinfeld, A., Fletcher, E.A., Theoretical and experimental investigation of the carbothermic reduction of Fe_2O_3 using solar energy, *Energy*, vol. 16, pp. 1011–1019, 1991.