Optimization of a proposed non-linear production model and the effect of direct reduced iron charging on CO2 emission and coke-energy consumption of ESCO blast furnace no. 3

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Abstract: The upward growth of steel industry has led to an increase in demand for raw materials and the release of about 7% of global greenhouse gases (An et al., 2018; Griffin and Hammond, 2019). Blast furnace (BF) is the most essential section of a steel company (Liu et al., 2016). Costs of production in steel companies are contributive to the competitiveness of such plants (Zhang et al., 2011). Due to the shortage of domestic lump and concerns about CO2 emission, Iranian steel industry has encountered serious challenges of supplying ferrous raw materials and coke for blast furnaces, while the overproduced direct reduced iron (DRI) and the vast sources of domestic natural gas and pulverized coal have made it possible to replace coke with these sources of energy and using DRI as ferrous raw material in the blast furnaces. High differences in the price of coke with natural gas and pulverized coal along with big price gap between DRI and lump, the influence of replacing complexity on the cost of ferrous raw materials, coke, and energy consumption, BF productivity, technical constraints, and carbon dioxide emissions level are the main reasons for conducting this research.

Design/methodology/approach: A non-linear optimization model, extracted from thermodynamic equations, process relations, and mass and energy balances, has been applied in this study. This model can be applied as a decision support system for purchasing and supplying coke-energy, ferrous burden materials, and examining the effect of consuming different raw materials on the CO2 emission and evaluating the production profit.

Findings: Results indicated that this model can decrease CO2 emission and is highly effective in gaining company benefits. Based on the research sensitivity analysis it was found that despite the advantages of the model, as long as there are no tough restrictions on CO2 emission like in Japan and in the developed European countries, and there is subsidized domestic lump charging DRI as BF burden materials, it is not economic. As a result, it was concluded that available ferrous raw materials options for Iranian blast furnaces are only lump, sinter and pellet.

Research limitations/implications: BF thermal reserve zone is assumed 1200k, which may vary from 1100 K up to 1300 K in practice; hot metal and slag temperatures are assumed fixed; chemical elements distribution is assumed fixed; and the state of gas rising from the bottom segment into the up segment of BF is ignored.

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Practical implications: The proposed model was implemented in MATLAB and validated using the data of Esfahan Steel Company. A comparison between the model results and the experience-based results for supplying ferrous materials blending indicated a good compromise between the model and real situation, and it leads to an increase in production benefit around 16% for ferrous raw material and 19% for energy when using the model to purchase them. Another advantage of this model is the ability of prediction of raw materials which affects production parameters. In this regard, the effect of DRI on the CO2 emission, energy consumption and the benefit were studied and validated.

Originality/value: Some of the innovation aspects of this study include:
i) compared to available studies, optimal decision making on the supply and replacement of raw materials and energy, together with new constraints, were analyzed;
ii) applying scrap and direct reduction iron (DRI) as environmental friendly ferrous raw materials for Iranian blast furnaces became possible, which contributed to a decrease in energy consumption;
iii) the coke consumption rate in a BF as a function of the blending of ferrous burden materials and other production variables was assumed to change; and
iv) for the first time in this study, the simultaneous consumption of carbon-bearing materials such as pulverized coal, natural gas, oil and coke were modeled.

Keywords: Nonlinear model, Optimization, Profit, CO2 emission, Blast furnace, DRI.

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