



Estimating Porosity of Agglomerated Products Using Optimized Sphere Packing


Jose Antonio Marmolejo-Saucedo, National Autonomous University of Mexico, Mexico*

 <https://orcid.org/0000-0002-8539-9828>

Igor Litvinchev, Nuevo Leon State University, Mexico

 <https://orcid.org/0000-0002-1850-4755>

Aitber Bizhanov, J.C. Steele and Sons, Inc., USA

 <https://orcid.org/0000-0002-0583-1984>

Georgiy Yaskov, Institute for Mechanical Engineering Problems, Ukraine

Tetyana Romanova, University of Leeds, UK

ABSTRACT

The article presents the results of studying the dynamics of changes in the porosity of two-component briquettes and pellets depending on the size of particles and the proportions of components in the mixture using an optimized packing of spheres. Knowing the patterns of change in the porosity allows to optimize the strength of the briquette and pellets as well as to improve their behavior in the reduction processes in blast furnaces, steel making furnaces and in direct reduction reactors. A computation experiment based on heuristic simulation model was designed to study the change of the estimated porosity under increasing/substituting the number of larger spherical particles in the mixture of spheres. The results obtained made it possible for the first time to reveal the extreme nature of the change in the porosity of the briquette/pellet with the addition of larger particles, depending on the fractional composition of the briquette. The results obtained open up new opportunities for optimizing the placement of fine-grained materials in the charge of metallurgical furnaces.

KEYWORDS

Briquettes, Estimated Porosity, Heuristic, Nonlinear Optimization, Sphere Packing

INTRODUCTION

The current stage of development of the ferrous metallurgy is marked by special attention to decarbonization as a key factor in reducing CO₂ emissions. The report of the Intergovernmental Panel on Climate Change (IPCC [Key World Energy Statistics, n.d.]) in 2018 set a goal to limit global warming to 1.5 °C by 2050.

Achieving this goal is largely due to the speedy introduction of the best available technologies (BAT) into metallurgical practice. The level of reduction of specific emissions in the steel industry by the introduction of BAT is estimated at 15–20% (from 1.8 to 1.44 t CO₂/t of steel [Holappa, 2020]).

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*Corresponding Author

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The greatest potential for reducing emissions from full-cycle steel mills comes from replacing sinter in the blast furnace charge with briquettes. The effectiveness of the synergy of briquetting and sintering with partial replacement of sinter with briquettes in a blast furnace charge was studied in detail for the first time in Bizhanov (2022).

An important role in the transformation of modern ferrous metallurgy into a green one is called upon to play cold (non-firing) briquetting. The manufacture of briquettes does not involve the consumption of carbon, in contrast to traditional industrial agglomeration technologies whereas 35–45 kg of coke breeze is consumed per 1 ton of sinter, and 18–25 m³ of natural gas is consumed for the production of pellets. Among the criteria for belonging to BAT, one of the most important is the almost complete absence of harmful emissions in the production of briquettes.

Briquetting will not lose its relevance in the realities of green metallurgy due to the intensive pyrometallurgical nature of the main metallurgical technologies, which inevitably lead to the formation of fine materials that are promising for recycling (dust, sludge, fines, etc.). Recycling of such materials without their preliminary agglomeration is impossible. The largest mining and metallurgical company VALE announced plans for the early commissioning of briquette factories with a capacity of 6 million tons of briquettes from hematite iron ore concentrate both for blast furnaces and DRI reactors in 2024.

The reducibility of the briquette is a key factor in obtaining a product with the desired metallurgical properties. In turn, the reducibility is largely determined by the porosity of the briquette material.

In most studies known from the literature, the porosity of briquettes is investigated depending on the magnitude of the applied pressure. It is clear that the amount of pressure applied in the production of briquettes manifests itself differently in different briquette technologies. Thus, in vibropressing, the briquetted mixture is practically not subjected to compression, and the compaction process is carried out due to fluctuations in the viscosity of the mixture synchronously with the vibration phases due to the properties of thixotropy manifested by the hydrated binder. The values of the applied pressure are insignificant (0.2 MPa) and may not be taken into account in extrusion briquetting, the pressure in the working chamber of the extrusion extruder reaches values of 3–4 MPa, which is an order of magnitude less than the pressure values typical for roll briquetting (from 10 to 100 MPa).

High values of pressure exerted on the mixture briquetted by the roller press can significantly change the structure of the briquette components, the size and shape of their particles, which can cause both a decrease in porosity and its growth due to the appearance of internal cracks.

Speaking in general about the study of the metallurgical properties of briquettes, including porosity, an important remark should be made concerning the incorrectness of projecting the results of the study of laboratory briquettes, in the vast majority of cases manufactured by means available in the laboratory that have little in common with the main types of commercial briquette technologies, to the specific conditions of industrial briquetting process. A significant number of scientific studies of the briquetting process are based on the study of the properties of laboratory briquettes made by lever or piston presses, which obviously does not allow us to identify the features of the metallurgical properties of briquettes based on the studied mixtures during their manufacture by one or another briquetting equipment (roller, press, vibropress or extruder).

The method of manufacturing has a significant effect on porosity and, consequently, on the reducibility and metallization of briquettes.

The main contributions of the paper are as follows.

- 1) An optimized sphere packing problem is introduced to study the porosity of individual pellets (briquettes) and the porosity of layers of pellets on roasting machines and in the charges of metallurgical furnaces and reactors, depending on the particle size distribution.
- 2) Novel mathematical model of the optimized packing problem in the form of NLP problem is provided.
- 3) Intelligent solution technique is proposed based on a multistart strategy combined with a feasible starting point algorithm and nonlinear optimization.

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