energies

MDPI

Editorial

Modelling and Calculation of Raw Material Industry

Krzysztof Czajka [1,*], Witold Kawalec [2,*], Robert Król [2,*] and Izabela Sówka [3,*]

[1] Department of Energy Conversion Engineering, Faculty of Mechanical and Power Engineering, Wroclaw University of Science and Technology, 27 Wybrzeże Wyspiańskiego Street, 50-370 Wroclaw, Poland
[2] Department of Mining, Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, Na Grobli 15, 50-421 Wroclaw, Poland
[3] Department of Environment Protection Engineering, Faculty of Environmental Engineering, Wrocław University of Science and Technology, 27 Wybrzeże Wyspiańskiego Street, 50-370 Wroclaw, Poland
* Correspondence: krzysztof.czajka@pwr.edu.pl (K.C.); witold.kawalec@pwr.edu.pl (W.K.); robert.krol@pwr.edu.pl (R.K.); izabela.sowka@pwr.edu.pl (I.S.); Tel.: +48-71-320-23-24 (K.C.); +48-71-320-68-48 (W.K.); +48-71-320-48-76 (R.K.); +48-71-320-25-60 (I.S.)

Abstract: Scientific and technical issues related to the extraction and processing of raw materials are inextricably linked with environmental concerns. The extraction, transportation and processing of raw materials and the creation of new products place a heavy burden on the environment. Therefore, the development of new technologies for the extraction and processing of raw materials which meet the demand for specific products while respecting environmental resources and saving energy can be considered one of the key challenges of modern science. The development of methods to optimize the course of certain processes related to the raw materials industry, limiting its impact on the environment, and the use of modern measurement techniques or modeling are key areas of research and development for the economy. The aim of this Special Issue was to identify certain important issues, including those related to the raw materials industry and the optimization of its processes, obtaining energy from alternative fuels and research on environmental aspects of industrial activities. The results of the research and analyses presented in the articles show that meeting the objectives in the context of sustainable raw materials industry requires: the optimization of the use of mine deposits and the recovery of materials, reductions in energy consumption, minimizations in emissions of pollutants, the perfection of quieter and safer processes and the facilitation of the recovery of materials-, water- and energy-related modern techniques and technologies.

Keywords: sustainable mining; heating and energy processes; raw material sustainable-use fossil fuels; energy conversion and storage; energy recovery; air pollution; emission reduction methods; purification and removal techniques

Citation: Czajka, K.; Kawalec, W.; Król, R.; Sówka, I. Modelling and Calculation of Raw Material Industry. *Energies* **2022**, *15*, 5035. https://doi.org/10.3390/en15145035

Received: 29 June 2022
Accepted: 8 July 2022
Published: 10 July 2022

1. Introduction

The raw material mining and processing industry belongs to the most energy-exhausting and environmentally aggressive yet socially controversial branches of the economy. Therefore, its optimization should be targeted with regard to both its overall efficiency and the mitigation of its environmental impact; otherwise, the effects of mining- and fossil-fuel-based power generation would spread further than within the most developed countries. The development of modeling and calculation methods incorporating advanced cloud computing, artificial intelligence algorithms and sophisticated sensor technology allows comprehensive digital twins of objects, systems and processes to be built, representing the whole chain of the raw material mining and processing processes.

One of the most challenging industry processes in the modern economy is sustainable power generation in its transition course from being fossil-fuel-based to being based on "green" solutions to adhere to carbon and toxic emissions limits and to curb other environmental impacts such as dust, noise and vast areas of terrain degradation. Because this

industry is particularly capitally and operationally costly, complex investigations that could return substantial savings measured in money, energy consumed and social benefits need to be carried out. Therefore, bearing in mind the interdisciplinary nature of the issues and the development of cooperation within the Polish scientific discipline defined in national law as environmental engineering, power engineering and mining, the Guest Editors defined the topics of this Special Issue of *Energies* as: 1. The sustainable processing of raw materials for the optimization of mining, energy production and environmental engineering. 2. The improved efficiency of raw material mining and processing processes with the use of quality control tracking from deposit modeling through the modeling of mining, transport and final processing operations with regard to environmental issues. 3. Raw material solutions for sustainable energy conversion and storage with "green power" sources. 4. Resource recycling, efficiency and secondary raw materials' management as a contribution to climate change mitigation. 5. Strategies, the identification of sources, dispersion modeling and methods of reducing and limiting air pollutant emissions to the atmosphere in the heating, mining and energy industry. This article is a synthetical summary of the articles that are part of the Special Issue, entitled "Modelling and Calculation of Raw Material Industry".

The whole set of contributions of the Special Issue can be separated into three main research topics:

(1) The generation of energy from alternative fuels [1–4];
(2) Studies on environmental aspects of activities in key sectors of the modern economy [5–9];
(3) Improvements in raw material industry processes [10–14].

The research methods applied to solve the investigated issues reflect the nature of these main topics. In the papers that deal with fuels or wastes, laboratory tests were most commonly used—either with the use of standard procedures [4], with the application of typical equipment innovatively used for specific tests [1,2,7] or with the use of dedicated testing facilities, developed or tuned for the investigations that were performed [3,5,6,8]. The analysis of the test results was confirmed using already-known theoretical equations [1,3,4], experimentally identified dependencies (linear and non-linear regression) [1,3], advanced methods of picture analysis [2] and spectral analyses [6,8]. The comparison of developed models of investigated processes was supported with statistical analyses [3,7]. The spatial distribution of measured parameters in situ was modeled with the use of the Arc-GIS Pro tools [5,6].

Papers that address the topic of improvements in raw material industry processes employed digital modeling of the technological equipment rather than laboratory tests. Depending on the given scope of the research, the "digital twin" could be either of a subassembly of a complex machinery [10], of a single object [11] or of a whole technological system [12]. These digital representations of the analyzed objects were built either on the basis of the specialized software environment implementing FEM [10], discrete simulation methods [10,12] or on the basis of the diversified family of in-house software solutions that are typical for aiding the design and analysis of less common technological objects [11,14]. The provision of better solutions for the more sustainable raw material processing does not always require novel developments. A great deal of knowledge has already been gathered by raw material industry companies. The formulation of the BAT guidelines could be successfully supported with the help of thee proper classification of objects, methods and procedures which have been truthfully verified against the versatile operational conditions of the analyzed operations [13]. Physical experiments were also used in these papers, e.g., tests were performed using a large-scale model of heavy-duty mining equipment [14].

2. Brief Characteristics of Directions and Research Areas under Study

Traditional fuels and raw materials, hard coal, lignite and biomass still account for 28% of primary energy sources [15]. The abandonment of fossil fuels and the transition to environmentally neutral energy sources will take decades; thus, it is vitally important to process and use traditional raw materials as efficiently, cleanly and safely as possible. Additionally, the retrofitting of existing solid fuels' infrastructures is crucial for successful

adaptation to the transfer to clean energy systems, in which, for example, solid recovered fuels or hydrogen will play an important role. The use of solid fuels for energy and electricity production raises numerous concerns related to the environmental cost, among other concerns related to the emission of gaseous pollutants such as nitrogen oxides, NO_x, sulfur dioxide, SO_2, and carbon dioxide CO_2, which contribute to smog, acid rain, the greenhouse gas effect and respiratory illnesses.

Among the important issues related to the assessment of the impact of processes—in different areas of the economy—on the environment, there are issues related to, inter alia, the characteristics of their course and conditions, the identification of emission sources, impact assessment and technologies for limiting and reducing the pollution introduced to the environment with particular emphasis on resource savings or their reuse. Further issues are related to the modeling and calculation of the raw material industry.

Some technological processes in the raw material industry (such as sieving screens) are made with the use of vibrating machines. These machines consume relatively large amounts of energy and are prone to excessive wear. The innovative design of a vibrating subassembly built of one motor and two coaxial unbalanced masses has been analyzed, modeled and tuned to provide the realization of complex trajectories of motion that are more technologically efficient for variable parameters of the treated media and energy saving in sieving screens and other vibrating machines [10].

Continuous surface mining technology is declining in Europe due to the approaching cessation of lignite fueled power generation. However, there is still a room to improve the overall energy efficiency of mining processes. Under some technological arrangements in which the overburden is transported several dozen meters down to a spreader operating on a lower located dumping level, there it is possible to convert the potential gravitational energy of conveyed-down overburden masses into electric energy [11]. The accurate calculations of the motion resistances of the downhill belt conveyors prove that depending on the actual schedule of removing the overburden masses onto the dumpsite, the recuperative overburden conveyor working in a generator mode can recover up to 60% of the potential gravitational energy of dozens of million tons of overburden. The recuperative overburden conveyors for downhill transport align with the targets of sustainable mining, which are understood as gaining the maximum benefits from the exploited natural resources. Investments into the installation of regenerative inverters for electric power supply would be paid off within 3–4 years.

Complex mining and transportation systems can be effectively analyzed and tuned with the help of a "digital twin" built on the basis of discrete simulation methods [12].

A model based on a cyclical transportation system in a surface limestone mine, developed in the *Haulsim* software, served to evaluate alternative material transportation scenarios depending on the quality of the deposit, with regard to mineral extraction constraints. The analysis was performed for the production period of one full year, allowing for effective work and technological downtimes. The transportation model was built on the DTM of a mine, which provided a clear visualization of mining and transportation activities for the better understanding of developed solutions.

Mining aggregates and stones are still developing due to the growing demand from roadworks and railroad investments. Natural dimension stone processing generates large volumes of stone waste, causing a significant impact on the environment, as well as on the efficiency and profitability of stone processing plants. Research into the classification of the presented characteristics of dimension stone processing and the structure of the waste production processes in analyzed mines accounts for a huge portion of the state-of-the-art mining knowledge [13]. Stone waste constitutes 10–35% in relation to the quantity of the processed stone material, with the quantity of sludge being even threefold greater than the volume of solid scraps. Reducing the volume of stone waste is possible through improved planning of stone production, while at the same time, the efficiency of stone material usage can be maximized, and the most modern processing machines can be introduced.

Hard coal mines in Poland employ longwall mining technology with powered roof support. The raising depths of mined fields causes rising pressure on the roof-supporting equipment, which is addressed by its more accurate design. The hydraulic leg is the basic element that maintains the position of a powered roof support. It is located in the structure between the canopy and the floor base. Large-scale tests regarding the hydraulic leg provided valuable results that were compared with a theoretical analysis [14]. The results of the theoretical analysis showed consistency with the experimental results.

In environmental areas, it is important to use new methods in the monitoring of pollutants, which could be a complement to the traditional techniques used to measure and model air pollution [5,6] or methods that are developments or new solutions in the field of purification and removal techniques, including organic compounds and selected metals (Zn (II) and Mn (II) from solutions [7,8] and studies regarding the physicochemical properties of products obtained from used goods/products [9].

Analyzing the aspects associated with pollution reduction techniques, considerations include the various methods of NO_x reduction; the most widely recognized are so-called primary measures such as burner optimization, air staging, fuel staging, low NO_x burners and flue gas recirculation. These methods, which come under the term low-emission combustion techniques, are the most cost-effective; however, due to combustion with air deficiencies, they cause the corrosion of boilers. Thus, fast and reliable corrosion diagnostic techniques are becoming a necessity to maintain the security of the energy supply for the power grid. Hardy et al. [2] summarized the state of the art regarding non-destructive diagnostic methods for the corrosion risk assessment of industrial-scale boilers. The authors described their developed systems of online monitoring of the boundary layer gas composition which may help indicate the areas most susceptible to corrosion. Furthermore, they reviewed fast screening techniques for corrosion effects and available automatic systems with visual data processing. In conclusion, based on the collected practical experience, they recommended the electromagnetic acoustic transducer technique (*EMAT*) as a method that shows great potential and has the possibility of making quick measurements without time-consuming surface cleaning.

The corrosion of boilers is exacerbated when combusting low-quality fuels such as biomass high in potassium, *K*, phosphorus, *P*, and chlorine, *Cl*. Due to the relatively low evaporation temperature, compounds containing these elements may evaporate in the combustion chamber and condense on the superheater tubes. This phenomenon is known as fouling and weakens the alloys that tubes are made of. In their work, Król and Nowak-Woźny [4] presented two non-standard methods, i.e., a mechanical test and pressure drop test, to predict the temperature at which ash becomes viscous and starts fouling on the surfaces of heat exchangers. The comparison of the obtained results using non-standard methods with the data obtained using the standard Leitz method showed a linear relationship between them. Nevertheless, as indicated by the authors, the sintering temperatures determined using non-standard methods were lower than those obtained using the Leitz method, which seems to indicate the good potential of these tests for practical usage to prevent the weakening of heat exchanger tubes due to fouling.

Although the problem of the negative influence of SO_2 on the environment has been known since the 17th century, an optimal desulfurization method has still not been developed. The number of proposed types of flue gas desulfurization installations is constantly increasing, and one of the techniques of particular interest is the adsorption of SO_2 on carbonaceous materials. In their work, Kisiela-Czajka and Dziejarski [3] analyzed the SO_2 removal process by adsorbing it on unburned carbon obtained from fly ash and commercial activated carbons. The authors paid particular attention to the methods of determining the kinetic parameters of the processes using linear and non-linear regression analysis. They showed that regardless of the process conditions, linear regression more accurately reflected the behavior of the adsorption system. Interestingly, it was also indicated that the commonly used approach of minimizing the determination coefficient, R^2, and/or the correlation coefficient, R, does not provide the most valuable pairs of kinetic param-

eters and cannot be treated as evidence of the existence of a particular mechanism of adsorption reaction.

The gaseous pollutant that is causing particularly heated discussions at the moment is CO_2. Even though the impact of anthropogenic CO_2 on the natural environment is sometimes questioned, this pollution is subject to regulations, e.g., under the climate policy of the European Union. One of the promising methods of reducing CO_2 emissions while using fossil fuels is the gasification technique. Combined with carbon capture, utilization and storage, the concept of the gasification of fossil fuels in reactors in which CO_2 is the gasifying agent deserves special attention and has been intensively developed. In his work, Czajka [1] analyzed the gasification process using thermogravimetric analyses. He paid particular attention to the influence of thermal lag induced by the finite rate of heat transfer on the progress, reaction rate and kinetics of the process. Experimental studies supported by a modeling investigation indicated that the thermal lag was of importance from the perspective of the *char*-CO_2 reaction and has an impact on the kinetic parameters which is greater than 20%. The performed analysis indicated that to obtain trustworthy results, it is desirable to carry out thermogravimetric experiments with a low heating rate or to recalculate results obtained at high heating rates with a model presented in the work, which allows the determination of the true sample temperature.

3. Conclusions

The papers included in this Special Issue of *Energies*, entitled "Modelling and Calculation of Raw Material Industry", clearly prove that the investigations that addressed problems in the raw material industry have successfully adopted novel research methods and tools. As a result, there is an opportunity to improve the formerly environmentally unfriendly industry to meet the expectations of achieving the targets of sustainable operations—the decreased use of energy, quieter and safer processes, the maximization of the use of mined deposits and materials' recovery. Based on the solutions presented, greenfield investment in the raw materials industry and the use of environmentally friendly modern technological solutions can avoid most of the drawbacks and reduce the progressive degradation of the environment.

Author Contributions: Conceptualization, K.C., R.K., W.K. and I.S.; methodology, K.C., R.K., W.K. and I.S.; formal analysis, K.C., R.K., W.K. and I.S.; investigation, K.C., R.K., W.K. and I.S.; resources, K.C., R.K., W.K. and I.S.; writing—original draft preparation, K.C., R.K., W.K. and I.S.; writing—review and editing K.C., R.K., W.K. and I.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Czajka, K.M. Gasification of Coal by CO_2: The Impact of the Heat Transfer Limitation on the Progress, Reaction Rate and Kinetics of the Process. *Energies* **2021**, *14*, 5569. [CrossRef]
2. Hardy, T.; Arora, A.; Pawlak-Kruczek, H.; Rafajłowicz, W.; Wietrzych, J.; Niedźwiecki, Ł.; Vishwajeet; Mościcki, K. Non-Destructive Diagnostic Methods for Fire-Side Corrosion Risk Assessment of Industrial Scale Boilers, Burning Low Quality Solid Biofuels—A Mini Review. *Energies* **2021**, *14*, 7132. [CrossRef]
3. Kisiela-Czajka, A.M.; Dziejarski, B. Linear and Non-Linear Regression Analysis for the Adsorption Kinetics of SO_2 in a Fixed Carbon Bed Reactor—A Case Study. *Energies* **2022**, *15*, 633. [CrossRef]
4. Król, K.; Nowak-Woźny, D. Application of the Mechanical and Pressure Drop Tests to Determine the Sintering Temperature of Coal and Biomass Ash. *Energies* **2021**, *14*, 1126. [CrossRef]
5. Cichowicz, R.; Dobrzański, M. 3D Spatial Analysis of Particulate Matter (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$) and Gaseous Pollutants (H_2S, SO_2 and VOC) in Urban Areas Surrounding a Large Heat and Power Plant. *Energies* **2021**, *14*, 4070. [CrossRef]
6. Górka, M.; Bezyk, Y.; Sówka, I. Assessment of GHG Interactions in the Vicinity of the Municipal Waste Landfill Site—Case Study. *Energies* **2021**, *14*, 8259. [CrossRef]
7. Sobianowska-Turek, A.; Grudniewska, K.; Maciejewski, P.; Gawlik-Kobylińska, M. Removal of Zn(II) and Mn(II) by Ion Flotation from Aqueous Solutions Derived from Zn-C and Zn-Mn(II) Batteries Leaching. *Energies* **2021**, *14*, 1335. [CrossRef]

8. Urbanowska, A.; Kabsch-Korbutowicz, M.; Aragon-Briceño, C.; Wnukowski, M.; Pożarlik, A.; Niedzwiecki, Ł.; Baranowski, M.; Czerep, M.; Seruga, P.; Pawlak-Kruczek, H.; et al. Cascade Membrane System for Separation of Water and Organics from Liquid By-Products of HTC of the Agricultural Digestate—Evaluation of Performance. *Energies* **2021**, *14*, 4752. [CrossRef]
9. Urbańska, W.; Osial, M. Investigation of the Physico-Chemical Properties of the Products Obtained after Mixed Organic-Inorganic Leaching of Spent Li-Ion Batteries. *Energies* **2020**, *13*, 6732. [CrossRef]
10. Gursky, V.; Kuzio, I.; Krot, P.; Zimroz, R. Energy-Saving Inertial Drive for Dual-Frequency Excitation of Vibrating Machines. *Energies* **2021**, *14*, 71. [CrossRef]
11. Kawalec, W.; Król, R. Generating of Electric Energy by a Declined Overburden Conveyor in a Continuous Surface Mine. *Energies* **2021**, *14*, 4030. [CrossRef]
12. Krysa, Z.; Bodziony, P.; Patyk, M. Discrete Simulations in Analyzing the Effectiveness of Raw Materials Transportation during Extraction of Low-Quality Deposits. *Energies* **2021**, *14*, 5884. [CrossRef]
13. Strzałkowski, P. Characteristics of Waste Generated in Dimension Stone Processing. *Energies* **2021**, *14*, 7232. [CrossRef]
14. Szurgacz, D. Dynamic Analysis for the Hydraulic Leg Power of a Powered Roof Support. *Energies* **2021**, *14*, 5715. [CrossRef]
15. BP. Statistical Review of World Energy: 70th Edition. 2021. Available online: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed on 16 April 2022).