CHAPTER XVI

ARTIFICIAL COOLING IN CHARCOAL KILNS: SYSTEMATIC REVIEW AND TECHNOLOGICAL PERSPECTIVES

RESFRIAMENTO ARTIFICIAL EM FORNOS DE CARVÃO VEGETAL: REVISÃO SISTEMÁTICA E PERSPECTIVAS TECNOLÓGICAS

DOI: 10.51859/amplla.sset.3225-16

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ABSTRACT

Charcoal production in Brazil, the world leader in this sector, faces the challenge of a prolonged production cycle, with natural cooling of kilns taking up to 14 days. In this context, the present study conducted a literature review of recent journals addressing artificial cooling strategies in charcoal kilns, aiming to optimize the production cycle. The methodology consisted of a systematic review of articles published between 2018 and 2025, using research platforms such as Google Scholar, CAPES, Scielo, ScienceDirect, and Elsevier. Out of 23 studies found and related to the proposed descriptors “artificial cooling,” “kilns,” and “charcoal,” both in English and Portuguese, nine were selected and categorized into Experimental Studies, Computational Simulations (CFD), and Reference Works. The selection was based on the inclusion of studies that presented a direct relationship with the investigative proposal of this work. The results show that artificial cooling, has the potential to reduce cooling time by up to 91%, enabling significant productivity gains. In the survey conducted, it was found that 44.44% of the studies specifically address the cooling stage of charcoal production, 33.33% employ computational fluid dynamics techniques, and 22.22% analyze the use of heat exchangers in this process. Despite these advances, a significant gap is observed in the literature, evidenced by the scarcity of publications on the subject, which highlights the need for further research in this area.

Keywords: Artificial Cooling; Computational Simulation; Heat Exchangers.

RESUMO

A produção de carvão vegetal no Brasil, líder mundial nesse setor, enfrenta o desafio de um ciclo produtivo prolongado, com o resfriamento natural dos fornos podendo levar até 14 dias. Diante disso, o presente estudo realizou uma revisão bibliográfica de periódicos recentes sobre estratégias de resfriamento artificial em fornos de carvão vegetal, buscando otimizar o ciclo de produção. A metodologia consistiu em uma revisão sistemática de artigos publicados entre 2018 e 2025, utilizando plataformas de pesquisa como Google Acadêmico, CAPES, Scielo, ScienceDirect e Elsevier. De 23 trabalhos encontrados e relacionados aos descritores “resfriamento artificial”, “fornos” e “carvão vegetal” propostos, tanto em inglês como em português, nove foram selecionados e categorizados em Estudos Experimentais, Simulações Computacionais (CFD) e Trabalhos de Referência. A seleção

baseou-se na inclusão de estudos que apresentavam relação direta com a proposta investigativa deste trabalho. Os resultados demonstram que o resfriamento artificial, tem potencial para reduzir o tempo de resfriamento em até 91%, permitindo ganhos de produtividade significativos. No levantamento realizado, constatou-se que 44,44% dos estudos abordam especificamente a etapa de resfriamento do carvão vegetal, 33,33% empregam técnicas de fluidodinâmica computacional e 22,22% analisam a aplicação de trocadores de calor nesse processo. Apesar desses avanços, observa-se uma lacuna significativa na literatura, evidenciada pela escassez de publicações sobre o tema, o que ressalta a necessidade de aprofundar as pesquisas na área.

Palavras-chave: Resfriamento Artificial; Simulação Computacional; Trocadores de Calor.

1 INTRODUCTION

Charcoal has several applications, such as in the production of ceramics, cement, and food, and is widely used for cooking and heating in commercial and residential environments, as pointed out by the report from the Ministry of the Environment (MMA) (MMA, 2019). The production of this raw material plays a significant role in the national economy, with Brazil being the world leader in charcoal production, reaching 7 million tons in 2022, most of which was destined for the domestic market (IBÁ, 2023). Continuing this prominent scenario, in 2023 national production reached 24.2 million cubic meters, of which approximately 88% originated in Minas Gerais, corresponding to 21.4 million cubic meters (Schmid et al., 2024).

Despite the wide use of charcoal in industry, its production in Brazil is still characterized by rudimentary technologies, with little process supervision and the absence of systematic quality control and efficiency practices (Dallastra, 2010; Rodrigues, 2019). Although traditional masonry kilns predominate—whose construction properties extend the cooling phase due to high thermal inertia—recent studies highlight that the adoption of heat exchangers, based on natural or forced convection, can reduce cooling time by between 5% and 70% and increase productivity by up to 65% (Rodrigues et al., 2023).

The specialized literature indicates that kilns must be cooled from approximately 500 °C to a temperature close to 60 °C before charcoal removal, a process that may take between seven and fourteen days using natural approaches (Santos, 2013). Oliveira et al. (2020) emphasize that, although naturally conducted operations are capable of cooling charcoal production kilns, the time required to achieve the desired product is considerable. Despite the scarcity of specific studies on the cooling stage in

the biomass production cycle, promising alternatives for reducing this time have recently been explored.

Strategies have been considered and analyzed with the aim of reducing cycle time and increasing production efficiency. Among the alternatives, noteworthy approaches include the use of gravity to transfer charcoal to a separate cooling chamber (Lana, 2018), the application of heat exchangers in different configurations (Gomes et al., 2020; Busselmann & Lima, 2023), and the study of kiln thermal behavior based on gas circulation, material properties, and boundary conditions through computational fluid dynamics (Busto-Vanegas et al., 2018; Lima, 2024; Valentim et al., 2022). These methodologies include both experimental approaches and computational modeling, and they show significant potential in reducing cooling time and, consequently, shortening the charcoal production cycle.

From this perspective, it is observed that the cooling process in carbonization systems remains little explored. There is a need for specific investigations on the subject, and a promising alternative in this context is Computational Fluid Dynamics (CFD), which employs computational resources to predict fluid dynamics inside the equipment based on the conservation equations of mass, momentum and energy (ANSYS, 2021). Therefore, this study aims to conduct a literature review of recent journals addressing artificial cooling strategies in charcoal production kilns, with a focus on studies proposing optimizations of this critical stage of the production process.

2 METHODOLOGY

This is a descriptive systematic review study, developed from the analysis of recent journals addressing artificial cooling in charcoal production kilns. To achieve the proposed objective, a search for articles was conducted in August 2025, considering works published between 2018 and 2025. The search was carried out on Google Scholar, the CAPES Portal of Journals (Coordination for the Improvement of Higher Education Personnel), SciELO (Scientific Electronic Library Online), Elsevier's database, and the ScienceDirect database, with the purpose of expanding the research scope.

The research was structured in two stages. In the first stage, studies were selected using the English keywords: "artificial cooling", "kilns", "furnace", and "charcoal". In the second stage, the Portuguese terms "resfriamento artificial", "fornos", and "carvão vegetal" were used. In both phases, the Boolean operator "AND" was

applied to locate works addressing the proposed themes simultaneously. The time frame considered publications between 2018 and 2025, with the aim of gathering the most up-to-date studies on the subject.

Data processing consisted of selecting recent studies that address the cooling stage in charcoal production kilns, highlighting that this phase remains underexplored in the literature. It was observed that only a small portion of these works employ numerical simulations using Computational Fluid Dynamics (CFD) techniques. Therefore, the selection criteria excluded studies without CFD and focused on identifying, from the searches conducted, those articles that applied this methodology.

The extracted data were organized based on technical and thematic criteria, such as the type of kiln analyzed (rectangular, cylindrical, traditional, or structurally modified), the construction material used (masonry, stainless steel, among others), the cooling method adopted (forced, with heat exchangers, among others), and the type of study (experimental, theoretical, computational, or review).

3 RESEARCH PROCEDURES

In order to simplify data communication, the authors established a nomenclature composed of a letter and a number to refer to each work: the letter “A” denotes Articles, “D” denotes Dissertations, and “T” denotes Theses. The database search resulted in 23 articles, of which 4 were indexed with the search term artificial cooling and 2 with the terms heat exchanger and computational fluid dynamics, representing 22.22% of the total studies found.

In the case of the SciELO database, however, no articles related to the subject of this study were identified. It is worth noting that comprehensive searches were carried out using Boolean operators, with terms in both Portuguese and English, in order to broaden the scope of publication retrieval. Meanwhile, the search conducted in the CAPES database resulted in 1 article, which was directly related to the field of artificial cooling, representing 100% of the articles retrieved from this source.

Table 1 – Nomenclature for Articles with the works collected from the CAPES platform

NN°	IID	Title	Authors
11	AA01	Qualidade do carvão vegetal submetido a diferentes taxas de resfriamento com trocador de calor.	Gomes *et al*. (2020)

Font: Authors, 2025.

As the research continued, no articles related to the proposed descriptors were found in the Elsevier database, either in English or Portuguese searches. In the ScienceDirect database, one article was selected which, although it does not directly address the research subject, is relevant for contextualizing the study by providing information on charcoal production that complements the overall discussion of the review. The details of this work can be found in Table 2.

Table 2 – Nomenclature for Articles with the works collected from the ScienceDirect platform

N°	ID	Title	Authors
2	A02	*Charcoal: A discussion on carbonization kilns*	Rodrigues & Braghini Junior (2019)

Font: Authors, 2025.

Finally, in relation to the Google Scholar database, 23 works were found with the proposed descriptors, of which only 7 were specifically related to “heat exchanger” and “computational fluid dynamics”. Table 3 compiles the selected articles and organizes them according to the nomenclature, year of publication, and authorship.

Table 3 – Nomenclature for Articles with the works collected from the Google Scholar platform

Nº	ID	Title	Authors
3	A03	Simulação numérica do resfriamento de um forno de carvão vegetal utilizando um trocador de calor de tubo duplo.	Busselmann & Lima (2023)
4	A04	Preparação de carvão ativado usando casca de arroz em um forno micro-ondas modificado.	Silva (2022)
5	A05	*Carbonization temperature and charcoal properties at different positions in rectangular kiln.*	Oliveira *et al*. (2020)
6	A06	*Physical and thermal properties of eucalyptus wood charcoal*	Santos et al. (2021)
7	A07	*Thermal inertia effects of the structural elements in heat losses during the charcoal production in brick kilns.*	Bustos-Vanegas *et al*. (2018)
8	A08	*Experimental characterization of self-heating behavior of charcoal from eucalyptus wood.*	Bustos-Vanegas *et al. (*2018*)*
9	A09	*Thermal performance analysis of materials and configurations for cylindrical sidewalls of charcoal kilns.*	Valentim et al. (2022)
10	A10	*Sustainable charcoal for" green steel" production: The case of Brazil.*	Amaral *et al*. (2020)
11	A11	*Yield From Forest Harvesting Operations for the Production of Charcoal in the State of Minas Gerais.*	Lana *et al*. (2019)
12	A12	*Charcoal heaps volume estimation based on unmanned aerial vehicles*.	Carvalho *et al*. (2021)

Nº	ID	Title	Authors
13	A13	*Conversion of infected pine wood into energy charcoal material based on a transportable carbonization system.*	Ni *et al. (*2024)
14	A14	*Perspectives and challenges of world charcoal production in technological, social, and climate change fields.*	Pereira *et al*. (2023)

Font: Authors, 2025.

In the same perspective, regarding theses and dissertations, Table 4 presents the works collected from the Google Scholar platform, classified according to nomenclature, year of publication, and authorship.

Table 4 – Nomenclature for Theses and Dissertations with the works collected from the Google Scholar platform

N°	ID	Title	Authors
1	T01	Forno de alvenaria para incremento da produtividade por meio do resfriamento externo do carvão vegetal.	Lana (2018)
2	D02	Estudo sobre os aspectos produtivos, tecnológicos e de qualidade do carvão vegetal.	Ivanov (2018)
3	T03	Modelo de desenvolvimento de soluções conceituais de forno de carbonização.	Rodrigues (2019)
4	T04	Metodologia para definição de layout de praça de produção de carvão vegetal.	Zola (2020)
5	D05	Uso de geotecnologia na análise da dinâmica da eucaliptocultura para produção de carvão vegetal na região do Bico do Papagaio no estado do Tocantins.	Lustosa (2020)
6	T06	Influência da densidade na resistência à flexão de vigas de madeira em situação de incêndio.	Perini (2022)
7	T07	Análise de eficiência de trocadores de calor baseado em superfícies mínimas triplamente periódicas (TPMS).	Demétrio (2023)
8	T08	Avaliação da ação antimicrobiana do extrato pirolenhoso neutralizado e bidestilado.	Gama (2023)
9	T09	*Furnace-kiln system carbon balance and economic viability for charcoal production on small farm*	Schettini (2021)

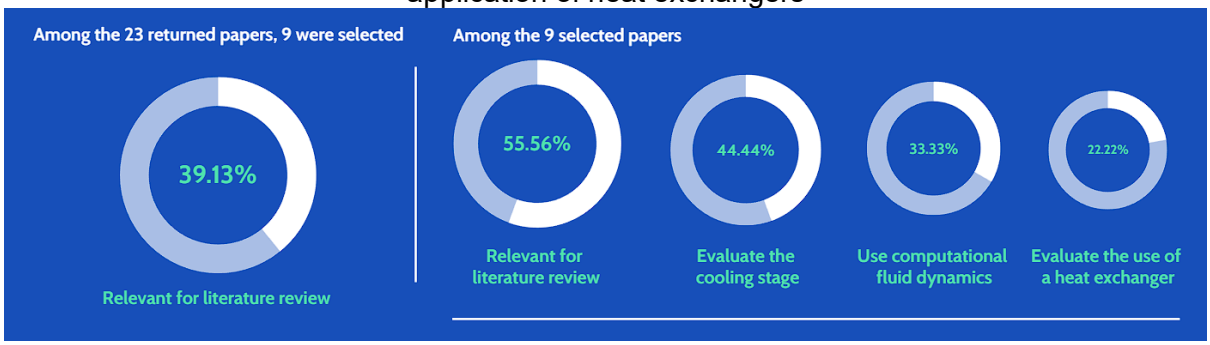
Font: Authors, 2025.

4 RESULTS AND DISCUSSION

The literature analysis, conducted based on 23 works retrieved from the research platforms, resulted in the selection of nine studies that align directly with the objectives of this research. As illustrated in Figure 1, 39.13% of the identified works were considered relevant for the literature review. Among the nine selected studies, 55.56% emphasize their relevance in supporting the theoretical framework, while 44.44% directly address the charcoal cooling stage. Additionally, 33.33% of the studies

employ CFD techniques, and 22.22% evaluate the application of heat exchangers in this process.

Figure 1 – Percentage distribution of the analyzed works regarding relevance for the literature review, focus on charcoal cooling, use of computational fluid dynamics, and application of heat exchangers



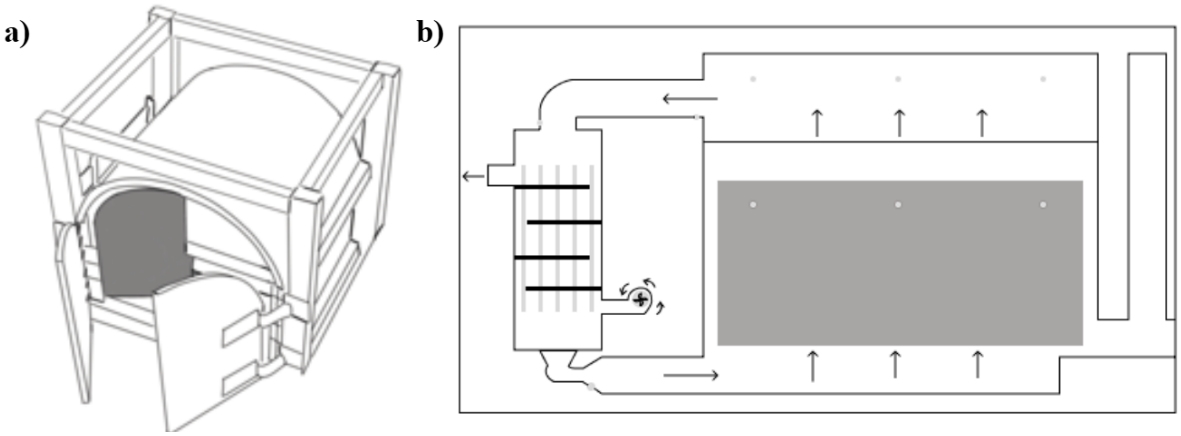
Font: Authors, 2025.

To facilitate the discussion, the works were classified according to their methodological and technological approaches into three main groups: Experimental Studies, Computational Simulations, and Reference and Review Works.

4.1 Experimental Studies Related to Cooling

This section addresses research that applied empirical methods to evaluate the cooling process. The study by Lana (2018) (T01) proposed an innovative cooling method in a masonry kiln through the discharge of the charcoal bed (Figure 2-a). The system, which uses gravity to transfer the material to a secondary container, reduced the process time to 12 hours while maintaining product quality.

Figure 2 – Kiln models used in the analyzed experimental cooling studies: a) Lana (2018) and b) Gomes et al. (2020)



Font: Lana (2018) and Gomes et al. (2020)

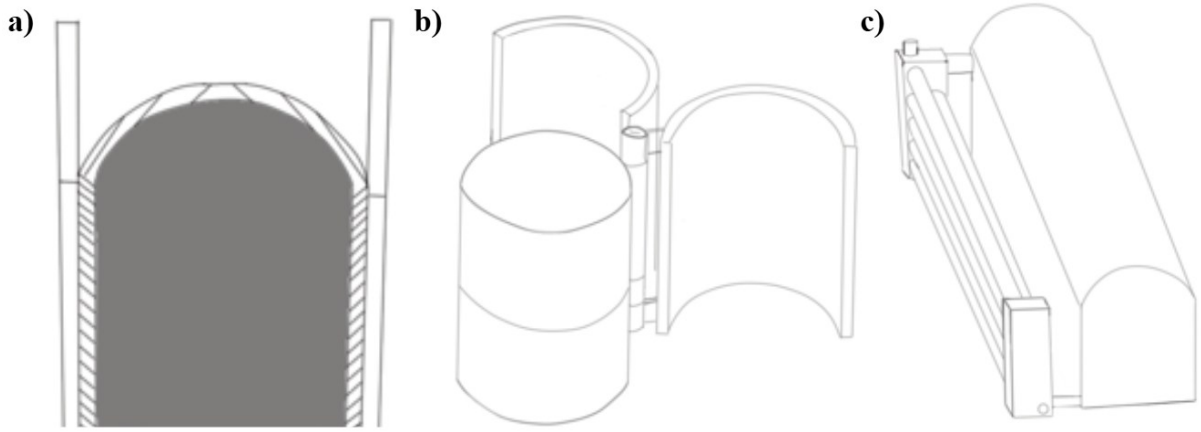
Tests were also conducted by Gomes et al. (2020) (A01) on rectangular kilns equipped with a shell-and-tube heat exchanger (Figure 2-b). Their experimental results demonstrated a reduction of up to 63% in cooling time, highlighting the applicability of heat exchange systems to optimize the process.

4.2 Computational Simulations for Thermal Profile Analysis

This category includes works that used numerical simulations to analyze the thermal behavior of kilns. Bustos-Vanegas et al. (2018) (A07) employed Computational Fluid Dynamics to investigate the thermal inertia of masonry kiln structures (Figure 3-a), concluding that the heat accumulated in the walls and floor is the main factor prolonging the cooling time.

In a similar approach, Valentim et al. (2022) (A09) applied CFD (ANSYS software) to analyze the thermal profile of cylindrical kiln walls (Figure 3-b). They proposed a movable sidewall design that can reduce cooling time by up to 91%, optimizing heat dissipation. Additionally, Busselmann & Lima (2023) (A03) used numerical simulation to study the cooling stage in a circular system with a double-pipe heat exchanger (Figure 3-c), demonstrating a 51% reduction in the cycle time.

Figure 3 – Kiln models used in the analyzed computational cooling studies: a) Bustos-Vanegas et al. (2018), b) Valentim et al. (2022), and c) Busselmann & Lima (2023)



Font: Bustos-Vanegas et al. (2018); Valentim et al. (2022); Busselmann & Lima (2023).

4.3 Reference and Review Works

This category encompasses studies with a broader perspective, serving as a theoretical or contextual foundation. Rodrigues and Braghini Junior (2019) (A02) conducted a literature review of patents highlighting the scarcity of research on cooling control, especially with heat exchangers. Rodrigues (2019) (T03), in turn, developed a conceptual model for kiln design that organizes different geometries and cycle

reduction principles, serving as a fundamental tool for the development of new technologies.

Finally, the studies by Oliveira et al. (2020) (A05) and Santos et al. (2021) (A06) contribute to understanding charcoal properties and the importance of temperature control. The study by Santos et al. (2021) (A06) is particularly relevant, as it investigates the physical and thermal properties of the biomass while emphasizing the importance of models that consider interstitial velocity for heat exchanger design.

To provide an overview of the strategies adopted and the results obtained in charcoal kiln cooling, the main studies were organized in Table 5, summarizing information on author, year, kiln type, methodology, time reduction, and the main conclusions of each study.

Table 5 – Comparison of the main studies on charcoal kiln cooling

Author (s), year and code	Kiln Type	Methodology	Time Reduction	Main Conclusions
Busselmann & Lima (2023) (A03)	Rectangular	Numerical simulation and mathematical modeling of a kiln and a double-pipe heat exchanger.	Up to 51%	Proposes a refinement of the mathematical models of the kiln and exchanger to increase cooling efficiency, considering that the double-pipe exchanger is a simple and effective solution.
Valentim et al. (2022) (A09)	Cylindrical	Numerical analysis of the thermal profile of different sidewalls.	Up to 91% for the pivoting sidewall	The pivoting sidewall proved to be the most promising, controlling heat exchange and optimizing the thermal performance of the kiln.
Gomes et al. (2020) (A01)	Rectangular	Influence of different gas velocities tested in the porous bed.	Up to 63% compared to natural cooling	It was concluded that gas flow velocity is more efficient, and the design should consider pressure differences.
Bustos-Vanegas et al. (2018) (A07)	Cylindrical	Computational fluid dynamics simulation to analyze thermal inertia.	Not applicable	Heat accumulated in the walls and floor reduces cooling efficiency. They suggest using low thermal conductivity materials and systems with artificial cooling.
Lana (2018) (T01)	Masonry kiln with inclined floor	Discharge of hot charcoal by gravity to a cooling container.	Kiln: 2 h / Container: 10 h	The use of temperature control ensured good-quality charcoal, while the system reduced cooling and carbonization times.

Font: Authors, 2025.

The authors were selected for their direct relevance to the topic of this research, employing different methods to validate the proposed objectives. Table 5 shows that both experimental approaches (Lana, 2018; Gomes et al., 2020) and computer simulations (Bustos-Vanegas et al., 2018; Valentim et al., 2022; Busselmann & Lima, 2023) can contribute to significantly reducing cooling time, confirming the applicability of artificial cooling devices.

The diversity of studies reinforces the importance of investigating thermal inertia and the properties and geometry of kilns, with the aim of advancing research and optimizing the production cycle in charcoal production, especially in Brazil, the world's largest producer.

5 CONCLUSIONS/FINAL CONSIDERATIONS

Based on the analysis of the selected studies, it is evident that artificial cooling is a viable approach to optimize the charcoal production cycle, enabling considerable productivity gains, which can exceed 90% in some approaches. However, the review also reveals the limitation and absence of studies specifically addressing this stage of the production cycle in the literature.

In this context, it can be concluded that, although artificial cooling represents an effective strategy for optimizing the production cycle, the continuation of research is essential to expand knowledge on the subject.

As a future perspective, it is important to intensify research aimed at improving kilns, incorporating technologies that enable the integration of computational simulations, practical experiments, and sustainability analyses. Advancing these processes allows for the reduction of the production cycle, enhancing the efficiency and productivity of the biomass. In the Brazilian context, as the world’s largest producer, this approach contributes to consolidating sustainable renewable energy production, optimizing the use of forest resources, and expanding the potential of this biofuel.

REFERENCES

Amaral, D. H., Silva, A. P. S., Anater, M. J. N., Neiva, S. A., & Coelho, S. T. Sustainable charcoal for “green steel” production: The case of Brazil. In 8th International Congress on Biofuels and Renewable Energy, Rio de Janeiro, Brazil. (2020, October).

ANSYS, Inc. ANSYS user manual. Canonsburg, PA: ANSYS Inc. (2021). https://storage.ansys.com/act/v211/ACTReferenceHTML/index.html

Bustos-Vanegas, J. D. (2018). Charcoal cooling kinetics: Computational simulation and industrial applications (Doctoral thesis, Universidade Federal de Viçosa). Universidade Federal de Viçosa.

Bustos-Vanegas, J. D., Martins, M. A., Carneiro, A. C. O., Freitas, A. G., & Barbosa, R. C. (2018). Thermal inertia effects of the structural elements in heat losses during the charcoal production in brick kilns. Fuel, 226, 508–515. https://doi.org/10.1016/j.fuel.2018.04.024

Busselmann, F., & Lima, T. P. (2023). Simulação numérica do resfriamento de um forno de carvão vegetal utilizando um trocador de calor de tubo duplo. ForScience, 11(2), e01184. https://doi.org/10.29069/forscience.2023v11n2.e1184

Carvalho, L. M. E., Melo, A., Umbelino, G. J. M., Mund, J. P., Santos, J. G., Rosette, J., Silveira, D., & Gorgens, E. B. (2021). Charcoal heaps volume estimation based on unmanned aerial vehicles. Southern Forests: A Journal of Forest Science, 83(3), 235–245. https://hdl.handle.net/10520/ejc-soufor-v83-n4-a9

Dallastra, E. C. (2010). Sistemas de produção de carvão vegetal existentes no Brasil: Uma análise de viabilidade econômica (Master's dissertation, Fundação Getúlio Vargas).

Demétrio, M. H. O. (2023). Análise de eficiência de trocadores de calor baseados em superfícies mínimas triplamente periódicas (TPMS) (Trabalho de Conclusão de Curso, Instituto Federal de Pernambuco).

Gama, G. S. P. (2023). Avaliação da ação antimicrobiana do extrato pirolenhoso neutralizado e bidestilado (Master's dissertation, Universidade Federal do Rio Grande do Norte). Natal, Brazil. (2023).

Gomes, A. F., Martins, M. A., Pereira, E. G., Santos, I. S., & Carneiro, A. C. O. (2020). Qualidade do carvão vegetal submetido a diferentes taxas de resfriamento com trocador de calor. Ciência Florestal, 30(4), 1007–1018.

IBÁ – Indústria Brasileira de Árvores. (2023). Relatório anual 2023. Brasília, DF: IBÁ. https://iba.org/wp-content/uploads/2025/05/relatorio-anual-iba2023-r.pdf

Ivanov, R. B. (2018). Estudo sobre os aspectos produtivos, tecnológicos e de qualidade do carvão vegetal (Master's dissertation, Universidade Federal do Rio Grande do Sul). Porto Alegre, Brazil.

Lana, A. Q. (2018). Forno de alvenaria para incremento da produtividade por meio do resfriamento externo do carvão vegetal (Doctoral thesis, Universidade de São Paulo). Piracicaba, Brazil.

Lana, G. C., Timofeiczyk Jr, R., Silva, D. A., Buratto, D. A., & Oliveira, G. S. (2019). Yield from forest harvesting operations for the production of charcoal in the state

of Minas Gerais. Journal of Agricultural Science, 11(14), 12–26. https://doi.org/10.5539/jas.v11n14p12

Lima, S. C. (2024). Modelagem e simulação do resfriamento natural de fornos circulares de produção de carvão vegetal (Master's dissertation, Universidade Federal dos Vales do Jequitinhonha e Mucuri). Diamantina, Brazil.

Lustosa, F. O. S. (2020). Uso de geotecnologia na análise da dinâmica da eucaliptocultura para produção de carvão vegetal na região do Bico do Papagaio no estado do Tocantins (Master's dissertation, Universidade Federal do Tocantins). Palmas, Brazil.

Ministério do Meio Ambiente. (2019). Produção sustentável de carvão vegetal: Manual de construção sistemas fornos, fornalha. Brasília, DF: MMA. https://files.acquia.undp.org/public/migration/br/9ef0c7e1095443cb107e069e52f67c8ae8ea6123b3c9c3f41ce90ef91048136c.pdf

Ni, L., Gao, Q., Ren, H., Su, M., Rong, S., & Liu, Z. (2024). Conversion of infected pine wood into energy charcoal material based on a transportable carbonization system. Biochar, 6(1), 24. https://doi.org/10.1007/s42773-024-00340-3

Oliveira, A. C., Ramos, D. C., Pereira, B., & Carneiro, A. (2020). Carbonization temperature and charcoal properties at different positions in rectangular kiln. Revista Brasileira de Agropecuária Sustentável, 10(2), 15–28. 10.5039/agraria.v15i4a8493

Pereira, A.K.S. et al. (2023). Perspectives and Challenges of World Charcoal Production in Technological, Social, and Climate Change Fields. In: de Souza, E.C., Muthu, S.S. (eds) Forest Science. Environmental Footprints and Eco-design of Products and Processes. Springer, Singapore. https://doi.org/10.1007/978-981-99-2846-0_1

Perini, P. V. (2022). Influência da densidade na resistência à flexão de vigas de madeira em situação de incêndio (Master's dissertation, Faculdade Jesuíta de Filosofia e Teologia). Belo Horizonte, Brazil.

Rodrigues, T. (2019). Modelo de desenvolvimento de soluções conceituais de forno de carbonização (Doctoral thesis, Universidade Tecnológica Federal do Paraná). Ponta Grossa, Brazil.

Rodrigues, T., Barcellos, D. C., & Braghini Junior, A. (2023). State of the art on development and improvement of slow carbonization kilns for charcoal production. Journal of Analytical and Applied Pyrolysis, 176, 106257. https://doi.org/10.1016/j.jaap.2023.106257

Rodrigues, T., & Braghini Junior, A. (2019). Technological prospecting in the production of charcoal: A patent study. Renewable and Sustainable Energy Reviews, 111, 170–183. https://doi.org/10.1016/j.rser.2019.04.080

Santos, I. S. (2013). Resfriamento artificial de carvão vegetal em fornos de alvenaria (Doctoral thesis, Universidade Federal de Viçosa). Viçosa, Brazil.

Santos, I. S., Martins, M. A., Gomes, A. F., Pereira, E. G., & Carneiro, A. de C. O. (2021). Análise física de carvão vegetal produzido e submetido a diferentes taxas de resfriamento para uso na siderurgia. In Madeiras nativas e plantadas do Brasil: Qualidade, pesquisas e atualidades (pp. 468–481). Editora Científica. https://doi.org/10.37885/210504780

Schettini, B. L. S. (2021). Estudo de propriedades do carvão vegetal (Master's dissertation, Universidade Federal de Viçosa). Viçosa, Brazil.

Schmid, M. L., Barros, A. C., Costa, F., & Rieth, L. C. T. (2024). Carvão vegetal no Brasil: Uma visão panorâmica do mercado e suas perspectivas. Boletim Técnico SIF, 4(5). https://sif.org.br/wp-content/uploads/2024/05/BOLETIM-INDEX_Maio24_Final1-1.pdf

SILVA, J. S. (2022). Preparação de carvão ativado usando casca de arroz em um forno micro-ondas modificado. In Anais do 25º Congresso Brasileiro de Engenharia e Ciência dos Materiais (CBECiMat), São Paulo, SP, Brasil. https://guaiaca.ufpel.edu.br/handle/prefix/12964

Valentim, A. R., Behainne, J. R., & Braghini Junior, A. (2022). Análise de desempenho térmico de materiais e configurações para paredes laterais cilíndricas de fornos de carvão vegetal. Energies, 15(16), 5872. https://doi.org/10.3390/en15165872

Zola, F. C. (2020). Metodologia para definição de layout de praça de produção de carvão vegetal (Master's dissertation, Universidade Tecnológica Federal do Paraná). Curitiba, Brazil.