Volume 13. Number 2. 249-256 DECEMBER 2024

Jurnal ilmiah pendidikan fisika Al-Biruni
https://ejournal.radenintan.ac.id/index.php/al-biruni/index
DOI: 10.24042/jipfalbiruni.v13i2.24535

p-ISSN: 2303-1832
e-ISSN: 2503-023X

Griddle and Chimney Conductivity in a Husk Furnace: An Influence of Oxygen Flow and Orifice Size

Irzaman[1], Rahmah Asri Nurani Hanifan[1], Ridwan Siskandar[2], Heriyanto Syafutra[1], Renan Prasta Jenie[3], Marina Indriasari[3], Suharno[1], Naila Nur Alifa[1], Fara Aulia Azzahra[1], Habibah Assa'addah[1], Renny Apriani Dwika Saputri[1]

[1] Department of Physics, Faculty of Mathematics and Natural Sciences, IPB University, Bogor, 16680, Indonesia
[2] Computer Engineering Research Program, Vocational School, IPB University, Bogor, 16680, Indonesia
[3] Graduate Department of Public Health, Faculty of Health Sciences and Technology, Binawan University

**Corresponding Address: irzaman@apps.ipb.ac.id*

Article Info

Article history:

Received: September 2, 2024
Accepted: December 10, 2024
Published: December 30, 2024

Keywords:

Husk Furnace;
Oxygen Flow;
Risk Husk;
Thermal Conductivity;
Valve Hole Size.

ABSTRACT

This research investigates the effect of oxygen flow valve orifice size on the thermal conductivity of a small-scale industrial husk furnace's pan and chimney. The researchers used a water boiling test to the thermal conductivity at varying valve hole sizes: 36×27 cm, 36×34 cm, 43×34 cm, and 50×34 cm. The pan, crucial for direct contact with cooking ingredients, and the chimney, responsible for fire flow during combustion, play vital roles in heating. The chimney, constructed of clay and zinc, exhibited thermal conductivity values ranging from 0.52 to 0.59 W m^{-1} °C^{-1}. The highest chimney thermal conductivity was observed at the 50x34 cm valve hole size, attributed to a smaller temperature difference between the inner and outer chimney surfaces. The pan's average thermal conductivity ranged from 2.95 to 4.10 W m^{-1} °C^{-1}, with the highest value recorded at 50×34 cm orifice. This finding suggests a direct relationship between the valve hole size, heat transfer rate, and the pan's thermal conductivity. The research reveals the influence of oxygen flow on heat transfer within the husk furnace, providing valuable insights for optimizing its design and efficiency. While the chimney's thermal conductivity remained relatively stable across different orifice sizes, the pan's conductivity showed greater variation, potentially indicating inconsistent heat distribution. Further research with more precise temperature measurement techniques is recommended to refine these findings.

INTRODUCTION

Indonesia, an agriculturally rich nation, relies heavily on its agricultural sector for economic stability and food security. Beyond their primary role as food sources, agricultural products are increasingly recognized for their potential as renewable energy resources (Bowman et al., 2023; Kashif et al., 2020; Kucher & Prokopchuk, 2020; Martinho, 2018). A significant source of this energy lies in agricultural waste, which is often underutilized (Iskandar & Siswati, 2012; Shahbazi et al., 2024). This waste, known as biomass, encompasses all organic material produced through photosynthesis (Parinduri et al., 2020).

How to cite Irzaman, I., Hanifan, Rahmah A. N., Siskandar, R., Syafutra, H., Jenie, R. P., Indriasari, M., Suharno, S., Alifa, N. N., Azzahra, F. A., Assa'addah, H., & Saputri, R. A. D. (20XX). Griddle and Chimney Conductivity in a Husk Furnace: Influence of Oxygen Flow and Orifice Size. *Jurnal ilmiah pendidikan fisika Al-Biruni, 13*(2), 249-256.

Effective biomass utilization offers a promising avenue for renewable energy generation, with Indonesia possessing an estimated potential of 146.7 million tons annually. Harnessing this resource offers a triple benefit: improved energy efficiency, cost reduction, and decreased landfill burden (Haqiqi, 2024).

However, biomass energy content is generally lower than fossil fuels, necessitating optimized conversion techniques (Iskandar & Siswati, 2012). Various methods exist for maximizing energy extraction from biomass, including pellet production (Wahyullah et al., 2018). Crucially, understanding the factors influencing energy output requires thorough investigation and testing.

Heat transfer plays a critical role in biomass energy optimization. Heat naturally flows from warmer to cooler objects, a process governed by the principles of thermodynamics (Lienhard, 2005; Taler, 2019; Varuvel et al., 2023). Three primary modes of heat transfer are conduction (in solids, described by Fourier's Law) (Wang & Wang, 2022; Zhang et al., 2024), convection (in fluids and between fluids and solids, governed by Newton's Law of Cooling), and radiation (between surfaces via electromagnetic energy exchange (Mauri, 2015), as defined by the Stefan-Boltzmann Law) (Sidebotham, 2015)

The thermal conductivity of a material property is a key factor in conductive heat transfer. Poor thermal conductivity significantly influences the heating process, hindering efficient heat transfer (Widianto et al., 2024). In combustion devices, thermal conductivity is particularly important, impacting overall heating performance. Generally, thermal conductivity increases with temperature (Hao, 2023; Ordonez-Miranda et al., 2022; Saputraa et al., 2022), highlighting the need for accurate measurement to assess heat transfer effectiveness within devices like husk furnaces.

Husk furnaces, characterized by their inverted pyramid-shaped combustion chambers and wall perforations (Hanifan et al., 2023), have been the subject of numerous studies. Previous research (Hanifan et al., 2023) focused on optimizing oxygen flow valve holes to improve heat efficiency, achieving a 54.99% efficiency. Building on this work, this research investigated the thermal conductivity of the pan and chimney within a husk furnace with the same valve hole configurations.

The chimney's construction utilizes clay, often lined with zinc, reflecting traditional designs. Clay's widespread use in biomass-fueled stoves stems from its strength and high melting point (Boafo-Mensah et al., 2020; Djafar et al., 2022; Mirmanto et al., 2018; Suluh et al., 2023).

This research employed a small industrial-scale husk furnace, incorporating the valve hole dimensions (36×27 cm, 36×34 cm, 43×34 cm, and 50×34 cm) previously studied by Hanifan et al. (2023). Unlike prior work, this research focused on thermal conductivity, providing deeper insights into material heat transfer properties. Understanding thermal conductivity is crucial for optimizing the heating process, particularly within the pan (which directly contacts cooking materials) and the chimney (responsible for gas flow).

Therefore, this research aimed to determine the effect of oxygen flow valve hole size (36×27 cm, 36×34 cm, 43×34 cm, and 50×34 cm) on the average thermal conductivity of both the pan and the chimney within a small industrial-scale husk furnace.

METHODS

The Water Boiling Test (WBT) method measured thermal conductivity in small-scale industrial husk furnaces. This simple simulation is performed by heating water to a lower boiling level (Quist et al., 2020; Rani et al., 1992; Zhang et al., 2017). The materials needed were dry rice husk and water. The tools needed were an infrared thermometer, 42 cm pan, pan lid, measuring cup, scales, matches, stopwatch, and husk furnace with variations of oxygen flow valve holes: 36×27 cm, 36×34 cm, 43×34 cm, and 50×34 cm. Another factor that needed to be considered was the mass of water heated during the test. The mass of water used was 6 kg and 18 kg, and each valve hole was tested twice. Figure 1 shows the flow chart of this research.

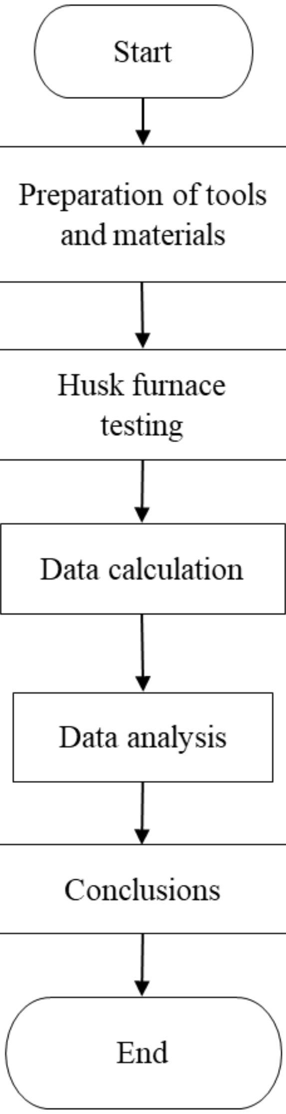

Figure 1. Research Flowchart

The effect of varying the size of the oxygen flow valve hole on the thermal conductivity of the pan and chimney can be known through the analysis of calculations and several parameters that can be calculated based on several points:

1. The thermal conductivity of the pan is the thermal conductivity value found on the outer surface of the pan. Thermal conductivity is the rate of heat flow per unit area in a solid or fluid (Forsberg, 2021).

$$\frac{H}{A} = -k\,\frac{dT}{dx} \tag{1}$$

H is the heat transfer rate (J/s), and k is the thermal conductivity in W m $^{-10}$ C^{-1} (1 Wm^{-10} C^{-1} = 1 W m^{-1} K^{-1}). The thermal conductivity of a frying pan is affected by the outer area of the pan (A_{p_o}), the thickness of the pan (L_p), and the temperature difference between the inner pan (T_{p_i}) and the outside (T_{p_o}).

$$\frac{H}{A_{p_o}}\int_0^L dx = -\int_{T_{p_o}}^{T_{p_i}} k_p\, dT \tag{2}$$

$$\frac{H}{A_{p_o}} L_p = k_p (T_{p_o} - T_{p_i}) \tag{3}$$

$$k_p = \frac{H L_p}{A_{p_o}} \frac{1}{(T_{p_o} - T_{p_i})} \tag{4}$$

The temperature of the outer pan (T_{p_o} and inner pan (T_{p_i}) are obtained based on the equation:

$$T_{p_o} = \frac{\sum A_{{p_o}_i} \times T_{{p_o}_i}}{A_{w_l}} \tag{5}$$

$$T_{p_o} = \frac{\left(A_{{p_o}_1} \times T_{{p_o}_1}\right) + \left(A_{{p_o}_2} \times T_{{p_o}_2}\right) + \left(A_{{p_o}_3} \times T_{{p_o}_3}\right)}{A_{p_o}} \tag{6}$$

$$T_{p_i} = \frac{\sum A_{{p_i}_i} \times T_{{p_i}_i}}{A_{w_d}} \tag{7}$$

$$T_{p_i} = \frac{\left(A_{{p_i}_1} \times T_{{p_i}_1}\right) + \left(A_{{p_i}_2} \times T_{{p_i}_2}\right) + \left(A_{{p_i}_3} \times T_{{p_i}_3}\right)}{A_{p_i}} \tag{8}$$

The temperature of the outer pan (T_{p_o}) and inner pan (T_{p_i}) is obtained by measuring the temperature at three points of the pan, i.e. bottom ($T_{{p_o}_1}$ and $T_{{p_i}_1}$), centre ($T_{{p_o}_2}$ and $T_{{p_i}_2}$), and top ($T_{{p_o}_3}$ and $T_{{p_i}_3}$) and is affected by the surface area of the pan (A_{p_o} and A_{p_i}). To determine the temperature of the outer and inner pan, it is necessary to know the surface area of the pan at each measuring point of the pan temperature, namely bottom ($A_{p_{o_1}}$ and $A_{p_{i_1}}$), centre ($A_{p_{o_2}}$and $A_{p_{i_2}}$), and top ($A_{p_{o_3}}$ and $A_{p_{i_3}}$).

2. The thermal conductivity of the chimney of a husk kiln is affected by the rate of heat transfer (H_c) in the chimney. This value is obtained using the interpolation method based on the value of the transfer rate on the coals (H_{coal}), the rate of displacement on the pan (H_{pan}), the length of the pan to the coals (l_{p-co}), and the length of the pan to the chimney thermal conductivity point (l_{p-c}).

$$\frac{H_{coal}-H_c}{l_{p-co}-l_c} = \frac{H_{coal}-H_{pan}}{l_{p-co}} \tag{9}$$

H_{coal} is known by multiplying the emissivity of the pan (ε_{pan}), Boltzmann constant (σ), the area from the coal to the pan (A_{co-p}), and the temperature at the ember (T_{coal}). Similarly, the H_{pan}, which is differentiated by the temperature on the outer pan surface (T_{p_o})

$$H_{coal} = \varepsilon_{pan}\sigma A_{co-p}(T_{coal}^4 - 0) \tag{10}$$

$$H_{pan} = \varepsilon_{pan}\sigma A_{co-p}\left(T_{p_{o_1}}^4 - 0\right) \tag{11}$$

After H_c is known, look for the value of the chimney's thermal conductivity in the cylinder wake. A_c is the surface area of the chaff furnace chimney, $d\theta$ shows the change in temperature of the outer and inner chimneys, and dr is the difference in radius inside and outside the chaff furnace chimney.

$$H_c = -kA_c\frac{d\theta}{dx} \tag{12}$$

$$H_c = -k_c(2\pi r h_c)\frac{d\theta}{dx} \tag{13}$$

$$H_c\frac{dr}{r} = -2\pi k_c h_c d\theta \tag{14}$$

$$\int_{r_1}^{r_2} H_c\frac{dr}{r} = -2\pi k_c h_c \int_{\theta_1}^{\theta_2} d\theta \tag{15}$$

$$H_c\left[\ln\frac{r_2}{r_1}\right] = 2\pi k_c h_c[\theta_1 - \theta_2] \tag{16}$$

$$(\theta_1 - \theta_2) = \frac{H_c}{2\pi k_c h_c}\ln\frac{r_2}{r_1} \tag{17}$$

$$k_c = \frac{1}{(\theta_1-\theta_2)}\frac{H_c}{2\pi h_c}\ln\frac{r_2}{r_1} \tag{18}$$

K is the thermal conductivity in the chimney of the husk furnace that occurs in a cylindrical chimney with an inner radius r_1 at temperature θ_1 and outer radius r_2 at temperature θ_2 is the temperature on the outside of the chimney, H_c is the heat transfer rate at the point of thermal conductivity of the chimney, and h e is the height of the chimney of the husk furnace.

RESULTS AND DISCUSSION

Thermal conductivity is a material property that shows the amount of heat that flows across a unit area (Iskandar, 2014; Webster & Eren, 2017; Zheng et al., 2021). In this research, thermal conductivity was needed to determine the nature of the pan and chimney of the husk furnace in flowing heat. The greater the thermal conductivity value, the better the material's properties are for conducting heat. The value of thermal conductivity is used in the industrial world as a reference to determine the new properties of the material. Through the value of the thermal conductivity of the material, the heat treatment and the time required for the material to achieve the desired properties and reduce errors in the heat treatment process on the material can be determined (Kulkarni et al., 2019; Pangestu et al., 2023).

The chimney of the husk furnace consisted of an insulator in the form of a jug of clay coated with zinc plates. Clay has a thermal conductivity of 0.39 - 0.63 W m^{-1} K^{-1} (1 W m K$^{-1\ -1}$ = 1 W m $^{-1\ 0}$C^{-1}). The thermal conductivity of pure zinc is 116 W m^{-1} K^{-1}. In this research, the thermal conductivity of the chimney is 0.52 - 0.59 W m^{-1} ^{o}C^{-1}. The thermal conductivity generated in this research refers to the clay material. Zinc only acted as a coating and had gone through a process to become a slab. Its content was not only pure zinc.

Table 1. Average Chimney Thermal Conductivity by Oxygen Flow Valve Hole Size

Oxygen Flow Valve Hole Size (cm)	**Average Chimney Thermal Conductivity (W m^{-1} ^{o}C^{-1})**
36×27	0.58 ± 0.09
36×34	0.52 ± 0.04
43×34	0.55 ± 0.12
50×34	0.59 ± 0.15

The largest chimney thermal conductivity was generated at the valve hole measuring 50×34 cm and the smallest at 36×34 cm. The thermal conductivity of the chimney was inversely proportional to the temperature difference between the outer and inner chimney and directly proportional to the heat transfer rate in the chimney of the husk furnace (equation (18)). The valve hole measuring 50×34 cm produced the smallest temperature difference between the inside and outside of the chimney. Therefore, a griddle and a chimney's thermal conductivity rises by size.

The thermal conductivity of carbon steel (1%C) is 43 Wm^{-1} ^{0}C^{-1} and chrome-nickel steel (18%C, 8%Ni) is 16.3 m^{-1} ^{0}C^{-1} (Prihartono & Irhamsyah, 2022). The pan's constituent materials include steel, aluminium, stainless steel, and metal. Based on this research, the average thermal conductivity of the pan obtained was 2.95 - 4.10 W m^{-1} ^{0}C^{-1}. The thermal conductivity of the pan obtained in this research tended to be low compared to steel's thermal conductivity. This low value was due to the pan used in this research containing materials other than steel as its constituent. Prihartono & Irhamsyah (2022) conducted thermal conductivity testing of carbon steel and chrome-nickel steel. The pan used in this research was not determined, so the resulting thermal conductivity was quite different from the thermal conductivity of steel.

Table 2. The Average Thermal Conductivity of Pans Based on Oxygen Flow Valve Hole Size

Oxygen Flow Valve Hole Size (cm)	**Average Thermal Conductivity of the Pan (W m^{-1} ^{o}C^{-1})**
36×27	3.40 ± 1.34
36×34	2.95 ± 0.47
43×34	3.35 ± 1.00
50×34	4.10 ± 1.72

The average thermal conductivity of the largest pan was produced in the husk furnace with an oxygen flow valve hole measuring 50×34 cm. The thermal conductivity of the pan was influenced by the heat transfer rate and the temperature difference on the outer and inner surfaces of the pan (equation (4)). The thermal conductivity of the pan was inversely proportional to the temperature difference between the outside and inside of the pan and directly proportional to the heat transfer rate. As the temperature difference between the outside and inside of the pan increased, the thermal conductivity of the pan decreased. A high heat transfer rate resulted in a high thermal conductivity as well.

The change in temperature and the difference in heat transfer rate previously found in the research by Hanifan et al. (2023) caused the thermal conductivity of the pan to be unequal. Even so, the overall value difference was only a little, with a small percentage of error. Small industrial-scale husk furnaces can deliver heat that is quite stable during the heating process because the value of the thermal conductivity of the chimney tends to be almost the same.

However, the pan's thermal conductivity had a significant range for each valve hole size, indicating that the heat energy received by the pan could be incomplete by affecting the conductivity value. Improper temperature measurement during the heating process was also another factor of thermal conductivity. A more detailed reference is needed for the pan's temperature during heating.

CONCLUSION AND SUGGESTION

The researchers successfully conducted research using a small industrial-scale husk furnace with valve hole sizes of 36×27 cm, 36×34 cm, 43×34 cm, and 50×34 cm. The thermal conductivity value provides more in-depth information on how well a material conducts heat. This provides a different observation of how influential the size of the husk furnace oxygen flow valve hole is on the heat transfer process during heating, especially in the pan and chimney of the husk furnace. The frying pan and chimney of the husk furnace have an important role during heating. The frying pan is in direct contact with the cooking ingredients, while the chimney is the part of the chaff kiln that flows the fire during the combustion process.

The highest average thermal conductivity of the frying pan was 4.10 ± 1.72 $Wm^{-1}°C^{-1}$, while the average thermal conductivity of the chimney was 0.59 ± 0.15 $Wm^{-1}°C^{-1}$ at the largest oxygen flow valve hole size of 50 × 34 cm. This is likely because the larger size of the oxygen flow valve hole increases the heat energy generated in the pan, resulting in the highest average thermal conductivity for both the pan and the chimney. We suggest evaluating the use of a larger griddle and chimney.

AUTHOR CONTRIBUTIONS

IRZ: Conceptualization, project administration, and methodology. RS, HS, RPJ, MI, and SHRN: supervision, resources, formal analysis, writing, and reviewing. RANH, NNA, FAA, HA, and RADS; writing—original draft and project administration

REFERENCES

Boafo-Mensah, G., Darkwa, K. M., & Laryea, G. (2020). Effect of combustion chamber material on the performance of an improved biomass cookstove. *Case Studies in Thermal Engineering*, *21*, 100688. https://doi.org/10.1016/j.csite.2020.100688

Bowman, G., Huber, T., & Burg, V. (2023). Linking solar and biomass resources to generate renewable energy: Can we find local complementarities in the agricultural setting? *Energies*, *16*(3), 1486. https://doi.org/10.3390/en16031486

Djafar, Z., Suluh, S., Amaliyah, N., & Piarah, W. H. (2022). Comparison of the performance of biomass briquette stoves on three types of stove wall materials. *International Journal of Design & Nature and Ecodynamics*, *16*(6), 145–149. https://doi.org/10.18280/ijdne.170119

Forsberg, C. H. (2021). Mass transfer. In *Heat Transfer Principles and Applications* (pp. 429–457). Elsevier. https://doi.org/10.1016/B978-0-12-802296-2.00011-1

Hanifan, R. A. N., Hajar, S., Har, N. P., Zuhri, M., Rustami, E., Nikmatin, S., & Irzaman, I. (2023). Efficiency improvement, design optimization, and expansion of oxygen flow valve holes in small industrial scale husk furnaces. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *12*(2), 231. https://doi.org/10.24042/jipfalbiruni.v12i2.18960

Hao, T. (2023). Resistivity of various metals described in a wide temperature range with a universal theoretical equation. *Physica B: Condensed Matter*, *655*, 414770. https://doi.org/10.1016/j.physb.2023.414770

Haqiqi, A. Z. (2024). Penggunaan biomassa sebagai energi alternatif pembangkit listrik di wilayah pedesaan. *Journal of Optimization System and Ergonomy Implementation*, *1*(1), 42–51. https://doi.org/10.54378/joseon.v1i1.6766

Iskandar, S. (2014). *Perpindahan panas*. Deepublish.

Iskandar, T., & Siswati, N. D. (2012). Pemanfaatan limbah pertanian sebagai energi alternatif melalui konversi thermal. *Buana Sains*, *12*(1), 117–122.

Kashif, M., Awan, M. B., Nawaz, S., Amjad, M., Talib, B., Farooq, M., Nizami, A. S., & Rehan, M. (2020). Untapped renewable energy potential of crop residues in Pakistan: Challenges and future directions. *Journal of Environmental Management*, *256*, 109924. https://doi.org/10.1016/j.jenvman.2019.109924

Kucher, O., & Prokopchuk, L. (2020). Economic aspects of biomass market development in Ukraine. *E3S Web of Conferences*, *154*, 01007. https://doi.org/10.1051/e3sconf/202015401007

Kulkarni, S. A., Kumbhar, A., & Karanth, N. V. (2019). *Heat-treatment process optimization using dilatometry technique and simulation tools*. 2019-26–0242. https://doi.org/10.4271/2019-26-0242

Lienhard, J. H. (2005). *A heat transfer textbook*. Phlogistron.

Martinho, V. J. P. D. (2018). Interrelationships between renewable energy and agricultural economics: An overview. *Energy Strategy Reviews*, *22*, 396–409. https://doi.org/10.1016/j.esr.2018.11.002

Mauri, R. (2015). Radiant heat transfer. In R. Mauri, *Transport Phenomena in Multiphase Flows* (Vol. 112, pp. 339–352). Springer International Publishing. https://doi.org/10.1007/978-3-319-15793-1_20

Mirmanto, M., Mulyanto, A., & Hidayatullah, L. R. (2018). Hubungan ketinggian dan diameter lubang udara tungku pembakaran biomassa dan efisiensi tungku. *Jurnal Teknik Mesin*, *6*(4), 225. https://doi.org/10.22441/jtm.v6i4.2048

Ordonez-Miranda, J., Anufriev, R., Nomura, M., & Volz, S. (2022). Net heat current at zero mean temperature gradient. *Physical Review B*, *106*(10), L100102. https://doi.org/10.1103/PhysRevB.106.L100102

Pangestu, S. F., Hiendro, A., & Taufiqurrahman, M. (2023). Analisis konduktivitas termal material logam menggunakan metode searle. *JTRAIN: Jurnal Teknologi Rekayasa Teknik Mesin*, *4*(1), 44–48.

Parinduri, L., Parinduri, T., Kunci, K., & Fosil, E. (2020). Konversi biomassa sebagai sumber energi terbarukan. *Journal of Electrical Technology*, *5*(2), 88–92.

Prihartono, J., & Irhamsyah, R. (2022). Analisis konduktivitas termal pada material logam (tembaga, alumunium dan besi). *Presisi*, *24*(2), 49–54.

Quist, C. M., Jones, M. R., & Lewis, R. S. (2020). Influence of variability in testing parameters on cookstove performance metrics based on the water boiling test. *Energy for Sustainable Development*, *58*, 112–118. https://doi.org/10.1016/j.esd.2020.07.006

Rani, C. S., Kandpal, T. C., & Mullick, S. C. (1992). Preliminary research of water boiling test procedures used for performance evaluation of fuelwood cookstoves. *Energy Conversion and Management*, *33*(10), 919–929. https://doi.org/10.1016/0196-8904(92)90106-7

Saputraa, A., Samhuddin, S., & Hasanudin, L. (2022). Perancangan dan analisis pengujian konduktivitas panas pada tipe material padat. *Enthalpy: Jurnal Ilmiah Mahasiswa Teknik Mesin*, *7*(1), 22. https://doi.org/10.55679/enthalpy.v7i1.24502

Shahbazi, M. J., Rahimpour, H. R., & Rahimpour, M. R. (2024). Agriculture waste to energy, technologies, economics, and challenges. In *Encyclopedia of Renewable Energy, Sustainability and the Environment* (pp. 71–80). Elsevier. https://doi.org/10.1016/B978-0-323-93940-9.00204-8

Sidebotham, G. (2015). Heat transfer modes: Conduction, convection, and radiation. In G. Sidebotham, *Heat Transfer Modeling* (pp. 61–93). Springer International Publishing. https://doi.org/10.1007/978-3-319-14514-3_3

Suluh, S., Lorenza, D., Sampelolo, R., Pongdatu, G., Ramba, D., & Widyianto, A. (2023). Evaluation of a biomass combustion furnace using different kinds of combustion chamber casing materials. *Eastern-European Journal of Enterprise Technologies*, *5*(8 (125)), 6–15. https://doi.org/10.15587/1729-4061.2023.288834

Taler, D. (2019). Mass, momentum and energy conservation equations. In D. Taler, *Numerical Modelling and Experimental Testing of Heat Exchangers* (Vol. 161, pp. 9–46). Springer International Publishing. https://doi.org/10.1007/978-3-319-91128-1_2

Varuvel, E. G., Sonthalia, A., Aloui, F., & Saravanan, C. G. (2023). Basics of heat transfer: Conduction. In *Handbook of Thermal Management Systems* (pp. 1–33). Elsevier. https://doi.org/10.1016/B978-0-443-19017-9.00003-9

Wahyullah, Putra, O. D., & Ismail. (2018). Pemanfaatan biomassa tumbuhan menjadi biopellet sebagai alternatif energi terbarukan. *Hasanuddin Student Journal*, *2*(1), 239–247.

Wang, Y., & Wang, P. (2022). Application of fourier's law in one-dimensional steady heat conduction calculation of cylinder wall. *Journal of Physics: Conference Series*, *2381*(1), 012002. https://doi.org/10.1088/1742-6596/2381/1/012002

Webster, J. G., & Eren, H. (Eds.). (2017). *Measurement, instrumentation, and sensors handbook* (0 ed.). CRC Press. https://doi.org/10.1201/b15474

Widianto, W., Junaidi, J., & Taufiqurrahman, M. (2024). Analisis konduktivitas termal material kaca menggunakan metode lee's disc. *JTRAIN: Jurnal Teknologi Rekayasa Teknik Mesin*, *5*(1), 73–77.

Zhang, X., Zhang, P., Xiao, C., Wang, Y., Ding, X., Liu, X., & Tian, X. (2024). Physical basis of thermal conduction. In X. Tian (Ed.), *Thermal Management Materials for Electronic Packaging* (1st ed., pp. 1–17). Wiley. https://doi.org/10.1002/9783527843121.ch1

Zhang, Z., Zhang, Y., Zhou, Y., Ahmad, R., Pemberton-Pigott, C., Annegarn, H., & Dong, R. (2017). Systematic and conceptual errors in standards and protocols for thermal performance of biomass stoves. *Renewable and Sustainable Energy Reviews*, *72*, 1343–1354. https://doi.org/10.1016/j.rser.2016.10.037

Zheng, Q., Hao, M., Miao, R., Schaadt, J., & Dames, C. (2021). Advances in thermal conductivity for energy applications: A review. *Progress in Energy*, *3*(1), 012002. https://doi.org/10.1088/2516-1083/abd082