High Performance Oven for Coconut Shell Charcoal Briquetting

Andreas Prasetyadi(✉) and Wibowo Kusbandono

Department of Mechanical Engineering, Universitas Sanata Dharma, Yogyakarta, Indonesia
pras@usd.ac.id

Abstract. Coconut shell charcoal briquetting usually applies thermal drying with LPG, CNG, and biomass as the common fuel for heating. Fuel price is significant for production cost in addition to raw material and environmental issue. Therefore, its price is subject to fuel price volatility. As the fossil price increases, the production is getting more expensive. An alternative approach for briquetting process using refrigerated drying was proposed. The research aimed to measure the oven performance applying refrigerated drying involving the machine performance and time for removing water content of the briquette. An experiment of drying 132 kg briquette was conducted in an oven of 197.5 cm x 100 cm x 112 cm dimension. The briquettes were cubes of 2.5 cm x 2.5 cm x 2.5 cm and had been aerated for 2 hours. The refrigerated drying machine has capacity of 715 W and the drying was performed in closed loop air method. It was recorded that the COP machine was 12.20 in average with drying process of 59 hours. The time processing was comparable to conventional one, but the energy price was lower.

Keywords: Coconut Shell, Briquetting, High Performance Oven

1 Introduction

Charcoal briquetting production generally consisting of molding and shaping, drying, and heating is high energy and time-consuming fuel processing. The shaping is a process to create specific form of the charcoal briquette after the raw materials have been mixed with some water addition. Following it, drying and heating up are applied to reduce the water content of the briquette and increasing its hardness, respectively [1]. Among the steps, drying and heating are the main energy consumer and subject to fuel price volatility. The processes usually need fuel such as LNG, LPG, and biomass. A good briquette has water content of 5% or less [2]. The drying and heating the briquette up are affected by environment condition and fuel price. Temperature, and humidity affect duration of the production process. Normally, it needs 6 days for briquetting with 4 days in oven for drying and heating up. The fuel price is significant in briquette production cost. Accordingly, application of the thermal heating using fuel implies on working environment as it increases the temperature and firing prone. Therefore, it is important to induce a new strategy in briquette processing especially drying to reduce production time and cost, such as vapor compression method.

M. Setiyo et al. (eds.), *Proceedings of the 4th Borobudur International Symposium on Science and Technology 2022 (BIS-STE 2022)*, Advances in Engineering Research 225,
https://doi.org/10.2991/978-94-6463-284-2_13

Application of vapor compression method for refrigerated drying has been studied. It was utilized on grain drying, corn chips drying [3] [4], wooden planks [5], clothes [6] [7] [8, 9], and briquette [10]. In corn chips production, the method was investigated for reducing the water content of the chips before frying. Extensive studies of the method for clothes have been conducted to find optimum condition for drying during laundry [10]. All reports show the method is very potential in drying process due to psychrometric advantage over thermal method. Moreover, it was noted that the temperature increased significantly when the process was conducted in closed system [11]. Circulating the air inside of the drying chamber increases the temperature of the air and reducing the water content. The features are important in briquetting process.

Aiming to measure the oven performance of drying process and its vapor compression process, the research was conducted and presented in an article confining 5 sections. The introduction starting the article showing the research rationale. The theories of vapor compression and psychrometric are the main topics of the second part to provide the understanding of the processes. Methods of experiment explaining the measurement strategy, the parameters, and its setting is the content of the 3rd section. Results of the experiment is presented in the 4th section that is followed with conclusion as the final part.

1.1 Theoretical review

Refrigerated drying is method to remove the water content of a material using psychrometric principle of condensation to reduce the humidity of the air [12] popular as heat pump drying [13]. Low air humidity allows the water removed from the surface of the solid to the air. At the same time, it also the way to increase diffusion of the water from the inner part of the material. The principle implies need of method increasing the condensation from the air. Vapor compression is a popular and a simple way in term of practical approach for heat pumping.

1.2 Psychrometric

The psychrometric describes relation of water content, temperature, and the enthalpy of the air. The relation is depicted on a chart, called psychrometric chart as shown in Fig. 1. The parameters have 1st capital letter of each word with values are following the gold arrow direction. The horizontal axis of the chart is dry bulb temperature. The sling shows the wet bulb temperature which is the condition of condensation. The vertical axis is absolute humidity or specific humidity, while slinging lines inside of the chart are the lines of relative humidity (RH). Crossing the chart in diagonal direction are the enthalpy and the specific volume. The direction of the enthalpy and specific volume values are similar to the wet bulb direction.

Increasing temperature of air allows more water vapor can be absorbed into the air. If the content of water vapor is still, it means that the relative humidity decreases. Increasing the temperature of the air implies higher enthalpy of the air at the same time. Such principle of reducing RH is applied for thermal drying or heating the air up. The method can be seen in Fig. 1 as the purple arrow from left to right direction (D to E) and the red arrow in the same direction (A to B).

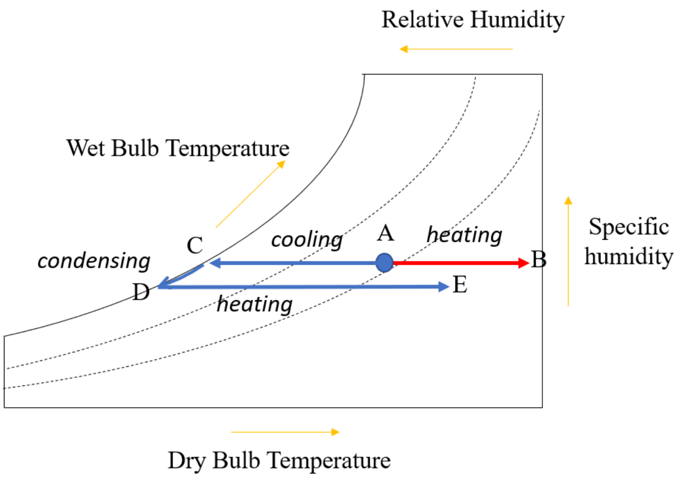

Fig. 1. The basic Psychrometric diagram.

Another way allowing drying process is to reduce the absolute humidity of the air. It happens when the water content of the air is getting lower through condensation or absorbing the water content using hydrophilic material. The process consists of reducing the temperature until its condensation point which reduces the absolute humidity of the air but it increases the RH (arrow AC), condensing through decreasing temperature (sling arrow CD), and heating (arrow DE) as seen Fig. 1.

1.3 Vapor Compression

Vapor compression is a method of transferring heat from low temperature bath to high temperature bath. To pump the heat, a kind of fluid namely refrigerant is cycled to evaporate at low temperature in evaporator and condense in the condenser with higher temperature. To do this work, the refrigerant pressure is controlled. In evaporator, the pressure of the refrigerant is set to be low using expansion equipment such as capillary tube or expansion valve. Therefore, the refrigerant can evaporate easily and absorb the heat from low temperature bath. Meanwhile, the pressure of refrigerant in condenser is set to be high using the help of compressor. The high pressure allows heat move to high temperature bath. The component of vapor compression machine is shown in Fig. 2. Compressor does input work for the cycle, the evaporator absorbs heat from low temperature bath, and the condenser releases heat to high temperature bath.

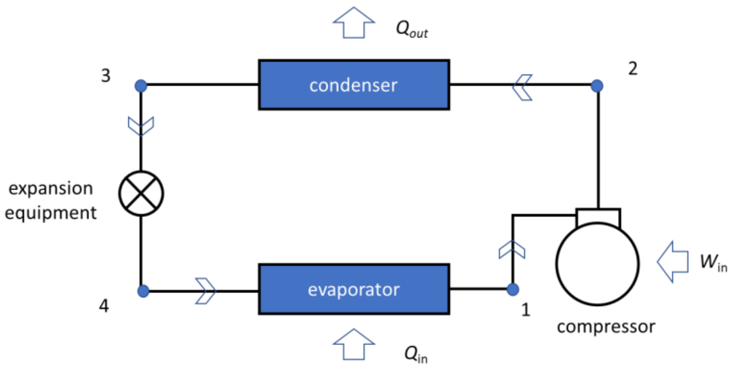

Fig. 2. The Refrigerator sections.

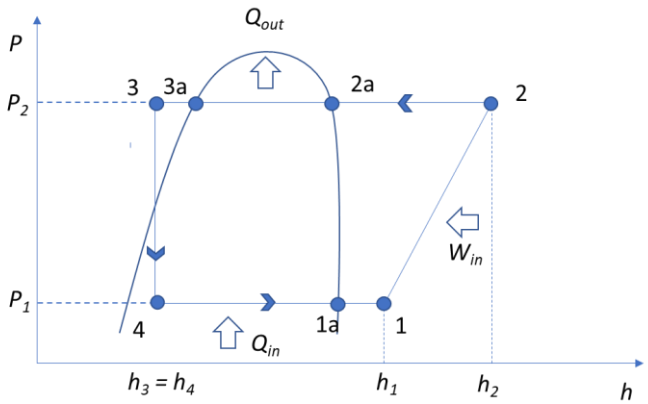

Fig. 3. Vapor compression cycle. Proper refrigerant allows superheating, de-superheating, and subcooling take place.

The cycle of vapor compression is shown in Fig. 3. It consists of boiling process, superheating, isentropic compression, desuperheating, cooling, subcooling, and condensation. The boiling process takes places in evaporator. In the process, the liquid refrigerant gets heat from the environment and heated up until its boiling temperature (4 – 1a). From 1a – 1, the process is called superheating, where all of the refrigerant is evaporated to be vapor. The next step is isentropic compression (1 – 2) where the compressor pumps this gaseous refrigerant to condenser. The desuperheating (2 – 2a) is the process of cooling this vapor until its boiling temperature followed by cooling (2a – 3a) and subcooling (3a – 3). Then, this vaporized refrigerant is condensed (3 – 4) using expansion process. The working pressure of evaporator is P_1, and the working pressure of the condenser is P_2. The subcooling and superheating are applied to increase the performance of the cycle. The superheating increases enthalpy of the refrigerant (h_1) before leaving the evaporator, while subcooling, reduces the temperature of the refrigerant ($h_3 = h_4$) in condenser before leaving it.

The specific thermal absorption of the refrigerant in evaporator is shown in Eq. 1. It is the enthalpy difference of the refrigerant rate at the evaporator outlet and evaporator inlet. The h_1 and h_4 are the enthalpy of the refrigerant at the evaporator outlet and inlet, respectively.

$$Q_{in} = (h_1 - h_4) \tag{1}$$

The specific thermal desorption in condenser is mentioned by Eq. 2. The value is the enthalpy of the refrigerant rate at the condenser inlet (h_2) minus the enthalpy of the refrigerant rate at the condenser outlet (h_3).

$$Q_{out} = (h_2 - h_3) \tag{2}$$

The work of the compressor is determined with the difference of the enthalpy leaving the compressor (h_2) and entering it (h_1). This work is shown in Eq. 3.

$$W_{in} = (h_2 - h_1) \tag{3}$$

The refrigerated drying coefficient of performance is determined with Eq. 4. The drying process depends on Qin for reducing the specific humidity and Qout at the same time for reducing the relative humidity.

$$COP = \frac{(Q_{in} + Q_{out})}{(W_{in})} \tag{4}$$

2 Method

The experiment of the research was conducted to measure the refrigerated drying process performance using the equipment setup as shown in Fig. 4. No 1,2,3, and 4, are shelves, the briquettes, refrigerated dryer, and water collector, respectively. No. 5 and 6 are the outlet and inlet of the refrigerated dryer, in respective order. The dimension of oven is 197.5 cm x 112 cm x 100 cm. The oven consists of 2 rooms, they are the A room for drying shelves and B room for drying machine. The capacity of the refrigerated dryer is 1 hp with compressor of 715 W. The wet mass of the briquette was 132 kg distributed on 8 shelves. It was targeted to be 100 kg dry briquette. The dimension of a briquette was 2.5 cm x 2.5 cm x 2.5 cm. In a kilogram, there were 72 pieces. Before the briquettes were put in the oven, they were aerated for 2 hours.

The collected data of the experiment was the psychrometric data of the refrigerated dryer inlet and outlet air. The dry bulb of the inlet was the oven temperature. The working pressures and pressure of the vapor compression cycle were collected from the data sheet. These data are used to find the temperature of the air leaving evaporator and leaving the condenser. The performance was calculated from the enthalpies obtained from the ph-diagram of the R-290 refrigerant following Eq. 1 – 4.

To determine completion of drying process, the condensed water was collected and measure. The collected water was assumed to be mass difference of the briquette. The measurement was conducted every three hours. When the weight of the briquette was

100 kg, the process was stopped. Some briquettes were collected for measuring its weight. In average, the weight of a briquette should be 13.8 g.

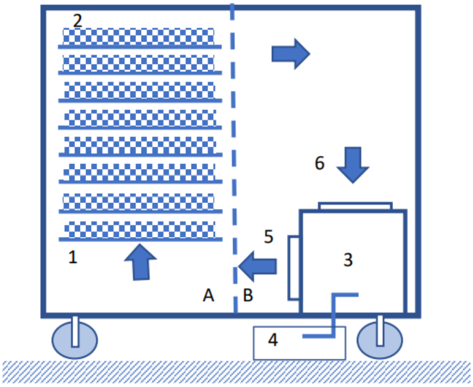

Fig. 4. The oven and the equipment setup.

3 Result And Discussion

Weight of the briquette shows refrigerated drying efficacy. Its weight is shown in Fig. 5 indicating that the weight of the briquette reduces following the exponential trend. This trend confirms the drying process of other materials. When the specific humidity of the air decreases, it needs more effort to reduce it. At the same time, the temperature of the air increases which also indicates higher enthalpy of the air. Assuming that the machine has constant COP, it implies that the machine efficacy decreases with the time due to psychrometric character of the air. The drying reduces specific humidity of the air by time. Loop of the cycle in psychrometric chart is getting small as shown in Fig. 6a, Fig. 6b, and Fig. 6c. Technically, the machine can't remove the vapor anymore, as the A – B line is overlapping with C – D line. At this condition, the refrigerated drying work as the thermal drying capacity which depends on relative humidity only. The psychrometric charts show that the relative humidity of the air in such condition is around 8%, with temperature of 55°C. These psychrometric conditions are comparable to other works [10,11].

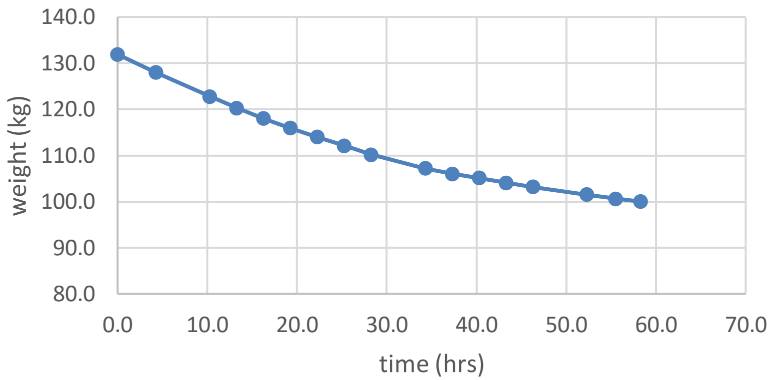

Fig. 5. The weight of the briquette over time. In 59 hours, the drying is completed.

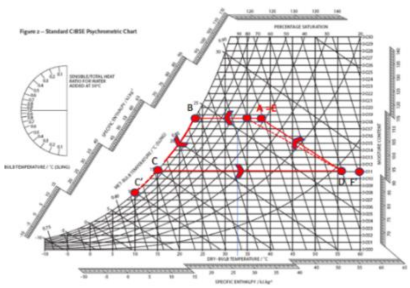

Fig. 6. a. The air cycle at 5 hours drying.

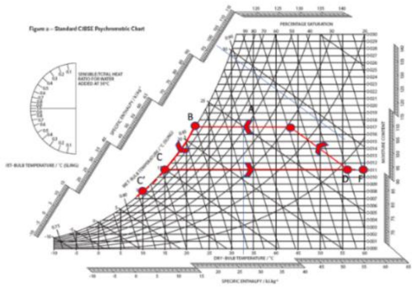

Fig. 6. b. The air cycle at 25 hours drying

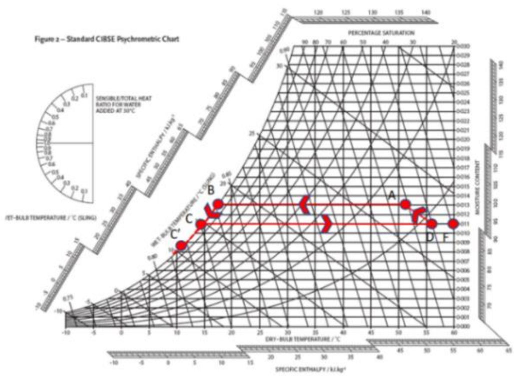

Fig. 6. c. The air cycle at 55 hours drying

The working pressures and temperature of refrigerant on the evaporator and condenser is shown in Table 1. The R-290 refrigerant worked at 6.326 bar and 21.179 bar in evaporator and condenser respectively. The temperature of the evaporator and condenser in respective order were 10°C and 60°C. These parameters indicate that the vapor compression cycle did not have any superheating nor subcooling as shown in Fig. 7. The figure shows the enthalpy of the refrigerant as shown in Table 2.

Table 1. The working pressure and temperature of the evaporator and condenser of the refrigerated drying.

Refrigerant	**Evaporator Working Pressure (P_1)** (bar)	**Condenser Working Pressure (P_2)** (bar)	**Evaporator Working Temperature ($T_{evap.}$)** (°C)	**Condenser Working Temperature ($T_{cond.}$)** (°C)
R-290	6.326	21.179	10	60

Table 2. The enthalpy of the vapor compression cycle of *refrigerated drying*.

Refrigerant	**Enthalpy**			
	h_1 (kJ/kg)	h_2 (kJ/kg)	h_3 (kJ/kg)	h_4 (kJ/kg)
R-290	583.92	623.08	364.68	364.68

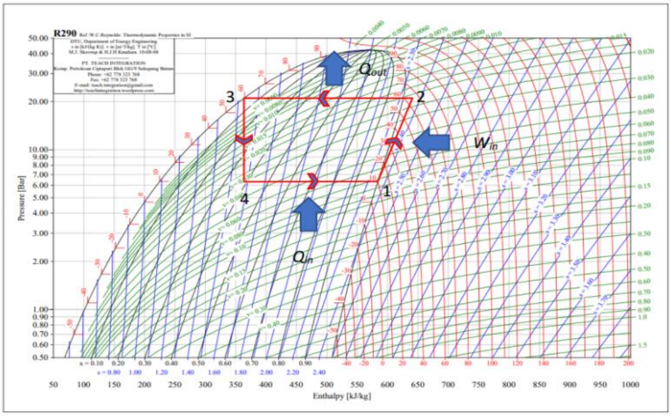

Fig. 7. The vapor compression cycle of R-290.

The performance of the vapor compression cycle of the refrigerated drying can be calculated following Eq. 1-4 using the data of Table 2. The COP of the system is 12.20, with Q_{in} and Q_{out} of 219.24 kJ/kg and 258.40 kJ/kg respectively. The work of the compressor (Win) is 39.16 kJ/kg. Every kilogram refrigerant cycle, it creates 258.40 kJ enthalpy effect drying through cooling process in condenser. This cooling effect is applied for condensing the water vapor and reducing the air temperature. Meanwhile, the heating up temperature is 219.24 kJ for every kg refrigerant cycle. This heating effect is bigger than its work. This performance was also mentioned in [10,11,12].

Comparing to the thermal drying that depends on heating up process only, the refrigerated drying has two advantages which are the explanation of list by Butz and Schwarz [11]. First advantage comes from the drying effect on cooling process which reducing water vapor content of the air. Less vapor part of the air is very significant in drying process. Secondly, this alleviation of absolute humidity process provides low enthalpy air which is easier for heating up in heating process. The direct drying has to increase the air temperature with higher water vapor content. The water vapor heat capacity is far greater than the dry air, so reducing water content first is very useful in drying process. Reducing water content allows less heat specific of the air.

4 Conclusion

The refrigerated drying oven was proposed for producing coconut shell charcoal briquette. The oven provides higher efficacy because of cooling effect and heating effect. The total COP of the system was 12.20, which is far higher than conventional approach using thermal drying. The method provides less energy cost of briquettes processing. The drying process was 58.25 hours for 100 kg charcoal briquette.

Acknowledgments. This research is funded by Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM) of Sanata Dharma University.

References

1. B. Asamoah, J. Nikiema, S. Gebrezgabher, E. Odonkier and M. Njenga, "Resource Recovery and Reuse Series 7 A Review on Production,Marketing and Use of Fuel Briquettes," CGIAR Research Program on Water, Land and Ecosystems (WLE), 2016.
2. S. Petrovic and B. Glavonjic, "Standards and Certificates for Charcoal and Charcoal Briquettes in The Function of Harmonization of Their Quality and Market Development," in *Development trends in economic and management in wood processing and furniture manucaturing* , Kozina, Slovenia, 2011.
3. D. Purwadianta and P. K. Purwadi, "Karakteristik Mesin Pengering Emping Jagung Energi Listrik," in *Prosiding Seminar Nasional Universitas Respati*, Yogyakarta, 2019.
4. P. K. Purwadi, S. Mungkasi and Y. B. Lukyanto, "Peningkatan Pemahaman Proses Pengeringan Kayu di SMK Pangudi Luhur Muntilan," *Jurnal Abdimas Dewantara,* vol. 3, no. 2, 2020.
5. W. Kusbandono and K. P. Petrus, "Effects of the Existence of Fan in the Wood Drying Room and the Performance of the Electric Energy Wood Dryer," *International Journal of Applied Sciences and Smart Technologies,* vol. 3, no. 1, pp. 83-92, 2021.
6. P. K. Purwadi and W. Kusbandono, "Inovasi Mesin Pengering Pakaian Praktis, Aman dan Ramah Lingkungan," *Jurnal Ilmiah Widya Teknik,* vol. 15, no. 2, 2016.
7. P. K. Purwadi and W. Kusbandono, "Mesin Pengering Pakaian Energi Listrik Mempergunakan Siklus Kompresi Uap," 2015.
8. P. K. Purwadi and W. Kusbandono, "Pengaruh Kipas terhadap Waktu dan Laju Pengeringan Mesinan Pengering Pakaian," *Teknoin Jurnal Teknologi Industri,* vol. 22, no. 7, 2016.

9. K. Wijaya and P. K. Purwadi, "Mesin Pengering Handuk dengan Energi Listrik," *Majalah Teknik Mesin Mekanika,* vol. 15, no. 2, p. 419, 2016.
10. P. K. Purwadi and et al, "Mengembangkan Industri Briket dengan Mempergunakan Mesin Pengering Briket Energi Listrik," *Abdimas Altruis Jurnal Pengabdian Kepada Masyarakat,* vol. 1, no. 2, 2018.
11. P. K. Purwadi, "Mesin Pengering Kapasitas Limapuluh Baju Sistem Tertutup," *Jurnal Ilmiah Widya Teknik,* vol. 16, no. 2, 2017.
12. P. K. Purwadi and A. Prasetyadi, "Characteristic of Wooden Furniture Drying Machine," *International Journal of Applied Sciences and Smart Technologies,* vol. 4, no. 1, pp. 75-88, 2022.
13. T. Kudra and A. S. Mujumdar, Advanced Drying Technology 2nd Edition, Boca Raton, FL: CRC Press, 2009.

The 4th BIS 2022

Borobudur INTERNATIONAL SYMPOSIUM 2022

Certificate

To certify that :

Andreas Prasetyadi, Wibowo Kusbandono

has contributed as

Presenter

in The 4th Borobudur International Symposium 2022

"The Innovation Chain: A Contribution to Society and Industry"

Rector
of Universitas Muhammadiyah Magelang

Dr. Lilik Andriyani, SE., M.Si

Chairman of 4th BIS 2022

Prof. Dr. Muji Setiyo, ST., MT.

Organized by :

unimma
Universitas Muhammadiyah Magelang

Co-host:

December 21st, 2022
Magelang, Central of Java, Indonesia