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Characteristics of Wooden Furniture Drying Machine

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Abstract

This study aims to determine the characteristics of the electric energy drying machine used to dry wooden furniture. Furniture made of mahogany. The research was conducted experimentally in the wood furniture industry. The size of the wood drying room is 8 m x 6 m x 3 m. The dryer works with a vapor compression cycle using R134a freon and several fans placed in the drying chamber. The drying process uses a closed air system. The total volume of dried wooden furniture is 12.9 m^3. The initial moisture content in the wood ranges from 18% to 23%. Wooden furniture is considered dry if the moisture content in the wood furniture is less than 12%. Research gives satisfactory results. The performance of the drying machine or *COP* is 10.85. The drying time for wooden furniture is about 72 hours.

Keywords: COP, wooden furniture, dryer, vapor compression

1 Introduction

Drying wood furniture in the wood furniture industry with wood fuel still has many shortcomings. Apart from being energy-intensive, it is also impractical, unsafe, uncomfortable, environmentally unfriendly and takes a long time. Economically, the

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drying process with wood fuel requires a large amount of money. Drying wood furniture referred to here is the process of drying wooden furniture that only relies on high temperature air to dry all wooden furniture. In general, the air temperature in the wood furniture drying room is not more than 70^{o}C. If the air temperature of the drying chamber is more than that, the air will damage wooden furniture and flammable wood. The air used in the drying process of wood furniture is air heated by a heat exchanger which has a much higher working temperature. By means of air passed through a heat exchanger, then the hot air produced is used to dry wooden furniture. In the heat exchanger flows a mixed gas (air and gas resulting from the fuel combustion process) which has a much higher temperature.

The use of fuel with wood wastes energy because the mixed gas resulting from the fuel combustion process that is discharged into the environment still has a high temperature. As is known, high-temperature exhaust gases have high energy as well. The process of drying with wood fuel is quite a hassle. It's a hassle, because the industry must provide wood fuel every time it will carry out the process of drying wood furniture, prepare for the combustion process, burn wood fuel, maintain and oversee the drying process of wood furniture from start to finish. Based on information from workers in the wood furniture industry, drying wood furniture takes more than 7 days. The drying process with wood fuel is considered unsafe. If the drying process is not maintained and controlled properly, the possibility of a fire is quite large. The process of drying wooden furniture also does not provide comfort. Not comfortable, because after the drying process is finished, the air in the drying room still has a high temperature (about 35^{o}C). Actually, the industry can still reduce the air condition to close to the outside air condition, but it takes a long time to get the same air temperature as the outside air temperature. The industry can't wait to immediately take out and import wooden furniture with the air condition in the drying chamber still quite high. This condition makes workers uncomfortable when loading and removing wooden furniture from the drying room. The drying process with wood fuel is not environmentally friendly. Not environmentally friendly because burning wood fuel produces dust, and exhaust gases that pollute the environment. It also produces soot that makes the walls of the drying room for wood furniture black. The drying time of wooden furniture is also relatively long. The duration

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depends on the volume of the wood being dried, the thickness of the wood, the type of wood, the type of furniture, and so on.

Many researches and applications related to the drying process have been carried out by experts [1-14] although with different objects being dried and the drying system chosen is also different. Research and application with fish objects has been carried out by A. Aryadillah and A. Mursadin [1], M. Nur Alam, et al, [2]. Research with briquette objects was carried out by P.K. Purwadi, et al [3]. Research with the object of corn chips has been carried out by D. Purwadianto [4]. Research with the object of towels has been carried out by K. Wijaya [5], and clothes by P.K. Purwadi and W. Kusbandono [6,7,8,9], Balioglu [10], T. Mitsunori [11], Bison [12]. Research and application with wooden planks has been carried out by W. Kusbandono and P.K. Purwadi [13], Purwadi, P.K., et al 14]. The research method used is a simulation and some is experimental. Apart from aiming to get good performance or better efficiency of the dryer, there is also a goal to get a dryer that can replace the drying process by drying directly under the hot sun. The dryer can work during the rainy season or can be done at night or can be done whenever needed. From the results of several studies that have been carried out, some researchers use a drying machine that works with a vapor compression cycle. Drying machines that work with a vapor compression cycle, in addition to providing good performance, also provide a fast-drying process.

The dryer is made and used in drying wood furniture, working with a vapor compression cycle. With the vapor compression cycle, air that is dry and quite hot can be produced. Dry air means that the water content in the air is quite low, with the resulting relative humidity (*RH*) of less than 35%. The air produced is quite hot, which causes the air condition in the drying chamber to be no more than 35^{o}C.

A. Vapor compression cycle

The main components of a vapor compression machine include: compressor, condenser, capillary tube and evaporator. Figure 1 presents a series of main components of a steam compression engine and Figure 2 presents the vapor compression cycle on the P-h diagram, which is accompanied by a further cooling and further heating process. There is no need for superheating and subcooling. The further cooling process is carried out so that the condition of the refrigerant when it enters the capillary tube is actually in

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the liquid phase. The further heating process is used so that when the refrigerant enters the compressor, it is actually in the gas phase. Both processes are used to increase the performance of the refrigeration engine and facilitate the function of the compressor to circulate the refrigerant flowing in the vapor compression cycle system. Compressor work becomes light and not easily damaged.

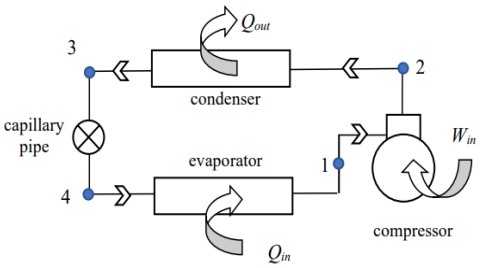


Figure 1. Vapor compression cycle component circuit

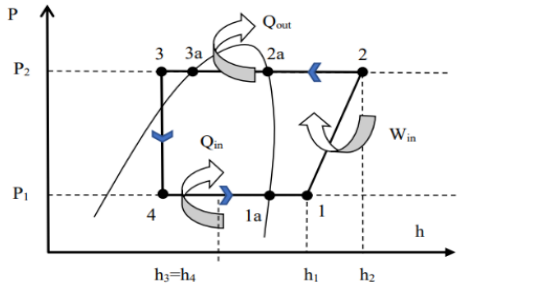


Figure 2. Vapor compression cycle on P-h diagram

The amount of heat absorbed per unit mass-refrigerant by the evaporator *(Q_{in})* can be calculated by Equation (1)

$$Q_{in} = h_1 - h_4 \quad (kJ/kg) \tag{1}$$

The amount of heat released per unit mass-refrigerant by the condenser *(Q_{uot})* can be calculated by Equation (2)

$$Q_{out} = h_2 - h_3 \quad (kJ/kg) \tag{2}$$

Compressor work per unit refrigerant-mass *(Win)* can be calculated by Equation (3).

$$W_{in} = h_2 - h_1 \quad (kJ/kg) \tag{3}$$

The performance of the steam compression cycle engine can be expressed by Equation (4). *COP* is the ratio between the amount of useful energy and the energy supplied to the dryer

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

The variables h_1, h_2, h_3 and h_4 in Equation (1) to (3), are the enthalpy of refrigerant entering the compressor, enthalpy of refrigerant leaving the compressor, enthalpy of refrigerant leaving the condenser and enthalpy of refrigerant entering the evaporator, respectively. The enthalpy that enters the evaporator is equal to the amount of enthalpy

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that leaves the condenser or enters the capillary tube. This is because the process that occurs in the capillary tube takes place with a constant enthalpy value

B. Wood Furniture Drying Process

The medium used for drying wood furniture is air. The air system used is a closed air system. During the wood furniture drying process, no outside air is entered or removed from the building which is used for the wood furniture drying process. The building for the wood drying process consists of a wood furniture drying room and a drying machine room. The thermodynamic processes experienced by air during the wood drying process include the following processes: cooling, cooling and dehumidifying, heating and cooling and humidifying. When the air passes through the evaporator, the air first undergoes a cooling process, then the air undergoes a cooling and dehumidifying process. After the air leaves the evaporator, the air undergoes a heating process as it passes through the condenser. When air is blown into the drying chamber by the condenser fan the air passes through the wooden furniture to be dried. In this process the air undergoes a cooling and humidifying process. Inside the drying room, several fans are installed. One of the functions of the fan is so that the cooling and humidifying process can run optimally. Figure. 3 presents a schematic of the wood furniture drying process carried out in this study.

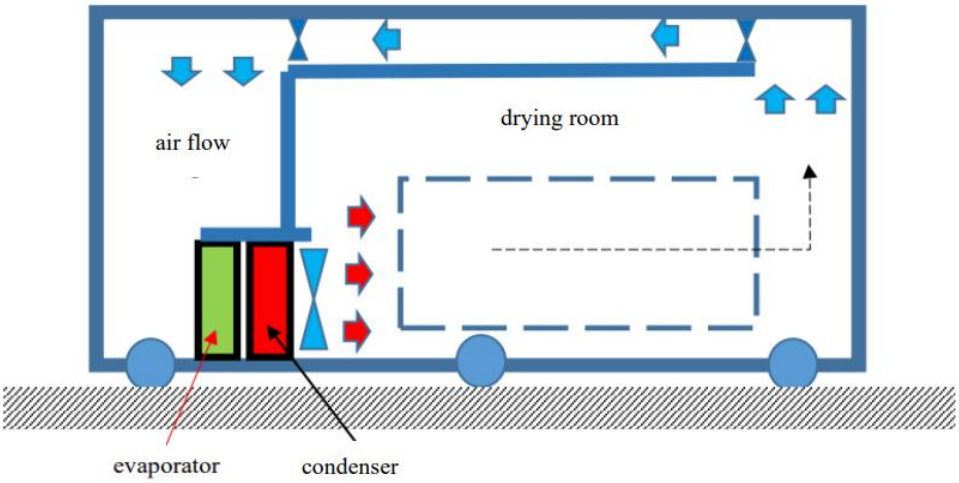


Figure 3. Schematic of wood furniture drying machine with closed air system

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2 Research Methodology

The research was conducted experimentally in the wood furniture industry, with a drying room size of 8m x 6m x 3m. The dryer works with a source of electrical energy. The drying machine works by using a vapor compression cycle, using a refrigerant R134a working fluid. The main components of the drying machine include: compressor, evaporator, condenser and capillary tube. The dried object is wooden furniture. Figure 4 shows some examples of dried wood furniture.



Figure 4. Some examples of wood furniture being dried in a drying room

In the process of drying wood furniture, the evaporator serves to get dry air, while the condenser functions to get hot enough air. When the dryer works, the air used to dry the wooden furniture is passed through the evaporator and condenser before being used to dry the wood furniture. The total electric power required to drive the compressor is about 3 HP, and the total electric power to drive the evaporator fan and condenser fan is about 80 watts. In the wooden furniture drying room, 6 fans are provided with a uniform fan power of @ 250 watts. In addition to functioning to accelerate air flow, the fan also functions so that all wooden furniture flows through the air. The dried wood furniture has a volume of 12.9 m^3, with various forms of wood furniture. Mahogany wood furniture. The initial condition before the drying process was carried out, the moisture content in the wood furniture was in the range of 18-23%. The drying process is stopped when all wooden furniture has a moisture content of less than 12% or below 12%. The process of

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drying wood furniture is carried out with a drying machine that works continuously without stopping.

3 Results and Discussion

The results of the research in the form of data are presented in Tables 1 to 4. Apart from the direct measurement results, data are also taken from the P-h diagram and tables of the refrigerant properties used (such as: enthalpy, condenser working temperature, evaporator working temperature). The data collection from this research was carried out with several assumptions, such as:

a. The compression process in the compressor that occurs in the vapor compression cycle takes place isentropically
b. The process of decreasing refrigerant pressure in the capillary tubes that occurs in the vapor compression cycle takes place isentalpically
c. The process of desuperheating and condensation or condensation of refrigerant in the condenser that occurs in the vapor compression cycle takes place at a constant pressure (P_2)
d. The refrigerant evaporation process in the evaporator that occurs in the vapor compression cycle takes place at a constant pressure (P_1).
e. The superheating and subcooling processes are ignored

From Table 3, it can be seen the characteristics of the dryer used for drying wood furniture in the industry where this research was conducted. The amount of heat absorbed by the evaporator per unit mass of refrigerant from the air is 126.43 kJ/kg. The heat absorbed by the evaporator causes the air to decrease in dry bulb air temperature and undergo a process of condensation of water vapor in the air. In other words, the air undergoes a cooling and cooling and dehumidifying process. The process of cooling and dehumidifying the air takes place at a relative humidity (*RH*) of 100%. The air becomes dry, because the water content in the air decreases. The value of the specific humidity of the air decreases. The amount of heat released by the condenser per unit mass of refrigerant into the air is 152.11 kJ/kg. This heat causes the air temperature to rise again, and the relative humidity of the air (*RH*) decreases by 19%. With dry air conditions, and relatively low humidity, the drying process of wooden furniture can be carried out

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successfully. In this drying process, the compressor work per unit mass of refrigerant required is 25.68 kJ/kg and the resulting drying machine performance is 10.85.

Table 1. Working pressure and temperature on vapor compression cycle machine

Researched machine	Evaporator working pressure (P_1)	Working pressure Condenser (P_2)	Evaporator working temperature (T_{evap})	Condenser working temperature (T_{kond})
	(kPa)	(kPa)	(°C)	(°C)
Vapor compression cycle machine of wood furniture dryer	414.61	1455.50	10	54

Table 2. Enthalpy values in the vapor compression cycle

Researched machine	h_1	h_2	h_3	h_4
	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)
Vapor compression cycle machine of wood furniture dryer	404.32	430.00	277.89	277.89

Table 3. Characteristics of the vapor compression cycle machine of the dryer

Researched machine	Q_{in}	Q_{out}	W_{in}	$COP=(Qi+Qout)/(Win)$
	(kJ/kg)	(kJ/kg)	(kJ/kg)	
Vapor compression cycle machine of wood furniture dryer	126.43	152.11	25.68	10.85

Table 4. Air conditions in the drying process of wood furniture

Researched machine	The condition of the air entering through the evaporator		Air temperature out of the evaporator	Condenser exit air temperature		Drying time
	$T_{db,A}$	RH	$T_{db,C}=T_{wb,C}$	$T_{db,D}$	RH	t
Vapor compression cycle machine of wood furniture dryer	30ºC	68%	16ºC	44	19%	72 hours

The air conditions in the air-drying process are not only presented in Table 4, but also presented in Figure 5. The A-B-C-D-A process in Figure 5 presents the air-drying process. The A-B and B-C processes in Figure 5 occur when the air passes through the evaporator, the C-D process occurs when the air passes through the condenser, and the D-A process

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when the air passes through the wooden furniture. The A-B process is the air-cooling process, the B-C process is the cooling and dehumidifying process, the C-D process is the heating process and the D-A process is the cooling and humidifying process. The cooling and humidifying process is assumed to run at a constant enthalpy value, so the process is also known as evaporative cooling. The evaporative cooling process experienced by the air, when the air carries out the process of drying wooden furniture. The evaporative cooling process takes place at a constant wet bulb air temperature.

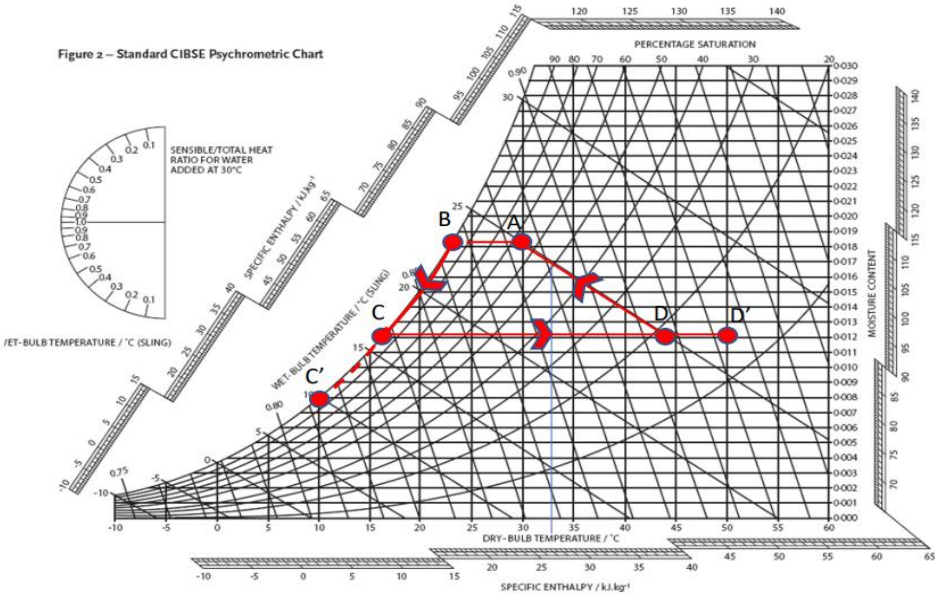


Figure 5. Air conditions in the drying process of wood furniture

In the A-B process, the air undergoes a cooling process. The dry bulb air temperature decreases in temperature until it reaches the dew point temperature of the water vapor in the air (point B in Figure 5). The air releases heat, and the enthalpy of the air decreases. The heat released by the air is used to vaporize or boil the refrigerant flowing in the evaporator pipe. In the A-B process, the process runs at a fixed specific humidity value, because there is no addition or reduction of water content in the air. The relative humidity of the air increases, as the dry bulb air temperature decreases. In the A-B process, the dry bulb air temperature and the wet bulb air temperature decreased until they reached the dew point temperature of the water vapor in the air (point B in Figure 5). The dry-bulb

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air temperature at point B is equal to the wet-bulb air temperature and the same as the dew point temperature of the water vapor in the air.

In the B-C process, the air is cooling and dehumidifying. In addition to the decrease in air temperature, dry bulb air also experienced a decrease in specific humidity. In this process the air releases heat, which causes the enthalpy of the air to decrease. The heat released by the air is used for the evaporation or boiling process of the refrigerant flowing in the evaporator pipe. As is known, the evaporator sucks heat from the air that passes through the evaporator pipe to be used to change the refrigerant phase from liquid to gas. The specific humidity of the air decreases because in this process there is a reduction in the water content in the air. The decrease in water content is caused because some of the water vapor in the air condenses. The B-C process runs at 100% relative humidity. During the process, the dry bulb air temperature is the same as the wet bulb air temperature.

In the C-D process, the air undergoes a heating process. The air temperature has increased in temperature, both dry bulb air temperature and wet bulb air temperature. This is because the air gets the heat released by the condenser. As is known, in the vapor compression cycle, the condenser releases heat to the air passing through the condenser. The heat released by the condenser comes from the desuperheating process and the refrigerant condensation process when the refrigerant flows in the condenser pipe. In this process the enthalpy of air increases. The process runs at a constant specific humidity, because there is no additional water content in the air, but the relative humidity of the air decreases as the air temperature increases.

In the D-A process, the air undergoes an evaporative cooling process. The air undergoes a cooling process and the addition of specific humidity. The dry-bulb air temperature decreases, but the wet-bulb air temperature remains the same. This is because some of the energy in the air is sucked in by the wooden furniture to evaporate some of the water in the wood furniture. As it is known that the evaporation process requires latent heat. With the process of evaporation of water in wooden furniture, it causes the water content in the wood to decrease. Over time, the wood will dry out. In this process, water is transferred from the wood to the air. This causes the water content per unit mass of air to increase, which causes the specific humidity of the air to increase.

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Unlike drying wood furniture using wood fuel, drying wood furniture with a steam compression cycle is not energy-intensive. The electrical energy used to drive the compressor and drive the fans are all useful for the drying process. Relatively no energy is wasted. The energy absorbed by the evaporator causes the air to dry out and the energy released by the condenser causes the air to increase in temperature. The resulting air condition provides benefits for the drying process of wood furniture. The electrical energy required by the condenser fan and evaporator fan is also useful in increasing the air flow rate required for the drying process. Likewise, the electrical energy used to drive the fans in the drying room. Even if there is a leakage of electrical energy that turns into heat, as happens in compressors or in electric motors from fans, then this heat energy will not go to waste. In the process of drying wood furniture, the air used also passes through the compressor and passes through the electric motor of the fans. In other words, the heat from the leak will be accepted by the air and cause an increase in the temperature of the air. The higher the air temperature, the faster the drying process. As is known, the position of the compressor and fans are placed in the building room. Because the system used in the drying process for wood furniture is not energy-intensive, it is only natural that the drying machine has a high performance (*COP* of the dryer is 10.85).

One of the characteristics of this wood furniture dryer with a vapor compression cycle is that it is practical. Practical because it does not bother the user. To run the dryer, the user just presses on from the on-off button which causes the compressor and fans to work. If you want to turn it off, just press the off button. Users are not bothered by having to maintain and control the drying process of wooden furniture. During the drying process of wooden furniture, users can leave the drying process area, because they are not required to be in the drying location.

The process of drying wood furniture with a vapor compression cycle can run safely and comfortably. Small chance of fire. The air condition in the drying chamber does not allow a fire to occur. There is no fire and no embers that allow a fire to occur. Unlike when using wood fuel, in the presence of fire, the temperature produced in the fuel combustion process can exceed 200^{o}C. By using a machine that works with a vapor compression cycle, there is no air condition that has a temperature above 50^{o}C. The air temperature in the wood furniture drying room is safe, the air temperature is only around

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30^{o}C. With such air conditions, workers can put wooden furniture in the drying room or take out wooden furniture, at any time. Workers do not feel hot, because the air temperature is not much different from the outside air temperature. More comfortable than the air condition when using the drying process with wood fuel. The air condition in the drying room is also relatively clean. No soot is produced from the drying process with this system.

Drying using a vapor compression system is relatively more environmentally friendly. Does not cause environmental pollution, both air pollution and noise pollution. The refrigerant used in the vapor compression cycle is selected which is environmentally friendly. Does not cause social problems for the surrounding community. No exhaust gas is produced from the process of using this electrical energy. All of the electrical energy used in this drying process is converted into work and heat.

With the high performance of the machine, the drying system used is able to carry out the drying process relatively quickly. To get the moisture content of all wooden furniture below 12%, the time needed is only about 76 hours or about 3 days. With a note, the machine works continuously without stopping. This can be done, because the drying process can be left behind. The drying process can be carried out continuously during the day and night. With fast drying time, the production capacity of wood furniture can be increased

4 Conclusion

Research on wood furniture drying machine using the vapor compression cycle has been successful. The process of drying wooden furniture can run as expected: it does not waste energy, is practical, safe, comfortable, environmentally friendly, and quickly dries wooden furniture. The dryer has a high performance, with a *COP* of 10.85. The drying process for wooden furniture takes about 72 hours (3 days).

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References

[1] A. Aryadillah, A. Mursadin, "Analisis perbandingan kinerja sistem distribusi panas pada variasi ruang mesin pengering ikan", *SJME Kinematika*, **1(**1), 27-36, 2016.

[2] M. Nur Alam, Sukarti, F.I. Lisanty, "Penerapan teknologi alat pengering ikan bagi kelompok pengusaha ikan teri kering di Kecamatan Ponrang Kabupaten Luwu", *Prosiding Seminar Nasional Hasil Pengabdian Kepada Masyarakat (SNP2M)*, 225-229, 2018.

[3] P.K. Purwadi, Y.B. Lukiyanto, S. Mungkasi, "Mengembangkan industri briket dengan mempergunakan mesin pengering briket energi listrik", *Abdimas Altruis Jurnal Pengabdian Kepada Masyarakat*, **1**(2), 52-61, 2018.

[4] D. Purwadianto, P.K. Purwadi, "Karakteristik mesin pengering emping jagung energi listrik", *Prosiding Seminar Nasional Universitas Respati Yogyakarta*, **1**(2), 116-123, 2019.

[5] K. Wijaya, P.K. Purwadi, "Mesin pengering handuk dengan energi listrik", *Majalah Ilmiah Teknik Mesin Mekanika*, 15(2), 31-35, 2016.

[6] P.K. Purwadi, "Mesin pengering kapasitas limapuluh baju sistem tertutup", *Jurnal Ilmiah Widya Teknik*, **16**(2), 91-96, 2017

[7] P.K. Purwadi, W. Kusbandono, "Mesin pengering pakaian energi listrik dengan mempergunakan siklus kompresi uap", *Proceeding Seminar Nasional Tahunan Teknik Mesin XIV (SNTTM XIV)*, MT 61, 2015

[8] P.K. Purwadi, W. Kusbandono, "Pengaruh kipas terhadap waktu dan laju pengeringan mesin pengering pakaian", *Teknoin Jurnal Teknologi Industri*, **22**(7), 514-523, 2016

[9] P.K. Purwadi, W. Kusbandono, "Inovasi mesin pengering pakaian yang praktis, aman dan ramah lingkungan", *Jurnal Ilmiah Widya Teknik,* **15**(2), 106-111, 2016.

[10] Balioglu, "Heat Pump Laundry Dryer Machine", *Patent Application Publication*, Pub. No: US 2013/0047456 A1, 2013

[11] T. Mitsunori, "Dehumidifying and heating apparatus and clothes drying machine using the same", *European Patent Specification*, EP 2 468 948 B1, 27.11.2013, 2013.

Volume 4, Issue 1, pages 75–88

p-ISSN 2655-8564, e-ISSN 2685-9432

[12] Bison, "Heat Pump Laundry Dryer and a Method for Operating a Heat Pump Laundry Dryer", *Patent Application Publication*, Pub. No: US 2012/0210597 A1, 2012.

[13] W. Kusbandono, P.K. Purwadi, "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*, **3**(1), 83–92, 2021.

[14] P.K. Purwadi, S. Mungkasi, Y.B. Lukiyanto, "Peningkatan pemahaman proses pengeringan kayu di SMK Pangudi Luhur Muntilan", *Jurnal Abdimas Dewantara*, **3**(2), 16-29, 2020.