The novel vacuum drying using the steam ejector

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The novel vacuum drying using the steam ejector Suryanto Suryanto, Nur Hamzah , and **Akhmad Taufik** 1

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ABSTRACT This research evaluated the performance of a novel vacuum dryer using the steam ejector. The performance observed was related to the energy efficiency and drying period of the vacuum dryer by comparing the dryer that operated near atmospheric pressure. The drying process applied to solid materials e.g., cocoa and coffee beans where their moisture ranged from 28 to 35%. The drying process 1

experiment was carried out at a temperature ranging from 50 to 60 0C, while the vacuum pressure was 82 kPa and 90 kPa. This experimental study showed that the energy efficiency of using the vacuum dryer was 11 to 12% lower and the drying time tended to be 1 to 2 hours faster than using the dryer with near atmospheric pressure. The energy consumption at a vacuum drying condition revealed a potential energy reduction by more than 10% using the novel drier with steam ejector 1. Introduction In chemical process

industries, a large part of energy is spent for drying. For example, in food processing and pharmaceutical, it is about 10-20% **of the total energy** usage. In **the** 6

wood and pulp, the consumption is higher; it could reach 30%. Even, at postharvest treatments, the drying takes up to 70% of total energy required.[1] Currently, several drying methods are used, from traditional to modern processing: e.g., direct sun, convective, microwave and infrared, ultra sound, centrifuge, freeze, and vacuum drying.[2] The various designs are also applied referring to the wet product characteristic, i.e., fluidized bed dryer for grain or powder, spray dryer to obtain dry powder from liquid, rotary dryer for grains, and tray dryer for higher size material such as cocoa and vegetables. The various designs are aimed to get higher efficiency as well as product quality. At high temperature drying, energy efficiency can reach

60%, while at freeze dryer is below 30%.[1] In this context the development of efficiency drying with low energy consumption is an important issue in drying technology research. Higher operational temperature can be an option for increasing energy efficiency and speeding up drying time. However, the product quality will degrade especially for food, and pharmaceutical.

Hot air drying leads to taste, color, and nutritional deterioration of agricultural products 3

.[3] Air dehumidification and evaporation which is potential for improving driving force for low or medium temperature could be suitable for heat sensitive products. Vacuum drying method can be a useful tool for solid products that are heat sensitive.[4] Reducing pressure in drying chamber is better to speed up air dehumidification and evaporation.

Some materials can experience problems at high temperatures 4

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For foods and pharmaceuticals, this can be valuable, as other drying process **can degrade quality and make the food less appealing or affect potency of heat-sensitive** 4

pharmaceutical products. Vacuum drying products properties such as shrinkage are

significantly lower, the rate of drying is higher and the duration of drying process is considerably shorter in comparison to convective drying 3

.[5] This paper discusses the optimization of the use of the steam ejector on vacuum drying with medium and low temperature dryer related to energy efficiency and drying time. Optimization carried out in this case was the development of the initial design that was done before. Several things were developed in the prototype development, such as the addition of the thickness of the thermal isolator, the installation of the ejector series which was previously only one. In addition, the development of a pressure and temperature control system integrated in the drying system has also been carried out. This study offers the use of a nozzle injector instead of a vacuum pump,

with the aim of increasing the efficiency of 10

energy use. The vacuum dryer is maintaining

pressure lower than the atmospheric pressure. The boiling point of water is reduced by these conditions, 2 **which increases rate of evaporation at the surface and results in temperature and total pressure gradients** favorable **to the flow of humidity through the thickness of**

object materials dried. In the case of vacuum pump dryers, additional power is needed to drive the pump. Meanwhile, if the steam ejector is employed, the steam as the drying medium to supply heat carries a dual function, that is, to provide a vacuum on the chamber and as a drying fluid, hence no pump is needed. 2. Materials and methods 2.1. Materials The drying process was subjected for two solid food materials; cocoa and coffee beans. They were obtained from south Sulawesi, Indonesia. The coffee beans were discarded and then washed before drying. The moisture content of materials varied from 30 to 35% (kg water/kg dry matter). 2.2. Experimental apparatus and procedures Figure 1 shows the scheme of a simple steam ejector to obtain the vacuum effect of replacing the vacuum pump. The pressurized saturated steam from the boiler passes through the injector nozzle before being fed to the steam jacket of the dryer. The pressurized steam with a certain speed accelerated on the injector before being passed to the nozzle. As a result of the speed of steams increases in the nozzle throat, this causes the pressure of the steam in the throat region of the ejector drops gradually to become vacuum (lower than atmospheric pressure, P2 < 1 bar). For the problem in the gas flow (compressible fluid) and by considering the elevation term is negligible, the Bernoulli equation can be modified to be an equation that can be written as[6]: For adiabatic flow heat supplied (Q¼0) and no work is resulted (W¼0), therefore Equation (1) can be expressed as Where q1, 2 is the density of fluid at points 1 and 2 and it can be considered constant, e1,2 are the energy transformed in to heat at point 1 and 2 respectively; whereas V1 is the steam velocity at the input injector region, V2 is the velocity of the fluid at the nozzle throat region (point 2). Since the fluid enters the nozzle throat where area A2 < Al, the fluid speed increases compared to the entry speed; therefore, as consequences the P2 pressure drops at point 2 in which reaches vacuum pressure, P2 < P atmospheric. As shown in Figure 2, the steam coming out of the ejector goes to the hollow shelves in the chamber and then it releases to the steam jacket (the space surrounding the drying chamber). The hot steam flows into the hollow shelves through an orifice in order to decrease the vapor pressure and velocity of the inlet to the steam jacket. It is necessary to reduce the vapor pressure that enters the steam jacket to avoid damaging. There is a connecting pipe between the drying chamber and the nozzle throat that causes air and moisture in the drying chamber can be sucked toward the nozzle neck. This causes the room chamber to also experience a vacuum condition. The dryer employs pressure and temperature sensors in the drying chamber and in the steam jacket to control the pressure and temperature conditions of the chamber. The signal feedback from those sensors is connected to a controller and then transmitted to the solenoid valve as actuators to regulate the incoming and outgoing steam streams in the drying system. Pressure and temperature in the chamber can be carefully controlled and adjusted to allow the material characteristics that are dried without damaging the quality of products. This is particularly important for in order the purposes of use on different types of agricultural material which have different characteristics in terms of drying constraints, this refers to studies conducted by the authors in Refs. [7] and [8]. Experimental test was conducted to assess

the performance of the vacuum **dryer. The dryer** tested **was** 9

a vacuum dryer using a steam ejector that has been developed from its original design to optimize its performance. Material objects

were placed on the hollow shelves (tray) **in the drying chamber** 8

which was closed tightly. Heat was supplied by passing steam through hollow shelves. The experiments were carried out at the certain vacuum pressures and temperatures according to conditions which did not impair the quality of the test material being dried to evaluate the drying rate. 2.3. Energy balances and efficiency Referring to Figure 3, mass and energy balance equations for the dryer are explained as follows. The hot saturated steam energy and the wet solid product energy are the energy input to the dryer system. The dry solid product energy, the moisture energy, the water energy latent and the energy loses to surrounding are the energy output of the system. and the wet solid product energy is m_ 1ph1p; The hot saturated steam energy is m_ 1s h1f þxh1fg The dry solid product energy is m_2ph2p; the energy moisture is m_ 2sh2s, while the water energy latent is m_ 2we L and Energy loses to surrounding system is Ql. Therefore energy balances of the dry vacuum system can be written as: Where m_ 1s and m1p are the input mass of steam and products (e.g., cocoa or coffee beans); m_2s, m_ 2p _and m_ 2we are the output mass of steam, product and water content evaporated respectively. Enthalpy h1f , h1fg, and h1p are the input energy of steam and product; h2p and h2s are the enthalpy output energy of product and steam; L is the water energy latent and Ql is heat losses to surrounding. Energy efficiency of the dryer system can also be calculated, where energy efficiency system is the total energy required for drying beans divided by thermal energy supplied to dryer.[9] ηThe drying efficiency can be expressed as follow, The use of vacuum pumps at this novel dryer system is unneeded, therefore the pump energy is negligible or W_ p¼0; the Equation (4) can be written as The

total energy required for drying beans is **calculated using equation** 7

, which is referred to Refs. [10] and [11] Where m2p is the mass of dry beans, Cc is the specific heat of beans, T1 is the ambient air temperature, T2 is the chamber temperature, m is the mass of initial water content of product, m2pw is the mass of water to be removed, Cp is the specific heat of water, and

L is the latent heat of vaporization **of water** 9 content. Energy thermal supplied (Qin) to the dryer system comes from the hot saturated steam and wet products which is given by:

where m _s **is mass flow rate of** steam, hf **is the** fluid enthalpy, hfg **is the** 8

fluid gas enthalpy of steam, and x is the steam dryness fraction. 2.4. Specific moisture extraction ratio SMER

is defined as the ratio of mass flow rate **of the** moisture **to** the total **energy** rate **input** to **the dryer** 7

or in other words, the reciprocal of the total energy required to remove 1 kg of water (moisture) from the wet (moist) product.[9,12] Specific Moisture Extraction Ratio (SMER) is calculated by the following equations, it refers to Refs. [2] and [13]. From the equation of SMER above, the pump energy is negligible or W_ p¼0; the Equation (8) can be written as 3. Results and discussion Sample per batch was 3 kg products that were placed on 3 trays in chamber (1 kg for each tray). The saturated steam was used as energy input for drying process. The saturated steam condition was 2.5 bar gauge on average, with the temperature in the steam jacket ranging from 110 to 120 C and the steam dryness (x) was 0.32. The temperature in the chamber ranged from 50 to 60 C. Drying process per batch had been carried out with a duration ranging from 7 to 9 hours and consumed 4 kg hot saturated steam. The vacuum pressure condition in chamber was between 82 kPa to 90 kPa. By using Equations (3–6) energy balance and dryer efficiency were calculated. The Sankey diagram, showing the example of energy input and output terms and energy efficiency values, is drawn for the drying system and given in Figure 4. The total energy input of the hot steam and wet product (cocoa beans) obtained was 15.451,3 kJ (100%), whereas the total energy consumed was 6081 kJ (36%) and the energy losses to surrounding was 9792 kJ (64%). Figure 5 shows the efficiency of a vacuum dryer using the ejector compared with a dryer without the ejector. Testing was carried out by taking samples of cocoa beans and coffee beans. The test

results showed that there was an increase of 10

energy efficiency when utilizing the dryer with a vacuum effect compared to a dryer without a vacuum effect (the dryer at near atmospheric pressure). The pressure in the internal moisture of seeds which was bigger than the pressure surounding of the seed made the drive force increase.). This is due to

the enhanced internal moisture migration under vacum, **the rate of drying can be** more **rapid** 5 compared to **that at**

atmosphere pressure.[12] Referring to the trend of Figures 5 and 6, the smaller the vacuum pressure is the more efficient the use of energy and the faster drying time is. However, the strength of the chamber material needs to be made thicker or stronger which can withstand the force due to the high level of vacuum. In this experiment the strength of the material was only designed up to 80 kPa. According to Perre et.al,

the higher specific volume of vapor associated with the reduced pressure is severe limitation for heat 5
ransfer **by convection**

. In the process of drying coffee beans, with the effect of vacuum pressure in the chamber, the overall drying efficiency reached 31%, whereas in the absence of vacuum pressure effect the overall system efficiency was only 20%. Meanwhile in the drying process of cocoa beans, the overall drying efficiency was 36% by vacuum pressure conditions and 24% in the near conditions to atmospheric pressure. The difference in energy use was relatively high for drying coffee beans, with the vacuum effect the efficiency was about 11% higher than that without vacuum effect. At the process of drying cocoa beans the energy used in the vacuum conditions was 12% higher than the one in the atmospheric pressure condition. This phenomenon might be caused by the characteristics of the outer surface of cocoa beans which contained lots of fiber and sugar. Table 1 shows the Specific Moisture Extraction Ratio (SMER) of Cocoa and Coffee Beans. The maximum results achieved at a vacuum pressure of 82kPa i.e., for coffee beans of 5.21x105 kg/kJ (0.19kg/kWh) and cocoa beans of 5.37kg/kJ (0.193kg/Kwh). This result is smaller than the convective kiln-dryer which can reach 0.80.9kg/kWh which is applied for wood drying.[12] The SMER value obtained for the two types of material depended on the performance of the drying machine used and other parameters such as temperature and pressure in the chamber. In general there was a lot of heat losses to surrounding (it was between 64% and 69% of the total energy input) as shown in Sankey diagram. The thermal insulation and the steam circulation in the steam jacket seemed to be ineffective. The condition of saturated vapor with low steam dryness caused the phase change of steam to saturated liquid to take place relatively fast in the water jacket. This caused the heat not distributed properly in the chamber. In order to reduce heat losses due to low quality steam conditions, the steam drying process is needed to change the saturated phase to superheated steam while maintaining low pressure conditions. In addition, it is necessary to review the material design and specification of thermal insulation. 3.1. Drying characteristics The drying time versus the moisture content of coffee and cocoa beans can be seen in Figures 6 and 7. They show the comparison of the rate of moisture decreasing under vacuum and atmospheric pressure for two types of materials; cocoa and coffee beans. It can be seen that there are the differences in drying time for different pressure conditions for the two sample materials tested. For example, to achieve the condition of both cocoa and coffee beans with a moisture content of 5% as shown in Figures 6 and 7, for the vacuum conditions, it took 8 hours while for the conditions at atmospheric pressure it took 9 hours. That means the drying process with vacuum conditions (97 kPa) was 1 hour faster than the drying conditions at atmospheric pressure. The drying rate declined at the last stage when the material moisture was below 10% as the characteristic of drying process for generally posts harvesting matter.[4,13] Compared with the results of a study conducted in Refs. [8] and [11], the drying time of the cocoa beans from the condition of 38% to 7.5% moisture content was 7 hours using hot gas in the batch tray dryer type; the drying time was almost the same as that obtained in the drying system tested. The experimental test reported in this paper is for coffee beans and cocoa only, however, the use of this vacuum dryer can be implemented for a variety of other materials, such as food products that sensitive to high temperatures (e.g., fruits and herbal products).[14,15] That is because this type of vacuum dryer operates at low to medium temperatures under vacuum conditions. Also, because using steam as the drying medium, there are several advantages when compared to flue gas. This is possible because steam is no oxidation, no toxic, and higher drying rates. Various advantages of using steam as the drying medium are discussed in more detail by other authors.[16] 4. Conclusions The effect of the vacuum dryer using the ejector was investigated experimentally. Shorter drying times as well as increasing energy efficiency were achieved by reducing the pressure in the dryer chamber comparing to drying at near atmospheric pressure. Since the drying operation utilized the steam ejector, there was no need to introduce the vacuum pump. Experimental tests on the development of a vacuum dryer design using an ejector revealed that the overall performance and reliability of dryer were improved. However there were a lot of heat losses to surrounding because the thermal insulation might be inappropriate. Funding This research was financed by The Higher Education Ministry of Indonesia (Direktorat Riset dan Pengabdian Masyarakat, DRPM), under Grant No.: 044/SP2H/LT/ DRPM/2019. References [1] Djaelani, M.; Van Boxtel, A. J. B. Development of a Novel Energy-Efficient Adsorption Dryer with Zeolite for Food Product. Drying Technol. 2014, 25, 1063–1077. [2] Jia, X.; Jolly, P.; Clemets, S. Heat Pump Assisted Continues Drying. Part 2: Simulation Results. Int. J. Energy Res. 1990, 14, 771–782. [3] Maskan, M. Kinetics of Colour Change of Kiwi Fruits during Hot Air and Microwave Drying. J. Food Eng. 2001, 48, 169–175. DOI: 10.1016/S02608774(00)00154-0. [4] Parikh, D. M. 2015, Vacuum Drying, Basics and Application, Feature Report, Chemical Engineering. www.Chemicalonline.com (accessed Apr 2015). [5] Figel, A.; Michalska, A. Overall Quality of Fruits and Vegetables Affected by Drying Processes with the Assistance of Vacuum-Microwaves. IJMS. 2017, 18, 71. DOI: 10.3390/ijms18010071. [6] Spurk, H. J.; Aksel, N. Fluid Mechanics, 2nd ed.; Springer-Verlag: Berlin, New York and London, 2008; pp. 279–281 [7] Franck, J. A. A. E.; Gaston, Z.; Steve, C. Z.; Robert, N. Optimization of Drying Parameters for Mango, Seed Kernels Using Central Composite Design. Bioresour. Bioprocess. 2015, 2, 8. DOI: 10.1186/s. 40643-015-0036-x. [8] Milly, A. P.; Zhongli, P.; Griffiths, G. A.; Gary, S.; James, F. T. Drying Characteristics and Quality of Bananas under Infrared Radiation Heating. Int. J. Agric. Biol. Eng. 2013, 6, 58–70. [9] Coskun, C.; Bayraktar, M.; Oktay, Z.; Dincer, I. Energy and Exergy Analyses of an Industrial Wood Cips Drying Process. Int. J. Low-Carbon Tech. 2009, 4, 224–229. DOI: 10.1093/ijlct/ctp024. [10] Seveda, M. C. Design and Development of walk-In, Type of Hemi Cylindrical Solar Tunnel Dryer for Industrial Use. Int. Sch. Res. Netw. 2012, 2012, 1–9. DOI: 10.5402/2012/890820. [11] Komolafe, C. A.; Adejumo, A. O. D.; Awogbemi, O.; Adeyeye, A. D. Development of Cocoa Beans Batch Dryer. Am. J. Eng. Res. (AJER) 2014, 3, 171–176. [12] Osman, P.; Arum, M. S. Drying of Pulp and Paper, Hand Book of Industrial Drying. Taylor and Francis Group LLC: Boca Raton, USA, 2006; pp. 921–922. [13] Schmidt, E. L.; Klocker, K.; Flacke, N.; Steimle, F. Applying the Transcritical CO2 Process to a Drying Heat Pump. Int. J. Refrig. 1998, 21, 202–211. [14] Davahastin, S.; Suvarnakuta, P.; Soponronnarit, S.; Mujumdar, A. S. A Comparative Study of LowPressure Superheated Steam and Vacuum Drying of a Heat-Sensitive Material. Drying Technol. 2014, 22, 1845–1867. DOI: 10.1081/DRT- 200032818. [15] Boxtel, V. Processing and Drying of Foods, Vegetables and Fruits. J. Drying Technol. 2013, 25, 83–96. [16] Mujumdar, A. S. Superheated Steam Drying, Hand Book of Industrial Drying. Taylor and Francis Group LLC: Boca Raton, USA, 2006; p.492

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