Use of a Double Condenser in a Dehumidifier with a Spray Dryer for Vitamin A Extraction in Tomato as a HeatSensitive Material

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Use of a Double Condenser in a Dehumidifier with a Spray Dryer for Vitamin A Extraction in Tomato as a Heat-Sensitive Material

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Abstract. Spray dryers are commonly operated at a high temperature (>100 °C), which becomes an obstacle for heat-sensitive materials. In this study, a refrigeration system that uses evaporator as dehumidifier and that recovers the heat released from the first condenser to preheat the drying air was utilised to reduce the drying temperature. Results showed that the degradation of vitamin A (measured with the high performance liquid chromatography method) in tomato increased significantly when the drying air temperature increased from 90 °C to 120 °C, and it cannot be controlled at a temperature higher than 120 °C. At an air flow rate of 450 lpm, the drying capacity at a drying air temperature of 60 °C (with refrigeration, humidity ratio of 0.005 [kg H_2O / kg dry air]) is equal to the drying capacity at a drying air temperature of 120 °C (without refrigeration, humidity ratio of 0.021 [kg H_2O / kg dry air]). The drying capacity at a drying air temperature of 90 °C (with refrigeration) even becomes 1.5 times the drying capacity at a drying air temperature of 120 °C (without refrigeration). The combination of a spray dryer system with a refrigeration system (double condenser) is therefore beneficial for drying heat-sensitive materials, such as vitamin A.

INTRODUCTION

Each year, the world's population continues to grow, and the need for foodstuff increases correspondingly. Consumers demand reductions in the use of synthetic additives to preserve food because of the potential short- and long-term health risks that these additives pose [1]. Since their introduction in 1870, spray dryers [2] are one of the tools used to dry foodstuff for various processed products [3], medicines for pharmaceutical purposes [4] or other non-food materials in the form of small-sized particles [5]. Spray dryers could also provide benefits in terms of storage, production or distribution because their light weight enables them to be used for various types of packaging. Spray dryers have helped catapult food drying technology as an alternative in food processing technology.

The temperatures and conditions of drying imposed on a product have an important influence on it [5]. The more heat is exposed to the material, the faster does the material dry [6]. Spray drying occurs at high entrance temperatures ($\geq$ 100 °C) [5,7] and in a continuous process; in the drying process, wet materials enter continuously, and dry materials are continuously expelled, as well [8]. In the drying process of heat-sensitive materials, such as those in food, the water content of the foodstuff is decreased (less than 5%) so that the microorganisms or enzymes contained in the food materials cannot reproduce [8]; the cells of the microorganisms in the food materials will be damaged if the drying air has a temperature of 60 °C to 80 °C [9]. The ideal drying condition for some foodstuff, including fruits, vegetables, beef, fish and other biologic substances, is an air temperature of the drying system outlet under 60 °C or the lowest temperature at 10 °C to 45 °C and RH $\geq$ 30% [9].

Vitamins (vital amine) are groups of organic compounds that play important functions in the metabolism of every organism, including humans, to help them grow and develop well and to provide health benefits. Vitamin A is fat-soluble; it plays a role in the arrangement of retina pigments and in the maintenance of healthy skin and immunity. In 1909, vitamin A was discovered to be contained in carrots, but it can also be found in milk (28 mg 3%); fish (Kakap (30 IU), kembung (30 IU)); vegetables (especially green and yellow-colored vegetables), such

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as carrot (835 ug 93%), broccoli leaves (800 mg 89%), sweet potato (709 mg 79%), kale (681 ug 76%), spinach (469 ug 52%), pumpkin (400 mg 41%), collard greens (333 mg 37%), beans (38 mg 4%) and broccoli (31 mg 3%); fruits (especially red and yellow fruits, such as red pepper (95[illegible] IU 32%), carrot (16706 IU, 557%), banana (300 IU), papaya (365 SI) and tomato (1800 IU,1500 SI, 3%); and liver (beef, pork, chicken, turkey, fish) (6500 mg 722%) [10,11]. The vitamin A content in tomatoes is quite important because of its health benefits. Tomato juice is an example of a heat-sensitive material that is difficult to dry because of its low glass transition temperature (Tg) resulting from the low-molecular-weight-sugar that it contains [12]. The sugar found in tomatoes is mostly in the forms of dextrose and levulose with glass temperatures of 31 °C and 5 °C, respectively [13]. Tomatoes are also highly hygroscopic and tend to stick when the drying temperature has a relatively high moisture or high temperature [12]. The recommended drying air temperature for tomatoes is approximately 140 °C to 150 °C [14]. However, the important nutrients of tomatoes, such as vitamin A, are degraded in this temperature. Vitamin A is prone to damage by heat, sunlight and air exposure. The storage temperatures should be kept at under 39 °C (102.2 °F) or at a temperature range of 15 °C to 30 °C (59 °F to 86 °F), a boiling point of 122.5 °C (252.5 °F) and a melting point of 63 °C (145.4 °F). Examining the vitamin A content of tomatoes is therefore interesting because determining it when a spray dryer is used is difficult.

In this study, the refrigeration system or dehumidifier used a double condenser installed in the spray dryer for the tomato liquid material so that the levels of vitamin A can be determined. The experiment in this study aimed to assess the optimal temperature (heat balance) of drying air and the performance of the spray dryer with the influencing parameters: airflow rate, material flow rate, humidity and degradation of vitamin A as a result of the increase in drying temperature.

MATERIALS AND METHODS

Materials

The material was prepared in liquid condition by considering the pure material and its mixture. The material in this study was tomato juice liquefied with the use of a blender. The solids were discarded, and the fluid was weighed. Maltodextrin was added at an amount of 1/3 of the weight of the tomato juice. The preparation of the tomato juice was performed sequentially per 0.5 kg of tomato to prevent it from spoiling.

Methods

The air from the environment was sucked by the blower by measuring the airflow debit from the readings on a Hitachi SJ200 rotameter and through the orifice Dwyer Pressure (SCFM-lpm). The pressure difference was measured in the orifice and then converted to height difference with a manometer, with the following blower variations: 150 lpm or 0.0029 kg/s, 300 lp or 0.0058 kg/s and 450 lp or 0.0087 kg/s. The air was flowed to the evaporator in the dehumidifier system. In the evaporator, the dehumidified air (with subtracted specific moisture), or the condensed air, was heated by the heat of the condenser's outlet and added by the heater in the spray drying system before being inserted to the drying chamber as the drying air.

The dehumidifier system here used an air refrigerating system that includes a hermetic compressor (Kulthorn AEA 2415Y), condenser, expansion valve, evaporator and blower. An evaporator is a calorie exchange tool that functions to cool the incoming air from the environment; therefore, the air compressed by the compressor already has a lower temperature and humidity compared with the environment temperature or is extracted to its specific humidity or dehumidified by setting the pressure through rotation of the needle valve to determine the evaporator outlet temperature from the condenser (evaporator temperature variations: 10 °C, 15 °C and 20 °C).

In addition, the value of RH in the air duct exiting the evaporator was also measured with the RH meter. Then, the air compression was continued at the condenser. The condenser was the calorie exchange tool that functions as the refrigerant condenser. Our study used R134a refrigerant. Calorie is released because of the high pressure and the temperature refrigerant vapour at the end of the condensation process. In this study, the two condensers performed the cooling methods differently. The first condenser performed cooling through the air that flowed to the heater chamber and, the second was through the hot air that would be heated further by a heater and flowed to the drying chamber in the spray dryer system.

The expelled heat in the condensation process definitely helps the heater reach the air heating control temperature in the spray dryer system so that the work of the heater could be minimised. However, if excess heat on the air exists, then the second condenser with a cooling fan will displace the heat into the environment. In the drying room, the materials that have been atomised by a pneumatics nozzle will mix with the air coming out of the heater. The expansion valve will expand the high-pressure and high-temperature refrigerant fluid adiabatically to reach the temperature and low pressure in the evaporator. This cycle will continue. Meanwhile, the material pump would be activated (peristaltic longer pump BT 100-2J and booster pump; Kemflo booster pump NF 1800) to set the material rate in which the fluid is transformed into droplets by spraying them with the atomiser. The pressure regulator is used to set the air pressure from the compressor in the pneumatic nozzle for

1 bar. The water droplets from the materials that have formed these droplets will be in contact with the high-temperature hot air expelled from the heater with the following temperature variations: 60 °C, 90 °C and 120 °C. In the drying chamber, the materials are atomised by the pressure nozzle with the aid of the compressor spray and mixed with the air from the heater. This contact causes the water droplets to dry and change their form into solid powder. The caloric and mass transfer processes occur in the drying chamber. The water in the material will evaporate, the dried material will fall into the collection basin under the drying chamber and some will be carried by air. Because of the influence of the cyclone on centrifugal force, some the materials will affect the wall and fall into the collection basin in the cyclone. The rest will be released to the environment with the air.

TABLE 1. Experimental Set-up Parameters.

Experimental Set-up Parameters	
Airflow mass flow (ma)	0.0029, 0.0058 and 0.0087 kg/s
Temperature of evaporated air (T2a)	10 °C, 15 °C and 20 °C
Temperature of environmental air (T1a)	30 °C
Temperature of refrigerant R 134 a	−4.31 °C in the pressure of 2.5 MPa or 1 bar
Condensation saturation temperature (Tcondensation)	40 °C, 50 °C and 60 °C
Compressor efficiency	90%
Temperature of the air exiting the condenser that would enter the spray drying heater chamber (T exit condenser)	50 °C, 60 °C, 70 °C, 80 °C and 90 °C
Temperature of the heater in the spray dryer	60 °C, 90 °C and 120 °C

After the variations mentioned above were performed, the peristaltic pump was arranged to dry the drying chamber. For each variation, the peristaltic pump was started from a low flow, with the dry drying chamber, then it was increased slowly until tomato juice was accumulated, which was the wet condition; the material flow before the accumulation occurs was the flow of the materials harvested. Data processing was performed by calculating the dry airflow rate, vapour flow rate and vapour flow rate in the dryer. The scheme of dehumidification is shown in Fig. 1.

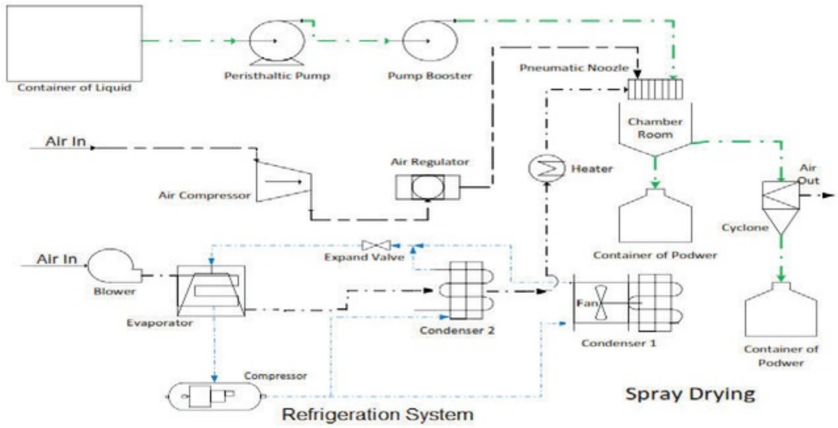

FIGURE 1. Dehumidification Scheme with a Spray Drying Using a Double Condenser, Department of Engineering, University of Indonesia, Depok 2015 [14].

An assessment was then performed. The vitamin A concentration in tomatoes with temperature variation generated from each drying temperature results was measured. The measurement of vitamin A concentration was performed in SIG (Saraswati Indogenetech) Laboratory in Bogor with the high-performance liquid chromatography method. A vitamin A concentration in μg /100 g unit was determined.

RESULTS AND DISCUSSION

The experiment aimed to measure the effects of drying air temperature on the concentration of vitamin A in tomato products.

TABLE 2. Vitamin A Concentration in Tomato Products at Different Drying Temperatures.

Temperature [^{o}C]	90	120	150
Concentration [µg/100 g]	360.53	26.73	16.59

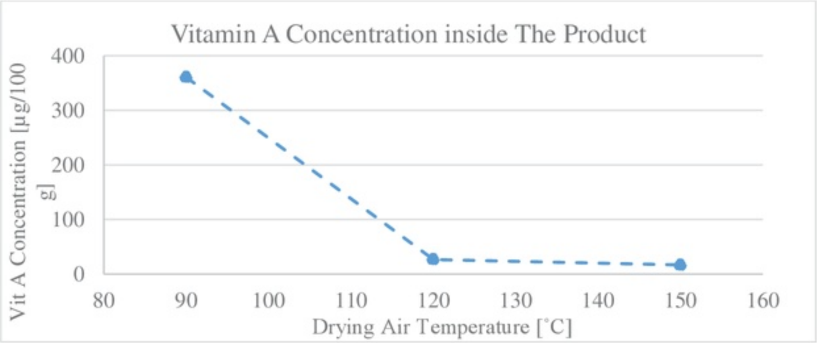

FIGURE 2. Degradation of Vitamin A as a Result of the Drying Temperature.

The concentration of vitamin A in tomatoes (U.S. Department of Agriculture) ranges from 1800 IU or approximately 540 [µg/100g]. In this study, however, the initial vitamin A content of tomato juice was not measured, so the vitamin A degradation could not be calculated. Nevertheless, Fig. 2 shows that at the temperatures of 120 ^{o}C and 150 ^{o}C, the concentration of vitamin A decreases substantially compared with that at 90 °C. At a drying temperature of 90 °C, the concentration of vitamin A is abundant, which is 360 [µg/100g]. However, when the drying temperature is increased to 120 °C, the concentration of vitamin A decreases substantially to 26 [µg / 100g], as shown in Fig. 2. This result means that the critical drying temperature of vitamin A in tomato juice is around 120 °C. This temperature corresponds to the boiling point of vitamin A, which is 122.5 °C (252.5 °F).

This finding implies that vitamin A can be produced more effectively in spray drying at the drying temperature of 90 °C. However, this result can be explored further in an experiment involving a temperature between 90 °C and 120 °C.

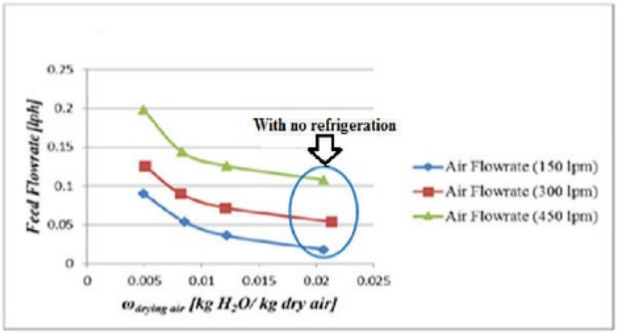

FIGURE 3. Influence of Specific Humidity and Air Flow Rate on the Feed Flow Rate at a Drying Air Temperature of 60 °C.

$\omega_{drying\ air}$ = humidity ratio of drying air [kg of vapor/kg of dry air]

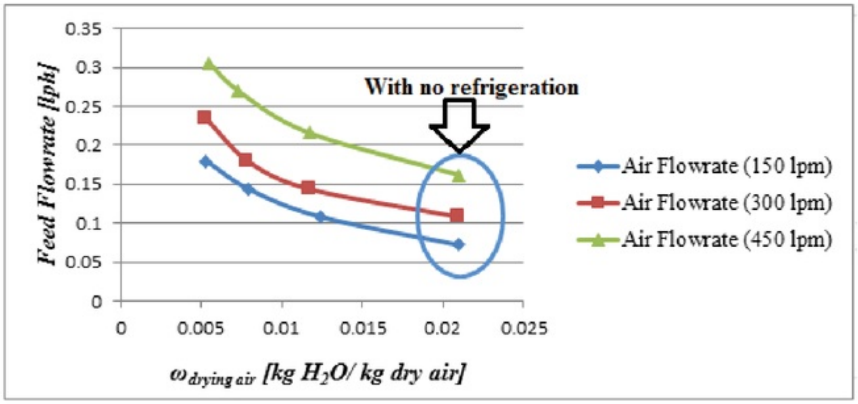

FIGURE 4. Influence of Specific Humidity and Air Flow Rate on the Feed Flow Rate at a Drying Air Temperature of 90 °C.

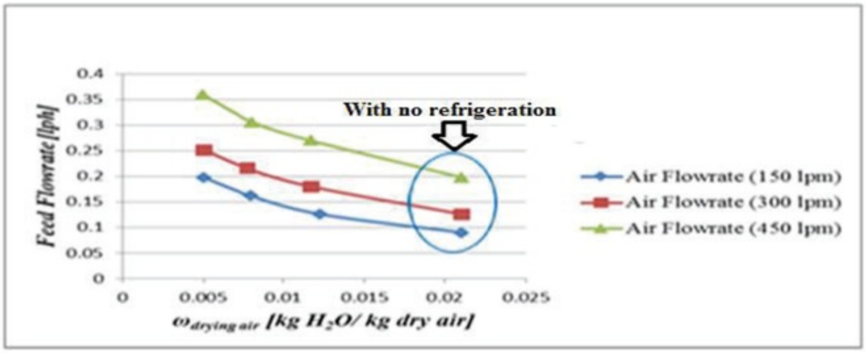

FIGURE 5. Influence of Specific Humidity and Air Flow Rate on the Feed Flow Rate at a Drying Air Temperature of 120 °C.

Figure 3 to Figure 5 above show that the higher is the air flow rate (150, 300 and 450 lpm), the higher is the drying air temperature (60 °C, 90 °C and 120 °C), and that the lower is the humidity ratio, the higher is the feed flow rate.

Without the refrigeration system at a drying temperature of 120 °C, the highest air flow rate of 450 [lpm] has resulted in a feed flow rate of 0.2 [lph]. This condition cannot be achieved (without a refrigeration system) for heat-sensitive materials, such as vitamin A, because their drying temperature is 120 °C, as explained previously. However, with the use of a refrigeration system, the feed flow rate of 0.2 [lph] can be achieved at a drying temperature of 60 °C by dehumidifying the drying air until its humidity ratio is 0.005 [kg H2O / kg dry air] (see Fig. 4). Even at a drying temperature of 90 °C (safe temperature for vitamin A) and a humidity ratio of 0.005 [kg H2O / kg dry air] (see Fig. 3), a feed flow rate up to 0.3 can be achieved [lph] (1.5 times of 0, 2 [lph]). Clearly, with this system, a spray dryer can be used for heat-sensitive materials without degrading their drying capacity; in fact, it can even increase their drying capacity.

CONCLUSIONS

From the data presented, the following conclusions are drawn:

1. Spray drying, combined with a dehumidifier and a double condenser to test vitamin A concentrations in a mixture of tomato juice and maltodextrin, can be operated up to a temperature of 90 ° C.
2. The higher is the air flow rate (150, 300 and 450 lpm), the higher is the drying air temperature (60 °C, 90 °C and 120 °C), and the lower is the humidity ratio, the higher is the feed flow rate.

3. At an air flow rate of 450 lpm, the drying capacity at a drying air temperature of 60 °C (with refrigeration, humidity ratio of 0.005 [kg H2O / kg dry air]) is equal to the drying capacity at a drying air temperature of 120 °C (without refrigeration, humidity ratio of 0.021 [kg H2O / kg dry air]), which is 0.2 [lph].
4. At an air flow rate of 450 lpm, the drying capacity at a drying air temperature of 90 °C (with refrigeration, a humidity ratio of 0.005 [kg H2O / kg dry air]) is 0.3 [lph]. This value is 1.5 times the drying capacity at a drying air temperature of 120 °C (without refrigeration, humidity ratio of 0.021 [kg H2O / kg dry air]).
5. The combination of a spray dryer system with a refrigeration system (double condenser) is very useful in drying heat-sensitive materials, such as Vitamin A, without degrading their drying capacity; in fact, it can even increase their drying capacity.

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