DEVELOPMENT AND THERMAL EVALUATION OF DOUBLE DRUM DRYER FOR READY-TO-EAT FOOD PRODUCTS TO SUPPORT STUNTING PREVENTION
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PENGEMBANGAN DAN EVALUASI TERMAL PENGERING DRUM GANDA UNTUK PRODUK MAKANAN SIAP SAJI DALAM MENDUKUNG PENCEGAHAN STUNTING

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DOI: https://doi.org/10.356.33/inmateh-64-04

Keywords: *design, double drum dryer, manufacture, stunting prevention*

ABSTRACT

The study aimed to develop a small-scale drum dryer to meet the small enterprises' demand in the context to produce ready-to-eat food products to support stunting prevention. The design, manufacture, and thermal evaluation of a double drum dryer had been carried out. The development stage consisted of sizing the main components, creating technical drawings, determining component materials, manufacturing, and performance tests. The dryer drum dimension was 500 mm in diameter and 400 mm in length and 20 mm in thickness. The capacity of the double drum dryer was 10 kg/batch. The double drum dryer was powered by a 3-phase electromotor 2.24 kW. There are three transmission systems applied, i.e. gearbox, chain-sprocket and belt-pulley. The feeding system applied was nip feeding. The heat source originated from the steamer using an electric heater. Results of the test showed that the double drum drying machine had worked well as expected. The temperature distribution of both drums was fairly uniform, and the temperature uniformity in the drum surface showed good uniformity (minimum gradient temperature). The double drum dryer was able to produce good characteristics of products in the form of ready-to-eat products made from several ingredients (i.e. millets and red bean) which contain high macro and micronutrient.

ABSTRAK

Penelitian ini bertujuan untuk mengembangkan drum dryer skala kecil untuk memenuhi kebutuhan usaha kecil dalam rangka memproduksi produk makanan siap saji untuk mendukung pencegahan stunting. Desain, pembuatan, dan evaluasi termal pengering drum ganda telah dilakukan. Tahap pengembangan terdiri dari pengukuran komponen utama, pembuatan gambar teknis, penentuan material komponen, pembuatan, dan uji kinerja. Dimensi drum pengering memiliki diameter 500 mm dan panjang 400 mm dan ketebalan 20 mm. Kapasitas pengering drum ganda adalah 10 kg/batch. Pengering drum ganda digerakkan oleh motor listrik 3-fase 2.24 kW. Ada tiga sistem transmisi yang diterapkan yaitu gearbox, rantai-sproket dan sabuk-puli. Sistem makan yang diterapkan adalah nip feeding. Sumber panas berasal dari steamer dengan menggunakan pemanas listrik. Hasil pengujian menunjukkan bahwa mesin pengering drum ganda telah bekerja dengan baik sesuai dengan yang diharapkan. Distribusi temperatur pada kedua drum cukup seragam, dan keseragaman suhu pada permukaan drum telah menunjukkan keseragaman yang baik (temperatur gradien minimum). Pengering drum ganda telah mampu menghasilkan karakteristik produk yang baik berupa produk siap saji yang terbuat dari beberapa bahan (mis. millet dan kacang merah) yang mengandung makro dan mikronutrien tinggi.

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INTRODUCTION

Based on Basic Health Research results in 2013 and 2018, Indonesia's stunting prevalence reached 37.2% and 30.8%. With the efforts made by the government in 2019, the stunting rate dropped to 27.67 per cent *(Ministry of Health of the Republic of Indonesia, 2019)*.

The introduction of supplementation in weaning foods prepared from readily available and low-cost ingredients is vital to meet the growing children's requirements (*Saeeda et al., 2009*). Weaning food is one of the ready-to-eat food products to prevent stunting due to lack of good nutrition. These ready-to-eat food products require equipment and process technology that can answer these challenges. One of the technologies used to produce ready-to-eat food products is drying technology of drum dryer using.

Drum dryer is a type of dryer widely used in the food industry for drying various liquid, semi-liquid, and paste food ingredients. Several types of drum drying products include powdered milk, baby food, flour, fruit and vegetable pulp, honey, maltodextrin, yeast cream, and many other foods and non-food products *(Bonaui et al., 1996; Elmholt et al., 2007; Kasiri et al., 2004; Pua et al., 2007; Rodriguez et al., 1996; Tang et al., 2003*). The dry product obtained is porous, easy to rehydrate, and ready to use (*Pua et al., 2007*). The dry products produced can be used as semi-finished products in milk, beverages, confectionery, and other industries (*Pua et al., 2007*). The purpose of drying is to extend the product's shelf life and reduce weight in transportation *(Pua et al., 2007*).

Drum dryers were first patented for use in the manufacture of pregelatinized starch in Germany by Mahler and Supf in 1921 *(Mujumdar, 1995)*. There are three types of cylinder type dryers: single-drum dryers, double drum dryers, and twin drum dryers. Based on the operation system, drum dryers are distinguished from open system dryers and vacuum dryers. Meanwhile, referring to the feeding method, there are four types of cylinder dryers, namely cylinder dryers with nip feed systems, splash feeds, dip feeds, and roller feeds (*Francis, 2000; Mujumdar, 1995; Tang et al., 2003*).

Some of the advantages of using drum dryers include: (a) relatively fast drying time, the thin film is spread over a large area resulting in fast heat and mass transfer, (b) the equipment is compact, uses relatively less space than other dryers, (c) short heating time, (d) the cylinder can be closed in a vacuum jacket, which allows the drying temperature to be reduced, and (e) the product is obtained in flakes, which are suitable for various purposes *(Choudhary, 2015)*. Other prior writings suggest that the advantages of using cylinder dryers are: (a) the product has good porosity and is easy to rehydrate, (b) drum dryers can dry very viscous slurry, such as gelatinized or cooked pastes and starches, which other methods cannot quickly dry, (c) drum dryers usually have high energy efficiency, (d) drying can be clean and hygienic, (e) drum dryers are easy to operate and maintain, and (f) are flexible and suitable for several other types of products *(Mujumdar, 1995)*.

There are also some disadvantages, including lack of control over (a) feed rate, (b) cylinder temperature, (c) film thickness, and (d) cylinder rotation speed *(Ahmed, 2013)*. Other publications say that some of the other disadvantages are: (a) Some products may not be able to dry out and do not form a good film on the cylinder surface, (b) some products, especially those containing high sugar, are not easily dredged from the cylinder surface, (c) the output relatively low compared to spray drying, (d) the cost of replacing the cylinder surface is quite expensive, (e) the possibility of the product being scorched due to direct contact with high temperatures on the cylinder surface, and (f) unable to process salty materials and corrosive materials (*Tang et al., 2003*).

Among the three types, single and double drum dryers are most often used for drying fruits and vegetables. Drum dryers are only used for drying materials that produce powder products. For materials sensitive to heat damage, a vacuum drum dryer can be used for reducing the drying temperature *(Mujumdar, 1995)*. The double drum dryer type has a higher production rate relative to other drum dryer types, it can handle products in a broader range and is more efficient (*Mujumdar, 1995; Okos et al., 1992*).

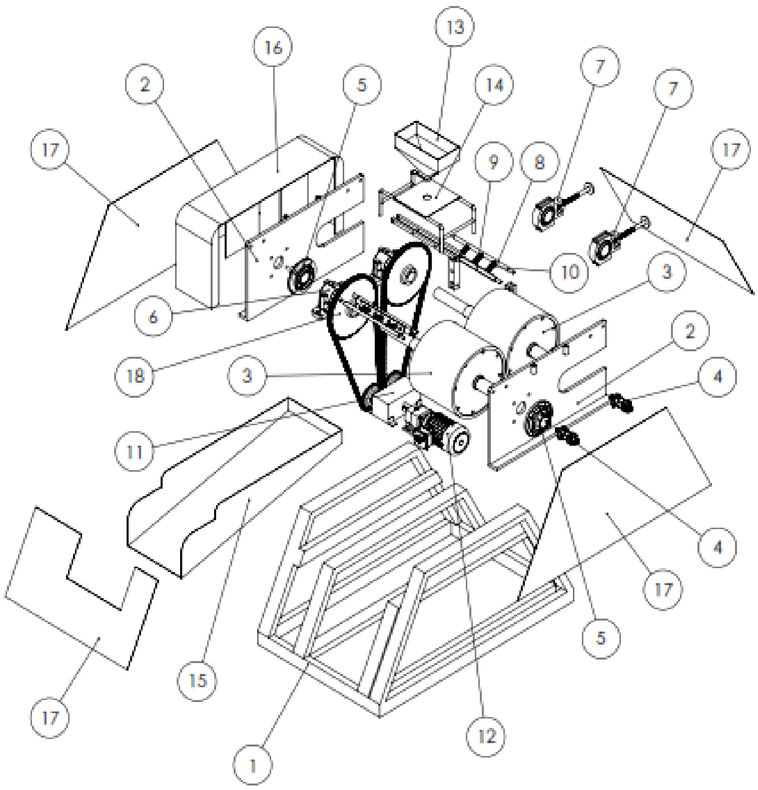
In Indonesia, drum dryer machines are generally imported from other country so that the costs are very high. Besides, the machine capacity is intended for large-scale businesses. Drum drying machines have not been developed especially for the needs of small and medium scale businesses in Indonesia. Therefore this research aimed to develop locally made drum dryers using available local materials in order to support the drying process of ready-to-eat food related to stunting prevention. The developed machine is expected to be appropriate with the small scale enterprise demand to produce high quality and standard ready-to-eat products.

MATERIALS AND METHODS

The development stage of the double drum drying machine consisted of a general description, sizing and determining the main components, creating technical drawings, manufacturing, and performing the functional test *(Hidayat et al., 2020)*.

Description of double drum drying machine

The double drum dryer, designed and constructed, is an open type (atmospheric) with a nip feeding system. Atmospheric double drum dryers are the most versatile and widely used type of drum dryer due to their products' versatility. This dryer type has a higher production rate, can handle a more comprehensive product range and is more efficient than other drum dryer types *(Mujumdar, 1995)*. Figure 1 shows an exploded view of a double drum dryer designed and constructed in this study.



1. *Frame*
2. *Buttress*
3. *Drum*
4. *Rotary Joint*
5. *Pillow Block Bearing*
6. *Plummer Block Bearing*
7. *Pillow Block Bearing Adjuster*
8. *Support Shaft*
9. *Scraper*
10. *Springs*
11. *Gear Box*
12. *Electric Motor*
13. *Hopper*
14. *Hopper Stand*
15. *Product Release Chute*
16. *Transmission Cover*
17. *Frame Cover*
18. *Chain Sprocket*

Fig. 1 - An exploded view of the double drum dryer designed

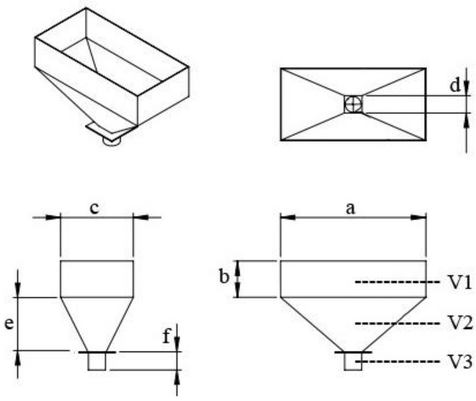
The double drum dryer is classified as a conduction dryer. The drying process is obtained by transferring heat from the condensing steam inside the drum to the material covering its external surface (*Jurendić & Branko, 2012; Karapantsios, 2006*). Just like the name, the double drum dryer consists of two cylinders rotating against one another. The feeding system applied in this double drum dryer was nip feeding. The food material to be dried was prepared in the mixer by adding the desired components and water. After mixing, the liquid or semi-liquid food material was poured into the hopper. The material fell into the drum dryer surface and was equally distributed along the body by opening the tap. After about three-quarters of a drum revolution from the point of feeding, the material was dried, and then scraped off. The scraped off material fell into drop chute and was finally collected in the container.

Sizing of the main components

The main components of a double drum dryer need to be designed based on the criteria of the machine which has a capacity of 10 kg per batch. Sizing main components consisted of hopper dimension, drum mass and dimension, shaft, scraper, power source, and transmission system.

Hopper design

Hopper dimension is required to be designed according to hopper capacity target per batch. The hopper design is shown in figure 2 and the capacity is calculated using the equation (1)-(4).



a = 40 cm
b = 10 cm
c = 20 cm
d = 4.7 cm
e = 15.3 cm
f = 5 cm

Fig. 2 - Orthogonal view of the hopper design

$$V_1 = a \times c \times b \text{ [cm}^3\text{]} \tag{1}$$

$$V_2 = \left[\frac{1}{3}(a \times c) \times e + \frac{1}{3}(d^2) \times e + \frac{1}{3}\sqrt{(a \times c) \times (d^2) \times e} \right] \text{ [cm}^3\text{]} \tag{2}$$

$$V_3 = \frac{\pi}{4} \times d^2 \times f \text{ [cm}^3\text{]} \tag{3}$$

$$\sum V = V_1 \times V_2 \times V_3 \text{ [cm}^3\text{]} \tag{4}$$

Results of calculation obtained that the gross volume of the hopper (ΣV) was 12827 cm^3 or 12.83 liters, taken into account 80% of capacity, the net volume for raw material is about 10 liters.

The statistical analysis results determined that the height of raw material in the hopper correlated quadratically with the volume. The correlation between the height of raw material and volume matched the equation of $y = 0.020x^2 - 0.237x + 0.768$, $R^2 = 1$, where X-axis is a height of material in the hopper, Y-axis is the volume of the raw material (figure 3).

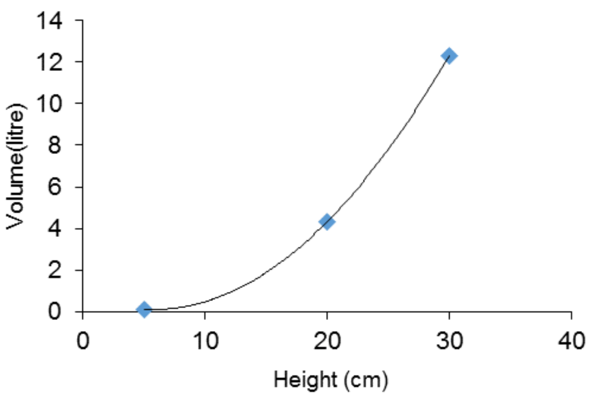


Fig. 3 - Correlation between height and volume of raw material in the hopper

Drum design

In developing a drum dryer, the drum is the most important part because the surface is where it comes into contact with the dried material so that the drum was constructed using cast iron (FCD 450). FCD 450 was chosen as it has a lower thermal expansion coefficient compared to stainless steel.
The coefficient of thermal expansion of FCD 450 and stainless steel are 10×10^{-6} K^{-1} and 17.3×10^{-6} K^{-1}, respectively. To increase hardness, durability, and avoid corrosion, FCD 450 was coated with chromium material. Drum design is shown in figure 4. The parameter of drum design consisted of surface area (A_D), drum volume (V_D) and drum mass (M_D), determined by using equation (5)-(7).

$$A_D = \pi \times D \times L \text{ [cm}^2\text{]} \quad (5)$$

$$V_D = A_D \times t \text{ [cm}^3\text{]} \quad (6)$$

$$M_D = V_D \times \rho \text{ [kg]} \quad (7)$$

where:

D is diameter of the drum, [m];
L – length of the drum, [m];
t – thickness of the drum, [m];
ρ – density of material [kg/m³]

Results of the calculation obtained that the surface area of the drum is 0.63 m^2, the volume of each drum is 0.0125 m^3, and the drum mass is 98 kg per drum (Cast iron density is 7874 kg/m^3). It means that the mass of the two drums is 196 kg.

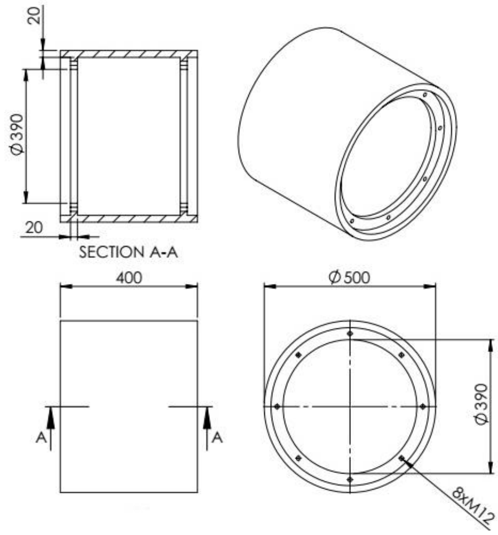


Fig. 4 - Drum dryer design and dimension (in mm)

Analysis of power needs

The electric motor is the source of power considered to be used to rotate the double drum part. In this case, the size of the motor needs to be calculated based on the mass of the double drum dryer part. Power needed *(P)* for rotating the drum dryer is calculated using equation (8)-(9).

$$T = M \times r \text{ [Nm]} \quad (8)$$

$$P = T \times \frac{2 \times \pi \times n}{60000} \text{ [kW]} \quad (9)$$

where,

T is torque, [Nm];
M – moment of force, [N];
r – radius of drum [m]
n – drum rotation, [rpm]

Based on some known parameters (i.e. drum mass is 98 kg, radius of the drum is 0.25 m, and the gravity is 9.81 m/s^2), the calculation of the torque value is 240.35 Nm. In this double dryer there are two drums so that the total torque is 480.7 Nm. Drum rotation is assumed to be at a maximum rotation of 10 rpm so the power obtained is 0.5 kW. Because there is a factor of motor efficiency that is assumed to be 60% and a safety factor of 2, the motor power required is 1.68 kW (2.25 HP) rounded to 3 HP.

Shaft design

Shaft design was carried out using the calculation method according to Sularso & Suga (2004). Shaft diameter is calculated using equation (10) and (11).

$$d_s = \left[\frac{5.1}{\tau_a} \times C_b \times K_t \times T \right]^{1/3} \text{ [m]} \tag{10}$$

$$\tau_a = \frac{\sigma_b}{Sf_1 \times Sf_2} \text{ [N/m}^2\text{]} \tag{11}$$

Where:

d_s is shaft diameter, [Nm];
C_b – bending load factor;
K_t – twisting load factor;
τ_a – allowable stress, [N/m²];
σ_b – tensile strength, [N/m²];
Sf_1 – safety factor due to shaft material;
Sf_2 – safety factor due to keyway

According to *(Sularso & Suga, 2004)*, the value of C_b and K_t depends on the load assumption that occurs on the shaft. In this case, the twisting load is assumed to be small so that the value of K_t is 1.5. There is also a possibility of bending loads so that the value of C_b is 2.3. Tensile strength of the shaft material is 4.8×10^8 N/m², Sf_1 is 6 and Sf_2 is 3. Based on the calculation, the minimum shaft diameter is 0.068 m or 68 mm, rounded to 70 mm.

Scraper

The material used for constructing a scraper was steel ST 25. To avoid damage to the dryer drum because of friction, the material of the scraper has to be softer than the drum. The hardness number of ST 25 is 123-183 HB and hardness number of FCD 450 is 143-217 HB. Scraper design is presented in figure 5.

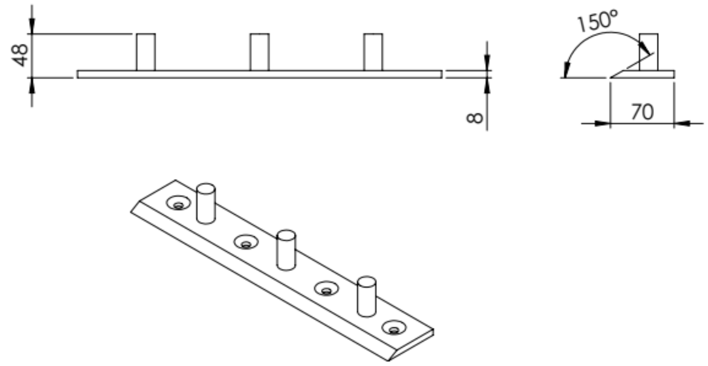


Fig. 5 - Scraper design and dimension (in mm)

Transmission system

There are three transmission systems applied in this double drum dryer, i.e. gearbox, belt-pulley and chain-sprocket. The transmission ratio of the gearbox used was 1:50, belt-pulley was 1:3, and chain-sprocket was 1:3. The rotation per minute of dryer drum theoretically was 3.22 rpm, due to losses occurred, the real rotation was 2.7 rpm. Various inverter frequency was used to adjust the rotation up to 0.5 rpm performed in 10 Hz frequency.

Evaluation of the drum dryer

There were two kinds of test conducted to evaluate the drum dryer i.e. functional test and performance test. Functional test was performed without using the test sample material. The parameter measured consisted of steam pressure and drum surface temperature. The heat source used to run the drum dryer was a steamer which uses 4500 watts of power. The steamer was set in a pressure range between 2 and 3.8 bar. When the pressure reaches the set point pressure, the electricity was automatically turn off and vice versa. There are three stages while operating the drum dryer: 1) turn on the steamer and wait until the pressure reaches the set point, 2) open the valve that connects the steamer to the drum, and it will drop the pressure, 3) wait until the pressure reaches the target and the drum dryer is ready to use. The steam pressure and drum temperature parameters of all stages were observed and evaluated to obtain parameters profile. The tool used for observing the drum temperature was infrared thermal imager (*Fluke TiS40*) with an accuracy of 0.1 °C.

Performance tests was conducted using two formulas of puree made from several ingredients which contain high nutrition that is specifically for toddlers in order to prevent stunting. The first formula consisted of red proso millet (*Panicum miliaceum* L.) 332.56 gr, red kidney bean (*Phaseolus vulgaris* L.) 262.5 gr, salt 8.74 gr, and water 3360 ml. The second formula consisted of white proso millet (*Panicum miliaceum* L.) 332.56 gr, red kidney bean (*Phaseolus vulgaris*) 262.5 gr, salt 8.74 gr, and water 3360 ml. The evaluation was only to observe the ability of the drum dryer to process puree into ready-to-eat products.

RESULTS

The prototype of double drum dryer

The prototype of double drum drying machine developed in this study is shown in figure 6, and the specification of the machine is presented in table 1.

Fig. 6 - The prototype of a double drum dryer

Table 1

Specification of a double drum dryer prototype

❑ Over all dimension	
• length	1600 mm
• width	1150 mm
• height	2050 mm
❑ Drum	
• length	400 mm
• diameter	500 mm
• thickness	20 mm
• material	Cast Iron FCD 450 Hardened with Chromium
❑ Scraper	
• length	500 mm
• width	56 mm
• thickness	8 mm
• material	ST 25, Zinc coated
❑ Power source	Electric motor 3 HP, 3 Phase, V 380 volt
❑ Transmission system	
• Gearbox ratio	1:50
• Sprocket ratio	1:3
• Pulley ratio	1:3
❑ Inverter	YD 101, 3 Phase 400 V, 0.4 -22 kW
❑ Drum rotation	0 – 3 rpm
❑ Feeding system	Nip
❑ Heat source	Electric steamer
❑ Capacity	10 kg/batch

Double drum dryer performance

A double drum dryer's operation stages included heating the steamer, opening the steam distribution valve to the dryer cylinder, and setting the condensate outlet. After the desired temperature had been reached, the material in the hopper was poured into the gap between the two cylinders, material feeding being managed by opening the tap in the hopper. The cylinder rotation was regulated by adjusting the inverter frequency.

The black line in figure 7 shows the pressure profile in the steamer, while the blue line shows the temperature at drum-1 and the red line shows the temperature at drum-2. Before the valve that connects the steam supply to the drum is opened, the pressure rises (stage 1). After the valve is opened, the pressure drops drastically (stage 2), and then the pressure rises again gradually (stage 3). The pressure on the steamer will also decrease when the steam trap tap is opened. The steam trap tap function is to remove the condensate in the dryer drum. When drying the material, pressure on the steamer and the temperature on the cylinder drum is relatively constant.

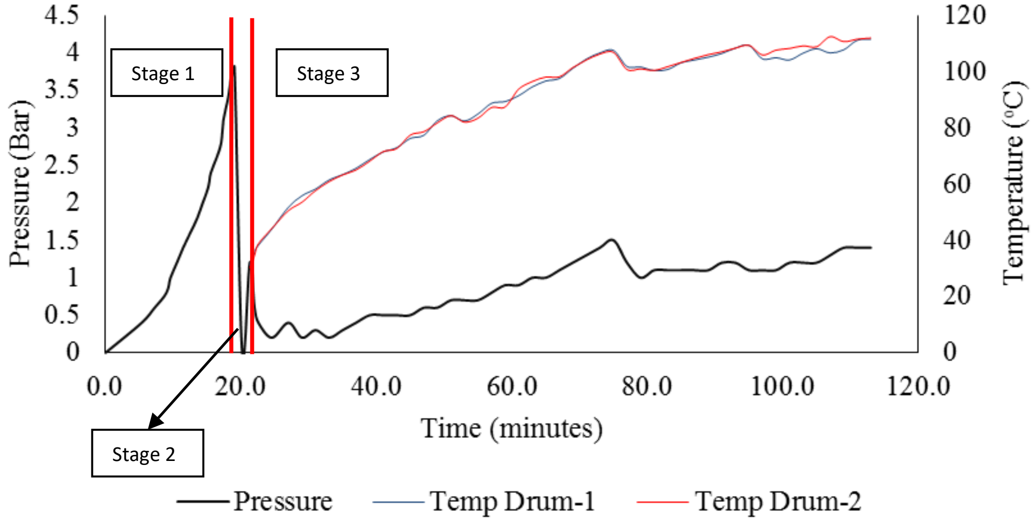
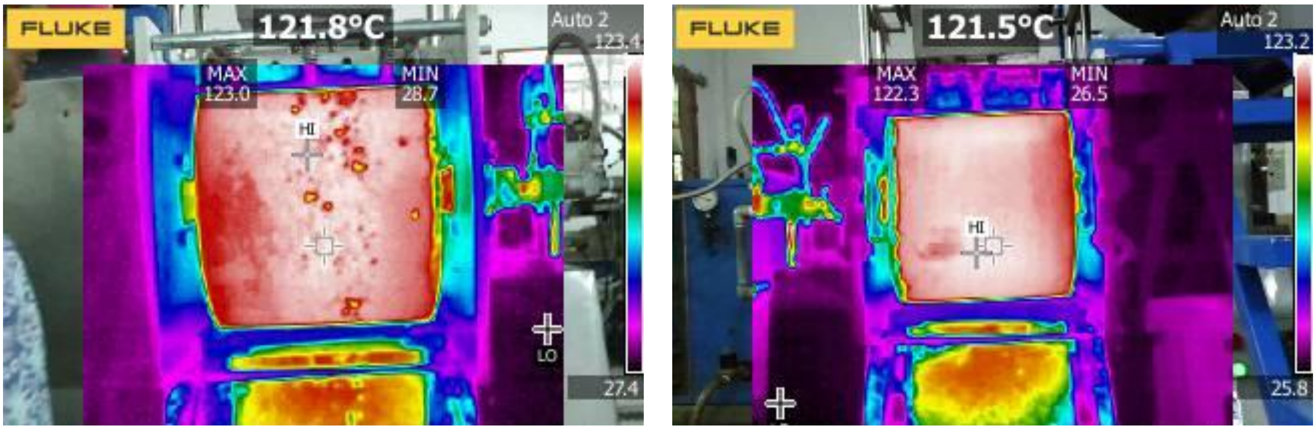


Fig. 7 - Profile of steam pressure and temperature on both drums during functional test

When drying, the temperature of both drums were collected to characterize the homogeneity of the heat distribution in both drums and were analyzed statistically. The paired t-test analysis results did not show a significant difference in the two cylinders' heat distribution. The statistical analysis results using paired t-test showed that the distribution of temperature in the two cylinders were not significantly different, t(48); p>0.05. The result of the temperature distribution in the both drums was also presented in figure 8. Beside the fact that the temperature of both drums was fairly uniform, the uniformity of temperature in the whole drum was also uniform according to figure 8.



(a) Drum-1 (b) Drum-2

Fig. 8 - Distribution of temperature in the both drum

This study also investigated the relation between steam pressure and drum temperature. Based on figure 9, it is shown that there is a strong correlation between steam pressure and drum temperature (R^2 is 0.9667). For further experiments, the desired drum temperature can be set based on the pressure set at the beginning of the process.

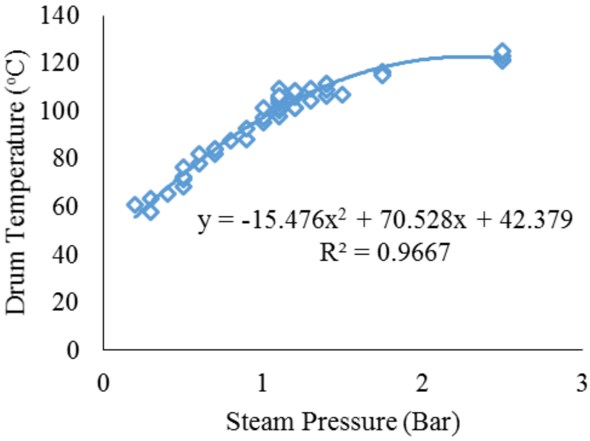


Fig. 9 - Correlation between steam pressure and drum temperature

Regarding the cylinder's rotation, the statistical analysis results obtained from the drum rotation correlated linearly with the frequency. The correlation between drum rotation and inverter frequency matched the equation of $y = 0.054x + 0.004$, $R^2 = 0.999$, where X-axis is a frequency (Hz) Y-axis is the rotation (rpm) as shown in figure 10.

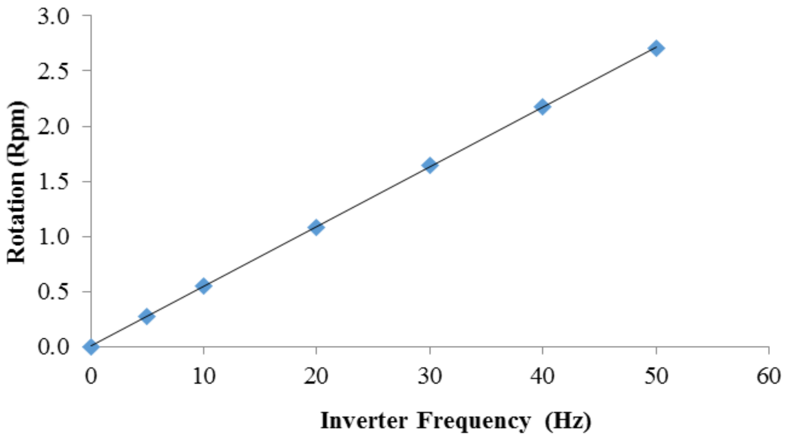


Fig. 10 - Correlation between drum rotation and inverter frequency

Figure 11 shows sample products of two formulas produced by a double drum dryer set at a temperature of 121°C (pressure of 2 Bars) and drum rotation of 1.6 rpm (30 Hz).

First formula Second formula

Fig. 11 - Thin-film product samples produced by the double drum dryer

The result shows that the double drum dryer has been able to produce good characteristics of both products in the form of ready-to-eat products made from several ingredients (i.e. millets and red bean) which contain high macro and micronutrient (*Kusumah et al., 2020; Shobana et al., 2013*). A combination of red kidney bean and proso millets can be used as ingredients to provide high-nutritional value in foods in the form of ready-to-eat food products that can be consumed by toddlers to prevent stunting problems. The ready-to-eat products can easily be produced by using drum drying technology.

CONCLUSIONS

A 10 kg/batch double drum dryer was developed and tested in this study. Dryer drum dimension was 400 mm length, 500 mm diameter and 20 mm thickness. The electromotor used to drive was 2.24 kW/3 phase. There were three transmission systems used, i.e. gearbox, sprocket-chain and belt-pulley. The rotation in processing was set by adjusting the inverter frequency. The double drum dryer designed and constructed had worked well, as expected. The temperature distribution of both drums was fairly uniform, and the temperature uniformity in the drum surface has shown good uniformity (minimum gradient temperature). The double drum dryer has been able to produce good characteristics of products in the form of ready-to-eat products made from several ingredients (i.e. millets and red bean) which contain high macro and micronutrient which are useful for preventing stunting in toddlers. Extensive performance evaluation is recommended to optimize the operational condition of double drum dryer in producing various formula of ready-to-eat food and other instant foods.

ACKNOWLEDGEMENT

Financial support from Indonesia Endowment Fund for Education, Ministry of Research and Technology, National Research and Innovation Agency (Indonesia) is gratefully acknowledged. We would like to appreciate all those who offered us the possibility to complete this research. We would also like to thank Teguh S., Maulana F., Dadang G., Iman R. and Taufik Y. for their help in constructing the prototype of this study.

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