Development of the solar-energized foodstuff drying system for urban communities

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Abstract. Urban in Indonesia, is no longer limited as a center of community settlement. Now the city also functions as a center of government, a central hierarchy, and a center of economic growth. As a logical consequence of the role of cities as a center of growth and economy, urban contributions to national economic growth are increasing. To overcome this problem, a portable conveyor of solar-energized drying system was designed. With the portable conveyor of solar-energized drying system, the dryer will be easily moved and flexible to use. The advantage of portable conveyor of solar-energized drying system is the drying process could be done continuously with a little human power. Therefore, this portable conveyor of solar-energized drying system is designed to use renewable energy sources. To examine the portable conveyor of solar-energized drying system, the foodstuff was used for a testing of ingredients. The portable conveyor of solar-energized drying system testing show that the amount of water content in the foodstuff reduced, the drying rate accelerate. In addition, the amount of heat energy needed for the drying process also reduced. Hence process of drying foodstuff more efficient.

Keywords: Drying, economic growth, portable conveyor, renewable energy, urban.

1. Introduction
Urban in Indonesia, is no longer limited as a center of community settlement. Now the city also functions as a center of government, a central hierarchy, and a center of economic growth. As a logical consequence of the role of cities as a center of growth and economy, urban contributions to national economic growth are increasing. This growth has a big impact on the city itself. In terms of population, for example, there is a large population growth from year to year. Of course also such rapid population growth has major consequences for cities. The increase in population in the midst of increasingly limited public space, making the city increasingly lose its function as a means of
comfortable settlement. The economic crisis that has hit Indonesia in recent years, has forced the city to bear an additional burden that is quite serious. Increasing urbanization from rural to urban areas, coupled with an increase in unemployment makes the problem of the city more complex. Therefore, to face these challenges and so that the economy of urban communities is increasing and improving amid increasingly fierce competition, then the innovation of developing a renewable energy-based food dryer system becomes one of the alternative solutions in solving economic problems in urban areas. Currently more and more renewable energy-based drying systems are being developed. Some developed a foodstuff drying system [1], developed a cocoa beans drying system [2], developed a wood drying system [3, 4], developed a shoe drying system [5], developed a biomass-energized drying system [6, 7], developed a cloth drying system [8], developed the radio frequency and microwave heating treatment to disinfect *kutu beras* (*Sitophilus oryzae* Linnaeus, 1763) [9], development of building rehabilitation with dry and wet systems [10], and development of heating zone temperature control for the drying process [11]. Hence the development of a drying system using this renewable energy source, becomes a challenge and also a solution for urban communities in their efforts to improve their economy and prepare for facing increasingly fierce competition.

2. Research methodology

2.1 Research flow diagram

In this paper, the research steps are shown in the following research flow diagram in figure 1 below:

![Figure 1. Research flow diagram.](image-url)
2.2. Portable conveyor of solar-energized drying system
Design of the portable conveyor of solar-energized drying system to be studied can be seen in figure 2 below, the advantage of this solar-energized drying system is the drying process can take place continuously using heat from solar energy. The main components of the portable conveyor of solar-energized drying system shown as the following picture:

![Diagram of the portable conveyor of solar-energized drying system](image)

**Drawing part list:**
1. Main Frame
2. Drive Pulley
3. Tail Pulley
4. Drive Plate
5. Tail Plate
6. Wiremesh Belt
7. Drive Foot Conveyor
8. Tail Foot Conveyor
9. Heavy Duty Roller Ø60 mm × 318 mm
10. Bracket Roller
11. Oven Room
12. Drive Unit
13. Roller Chain Unit
14. UCF 205
15. Adjuster
16. Pipe Bracing

**Figure 2.** The portable conveyor of solar-energized drying system components.
The explanations of these components are as follows:

i. Main Frame, is the main frame of the conveyor made of 3 mm thick plate and the other components are installed.

ii. Drive Pulley, is a pulley component that deals directly with the gearbox motor and serves as the initial drive of the conveyor system.

iii. Tail Pulley, is the last pulley component (end) of the conveyor which moves following the drive pulley and serves as a place for the rotation of the wiremesh belt from the conveyor. Tail pulley is usually the starting point of the transfer of material.

iv. Drive Plate, is a component that is the base of the pillow block drive pulley holder.

v. Tail Plate, is a component that is the base of the pillow block tail pulley holder.

vi. Wiremesh Belt, is the main component that functions to carry or move goods from tail pulley to drive pulley.

vii. Drive Foot Conveyor, is a conveyor support component which is also the seat holder of the motor gearbox.

viii. Tail Foot Conveyor, is another support component of the conveyor.

ix. Heavy Duty Roller, is a return roller component whose position is below the main frame and serves to support the wiremesh belt.

x. Bracket Roller, is a component that becomes a heavy duty roller holder.

xi. Oven, is a component that is a place for drying materials, the oven wall uses polycarbonate material with a 25 mm × 25 mm hollow frame and the hot air is flowed through a heat distribution pipe outlet that comes from the burner.

xii. Drive Unit, is a gearbox motor component that functions as a conveyor drive source.

xiii. Roller Chain Unit, is a transmission component consisting of a sprocket and chain that connects the gearbox motor and drive pulley.

xiv. UCF 205, is a pillow block component that functions as a drive pulley and tail pulley holder.

xv. Adjuster, is a component that serves to regulate the tightness of the wiremesh belt.

xvi. Pipe Bracing, is a binding component of tail foot conveyor to be stable and rigid.

2.3. Working principle of the portable conveyor of solar-energized drying system

The first step in the operation of this portable conveyor of solar-energized drying system is to place foodstuff such as grain, corn, pepper, coffee, soybean, vermicelli, etc., in a container called a baking sheet. Hot air is blown into the oven room through a heat distribution pipe that is in the oven room, with a heat source coming from the burner. The heat distribution pipe in the oven room is perforated 4 mm and evenly distributed along the pipe with a distance of 150 mm between the holes. With such a hole position, the distribution of hot air will be evenly distributed and fill the oven room, hence the foodstuff carried using the conveyor when passing through the oven room will be exposed to heat and cause evaporation of water contained in the foodstuff. With this evaporation, when the foodstuff comes out of the oven room will dry out. The heat source of the portable conveyor of solar-energized drying system can be supplied from a burner uses solar-energized system. The drying rate is regulated through the conveyor speed, so that the drying process can take place optimally and evenly.

2.4. Research stages

The research activity is planned to be divided into two stages as follows:

i. The initial stage is the initial design of the portable conveyor of solar-energized drying system.

ii. The second stage is the design and manufacture of working drawings of portable conveyor of solar-energized drying system, system simulations and performance tests.

3. Mathematical equation

The rate of evaporation of foodstuff water content in drying process is largely determined by the increase in temperature. The greater difference between the temperature of the heating medium and the dried foodstuff, the greater the speed of heat transfer into the foodstuff, hence the evaporation of water content from the foodstuff will be more and faster [2]. The higher the temperature and speed of the dryer air flow, the faster the drying process takes place. The higher the air temperature, the greater
the heat energy carried by the air. Furthermore, increasingly mass of liquid is evaporated from the surface of the dried foodstuff. If the speed of the dryer air flow is higher, the faster the mass of water vapor is transferred from the foodstuff to the atmosphere [2]. The water content of the foodstuff shows the amount of water content in the weight of the foodstuff. In this case there are two methods to determine the foodstuff water content, based on wet base and dry base water content. The wet base water content in the foodstuff was calculated using the following equation:

$$ MC_{wb} = \frac{W_a}{W_b} \times 100 \% $$ \hspace{1cm} (1)

Then calculate the dry base water content in the foodstuff using the following equation:

$$ MC_{db} = \frac{100MC_{wb}}{100 - MC_{wb}} $$ \hspace{1cm} (2)

The drying rate can be calculated using the following equation:

$$ M = \frac{M_0 - M_t}{\Delta t} $$ \hspace{1cm} (3)

The amount of heat used for drying can be calculated using the following equation:

$$ Q = Q_1 + Q_2 + Q_3 $$ \hspace{1cm} (4)

Where $Q_1$ (sensible heat of the foodstuff) is obtained from the following equation:

$$ Q_1 = m_k \cdot c_p \cdot (T_1 - T_0) $$ \hspace{1cm} (5)

$Q_2$ (sensible heat of the water) is the heat used to increase the temperature of the water in the foodstuff obtained from the following equation:

$$ Q_2 = m_a \cdot c_a \cdot (T_1 - T_0) $$ \hspace{1cm} (6)

$Q_3$ (latent heat of the water evaporation) is the amount of heat used to evaporate the water from the foodstuff obtained from the following equation:

$$ Q_3 = m_w \cdot h_{fg} $$ \hspace{1cm} (7)

To determine the amount of heat given by hot air in the dried foodstuff, using the following equation:

$$ q = \rho \cdot V \cdot c_u \cdot (T_{in} - T_{out}) $$ \hspace{1cm} (8)

To determine the drying efficiency, using the following equation:

$$ \eta = \frac{Q}{q} \times 100 \% $$ \hspace{1cm} (9)

where:
- $MC_{wb}$ = Wet base water content (%)
- $MC_{db}$ = Dry base water content (%)
- $W_a$ = The water mass in the foodstuff (kg)
Wb = The wet foodstuff mass (kg)
M = Drying rate (kg s⁻¹)
M₀ = The initial mass of the dried foodstuff (kg)
Mₜ = The final mass of the dried foodstuff (kg)
Δt = The drying time interval (s)
Q = The amount of drying heat (kJ)
Q₁ = Sensible heat of the foodstuff (kJ)
Q₂ = Sensible heat of the water (kJ)
Q₃ = Latent heat of the water evaporation (kJ)
q = Heat received by the foodstuff from the air dryer (kJ)
mₙ = The dry foodstuff mass (kg)
mₐ = The water mass (kg)
mₕ = The mass of the water evaporated (kg)
cₚ = Specific heat of the foodstuff (J kg⁻¹ °C⁻¹)
cₐ = Specific heat of the water (J kg⁻¹ °C⁻¹)
cₐ = Specific heat of the air (J kg⁻¹ °C⁻¹)
hₕₑ = Latent heat of the water evaporation (J kg⁻¹ °C⁻¹)
ρ = Density of the dried foodstuff (kg m⁻³)
V = Volume of the drying chamber (m³)
T₀ = Initial temperature of the foodstuff (°C)
T₁ = Final temperature of the foodstuff (°C)
Tᵢₙ = The burner inlet temperature (°C)
Tᵢₜₜ = The burner outlet temperature (°C)
η = The drying efficiency (%) 

4 Result and discussion

4.1. Calculation and analysis of drying process on the portable conveyor of solar-energized drying system

The drying process on the portable conveyor of solar-energized drying system will be calculated using Autodesk CFD Motion software [12]. In the analysis process using Autodesk CFD Motion software, data are obtained as shown in table 1.

Table 1. The analysis results using Autodesk CFD Motion software.

| No | Parameters                           | Value  | Unit   |
|----|--------------------------------------|--------|--------|
| 1  | Total mass flow in                   | 0.087  | kg s⁻¹ |
| 2  | Total volume flow in                 | 0.087  | m³ s⁻¹ |
| 3  | Total mass flow out                  | 0.122  | kg s⁻¹ |
| 4  | Total volume flow out                | 4.82 × 10⁻³ | m³ s⁻¹ |
| 5  | Heat transfer from air to wall       | 628.4  | W      |
| 6  | Total power of heat transfer         | 35 168 | W      |
| 7  | Inlet temperature (Tᵢₙ)              | 76.6   | °C     |
| 8  | Outlet temperature (Tᵢₜₜ)            | 51.2   | °C     |
| 9  | Length of drying chamber             | 6      | m      |
| 10 | Initial foodstuff temperature (Tᵢₕ) | 25     | °C     |
| 11 | Final foodstuff temperature (T₁)     | 41     | °C     |
| 12 | Wet foodstuff mass (mₙ)              | 800    | g      |

Table 1. continue to the next page.
Table 1. Continued

| No | Parameters                      | Value | Unit          |
|----|---------------------------------|-------|---------------|
| 13 | Air specific heat ($c_a$)       | 1 004 | J kg$^{-1}$ºC$^{-1}$ |
| 14 | Water specific heat ($c_w$)     | 4 180 | J kg$^{-1}$ºC$^{-1}$ |
| 15 | Foodstuff specific heat ($c_p$) | 1 700 | J kg$^{-1}$ºC$^{-1}$ |
| 16 | Latent heat of water evaporation ($h_{fg}$) | 2 260 | kJ kg$^{-1}$ |

The data in table 1 will be used as a reference to calculate the drying process and drying efficiency using equation (1) to equation (9) as shown in table 2 and table 3.

Table 2. Calculation results of drying process.

| Output (rpm$^*$) | $V_c$ (m s$^{-1}$) | t (s) | $V$ (m$^3$) | $m_a$ (g) | $m_h$ (g) | $MC_{wb}$ (%) | $MC_{db}$ (%) | $M$ (g s$^{-1}$) |
|------------------|-------------------|------|-------------|-----------|-----------|---------------|---------------|-----------------|
| 14               | 0.088             | 68.21| 0.329       | 614       | 186       | 76.74         | 329.84        | 9               |
| 15               | 0.094             | 63.66| 0.307       | 573       | 227       | 71.62         | 252.36        | 9               |
| 16               | 0.101             | 59.68| 0.288       | 537       | 263       | 67.14         | 204.35        | 9               |
| 17               | 0.107             | 56.17| 0.271       | 506       | 294       | 63.19         | 171.69        | 9               |
| 18               | 0.113             | 53.05| 0.256       | 477       | 323       | 59.68         | 148.03        | 9               |
| 19               | 0.119             | 50.26| 0.242       | 452       | 348       | 56.54         | 130.11        | 9               |
| 20               | 0.126             | 47.75| 0.230       | 430       | 370       | 53.71         | 116.05        | 9               |
| 21               | 0.132             | 45.47| 0.219       | 409       | 391       | 51.16         | 104.74        | 9               |
| 22               | 0.138             | 43.41| 0.209       | 391       | 409       | 48.83         | 95.43         | 9               |
| 23               | 0.145             | 41.52| 0.200       | 374       | 426       | 46.71         | 87.65         | 9               |

*Note: 1 rpm = 1/60 Hz (SI)

Table 3. Calculation results of drying process.

| Output (rpm) | $Q_1$ (kJ) | $Q_2$ (kJ) | $Q_3$ (kJ) | $Q$ (kJ) | $Q$ (kJ) | $\eta$ (%) |
|--------------|------------|------------|------------|----------|----------|------------|
| 14           | 5.06       | 41.06      | 0.74       | 46.86    | 57.79    | 81.09      |
| 15           | 6.18       | 38.32      | 0.69       | 45.19    | 65.80    | 68.67      |
| 16           | 7.15       | 35.92      | 0.65       | 43.72    | 71.42    | 61.22      |
| 17           | 8.01       | 33.81      | 0.61       | 42.43    | 75.30    | 56.35      |
| 18           | 8.77       | 31.93      | 0.58       | 41.28    | 77.90    | 53.00      |
| 19           | 9.46       | 30.25      | 0.55       | 40.26    | 79.55    | 50.61      |
| 20           | 10.07      | 28.74      | 0.52       | 39.33    | 80.49    | 48.87      |
| 21           | 10.63      | 27.37      | 0.50       | 38.49    | 80.89    | 47.59      |
| 22           | 11.13      | 26.13      | 0.47       | 37.73    | 80.89    | 46.65      |
| 23           | 11.60      | 24.99      | 0.45       | 37.04    | 80.58    | 45.96      |
The graphs in figure 3 and figure 4 are graphs of calculation results of drying process and efficiency:

**Figure 3.** Graph of base water content vs motor rotation output.

**Figure 4.** Graph of drying efficiency vs motor rotation output.

### 5 Conclusion

The results of CFD analysis can be used as a reference to calculate the foodstuff water contents, the foodstuff drying rate, the sensible heat of the foodstuff, the sensible heat of water, the latent heat of water evaporation, the amount of drying heat, the foodstuff heat given by the air and drying efficiency. When the smallest motor rotation output is 14 rpm, the drying efficiency of 81.09 % with the dried water content was 76.74 % for wet base and 329.84 % for dry base. But when the motor rotation output is 23 rpm, the drying efficiency also decreases to 45.96 % with the dried water content was 46.71 % for wet base and 87.65 % for dry base.
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