บทความวิจัย (Research Article)

A Study and Development of the Control System of Fruit Dehydration Machine by Biomass Energy

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Abstract

This article presents the study and development of the control system of fruit dehydration machine by biomass energy in which manual control system was upgraded to the Auto one. Study results revealed that Auto control system required less operation time for as much as 1.30 hour. By comparing energy consumption of the two systems, the upgraded system required less energy approximately 751.30 baht/month and 9,016.32 baht/year. When the break-even point is taken into consideration, this system upgrade could payback after 3.33 year. The author really hopes that this study can be used as a guideline for those interested or involved in the development fruit dehydration machine.

Keywords: study and development, fruit dehydration machine, biomass energy

1. Introduction Related Theories

Thailand is recognized as one of the centers of agricultural products and premium foods based on its biodiversity. Thailand is even known as an exporter of agricultural technologies regarding seeds, vaccines and animal feeds [1-2]. Agricultural industry and biotechnology can be categorized into 2 groups as follows: 1) Advanced Agriculture which refers to the development of varieties of tool including traditional breeding techniques aiming at altering living organisms or part of them in order to obtain new plant or animal products as well as development of microorganisms for specific use in agricultural activities which will provide farmers with the tool that can effectively reduce production cost or higher yield. 2) Biotechnology refers to those applying scientific knowledge to living organisms or parts or products of such organisms for the benefit of human being whether in relation to production or other processes relevant to goods or services in order to meet their purposes e.g. agriculture, foods, environment or medical science etc. [3-4]

As far as fruit products are concerned, seasonal over supply appears to be a common problem among farmers who are sometimes forced to deal with massive rotten products. [5] As such, various fruit preservation methods have been invented to minimize unprofitable products. For instance, food preservation methods include pickling or fermentation, drying or dehydration etc. Dehydration, in particular, is one of the popular methods as it is an easy, convenient and timesaving. The product obtained from this method is also highly popular among consumer. Generally, fruit dehydration needs proper control of relevant factors such as temperature, humidity, hot air velocity etc. It is therefore important to study and carefully test the function of dehydrator as excess heat can burn the fruits while inadequate heat prolong the dehydration process and waste energy. [6-7]

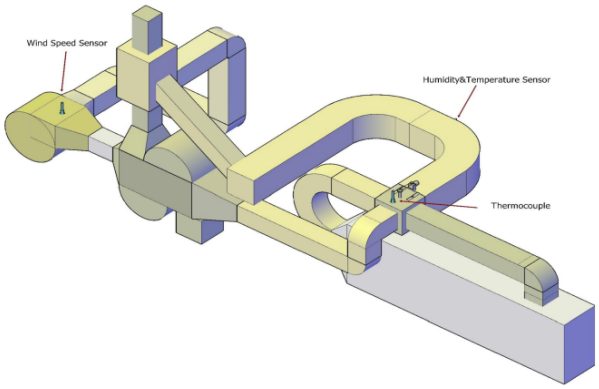

Fig. 1 Fruit Dehydration Machine

From the above, the researcher wishes to develop the temperature control system of fruit dehydration machine by biomass energy by means of reusing excess heat with a view to saving energy for supplying heat to fruit dehydration machine. This paper is expected by the researcher to become a model for those interested in the development of high performance fruit dehydrator.

2. Related Theories

2.1 Hot Air Drying [8-10]

Hot air dehydration or drying is a process applying the machine generating hot air (non-natural) converted from other energy sources e.g. electricity or combustion (liquid propane gas (LPG), fuel oil or firewood). This type of dehydration method requires less space than sun drying (natural method) while user can control consistency in product quality and cleanliness. Drying process requires the following elements to be controlled:

- Humidity which refers to water volume in the food. Humidity is presented in percentage of the weight of water contained in the food against the weight of such food. According to AOAC standard, water weight is calculated by weighing food and then baking the food at 100 Degree Celsius to evaporate water away until food weight is stable.

$$\%Humidity = \left(evaporayed\ water\ /\ food\ weight\right)\times 100 \quad (1)$$

- Moisture content refers to water content in the material which can be presented by water volume per total wet mass (Wet Base) or water volume per total dry mass (Dry Base). While being under drying process, the total mass will simultaneously change. Calculation of moisture content by Wet basis will render irregular change of moisture content. Below are the formulas for calculating moisture content:

ω_w = [kg(water)/kg(wet mass)] (2)

ω_d = [kg(water)/kg(dry mass)] (3)

- Relative Humidity (RH) refers to the ratio of the current absolute humidity to the highest possible absolute humidity (which depends on the current air temperature). A reading of 100 percent relative humidity means that the air is totally saturated with water vapor and cannot hold any more. According to AOAC standard, water weight is calculated by weighing food and then baking the food at 100 Degree Celsius to evaporate water away until food weight is stable.

$$RH = \left(\frac{Actual\ vapour\ density}{Saturation\ vapour\ density} \right) \times 100\% \qquad (4)$$

- Drying Rate means the ratio of water evaporated from material against surface of material per unit of time during dehydration process. The equation of dehydration rate depends on existing condition of food before dehydration and the ambient condition during dehydration e.g. type of dehydration machine, temperature, period of time, relative humidity or convection heat transfer coefficient etc.

$$R_c = \frac{h_v}{\lambda}\left(T_v - T_i\right) \qquad (5)$$

When R_c = Constant Drying Rate

h_v = Heat Transfer Coefficient ($w/m^2\,^\circ C$)

T_v = hot air temperature ($^\circ C$)

$hour$ = material surface temperature ($^\circ C$)

- Drying rate and graph demonstrating drying properties: when material with sufficient surface moisture is hung in the hot air current and then monitoring moisture against temperature of such material, in general, the results will be as shown in Fig. 2. Drying mechanism can be divided into 3 periods of different characteristics as follows: (I) initial adjustment period (II) constant drying rate period (III) falling drying rate phase

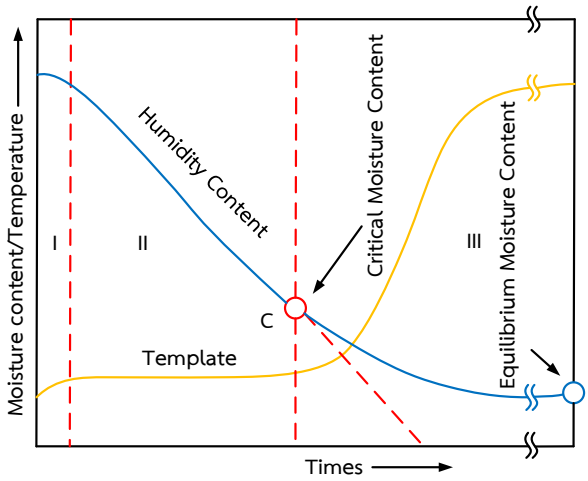

Fig. 2 Alteration of material moisture content and temperature

2.2 Calculation of Energy [11-12]

Calculation of power charge is done by applying electric power used by given electric appliance in order to find out power unit reflecting power consumption of such facilities. The calculation method refers to summation of the watts of respective appliance multiplied by operation time per month. This will present initial figures of power consumption (1 Unit refers to 1000-watt appliance operated in 1 hour). The formula is provided below:

$$Unit = \frac{Power \times Number\ Electronics \times hour}{1000} \qquad (6)$$

When $Unit$ = unit number

$Power$ = electric power of an appliance (W)

$Number\ Electronics$ = number of electric appliance

$hour$ = number of operation hour per day

3. Implementation

The implementation of control system development for fruit dehydration machine by biomass energy is carried out by applying Arduino board for helping control the operation of fruit dehydration machine (auto system). Detailed implementation steps are as follows:

Fig. 3 fruit dehydration machine by biomass energy

3.1 Control System

The control system of fruit dehydration machine is classified into 2 systems, namely, Manual Control System and Auto Control System details of which are discussed below:

3.2 Manual Control System

When the manual control system is initiated, motor blower will blow hot air into the chamber and release it via another vent and this hot air will dehydrate fruit. The user needs to periodically monitor and control temperature, %humidity, heat (from fuel) to ensure that those parameters are still within required limits to avoid possible loss to dehydrated fruits.

3.3 Auto Control System

When auto control system is initiated, motor blower will blow hot air into the chamber (similar to that of manual control system) but the system is equipped with Inverter which will control motor speed and regulate temperature, %humidity and heat within their respective required limits and thus needs no operator to manually control those parameters while the machine is being under operation.

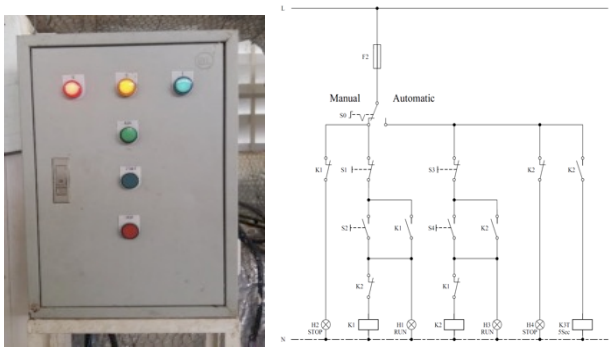

Fig. 4 Control Box and Control Circuit for Manual System

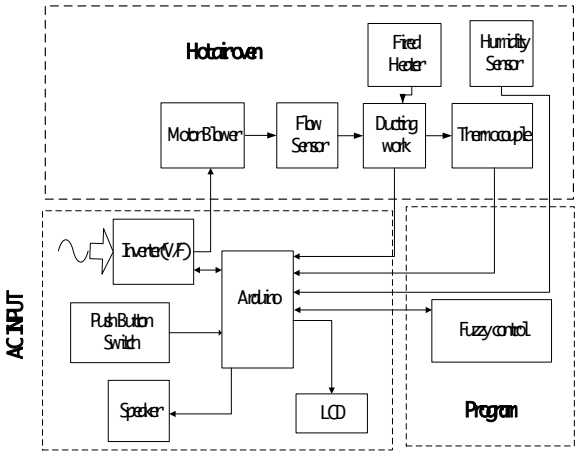

Fig. 5 Auto control system

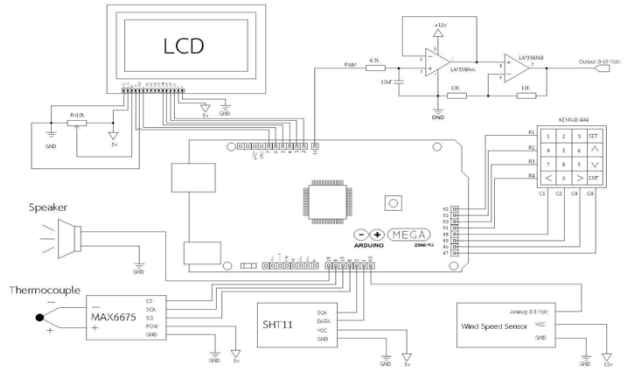

Fig. 6 Arduino Circuit Chart

Fig. 7 Control Box for Auto System

4. Operation

The research conducted the test of fruit dehydration machine by biomass energy used for drying mango sheet of the mango sheet factory in Photharam District of Ratchaburi Province.

Fig. 8 Fruit Dehydration Machine's control system

4.1 Manual Control System's operation

For manual control system's operation, motor blower will function at maximum speed all the time. During the entire drying process, fuel is continually added every 15 minutes and time is set backward for every 25 minutes. The study results revealed that by using this method for drying fruit, the total length of time was 7 hours.

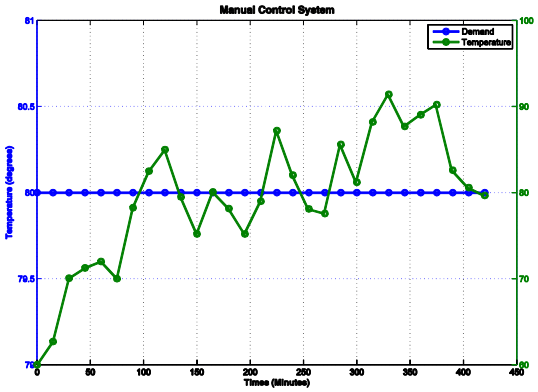

Fig. 9 Temperature of manually-controlled fruit dehydration machine

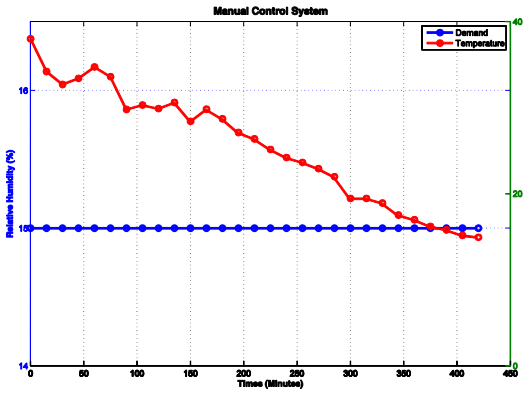

Fig. 10 %humidity of fruit dehydration machine Manual type

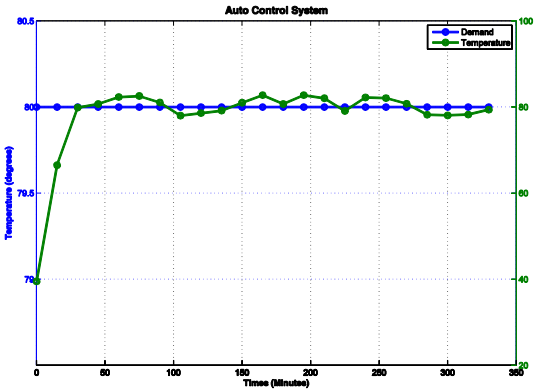

Fig. 11 Temperature of automatically-controlled fruit dehydration machine

4.2 Auto Control System's operation

By applying Auto Control System, operation is set at the required temperature (set point) while humidity will be set at 15% and temperature is set forth at 25 degree Celsius and parameters will be collected every 15 minutes. The study results revealed that this drying method took 5.30 hours with measured parameters as demonstrated below:

According to the test of the operation of both methods, the researcher found that auto control system's operation could better lower temperature and humidity than that of the manual control system because the latter's electric motor would function at the rated value and thus heat was not transferred to the drying chamber regularly and it also took longer time.

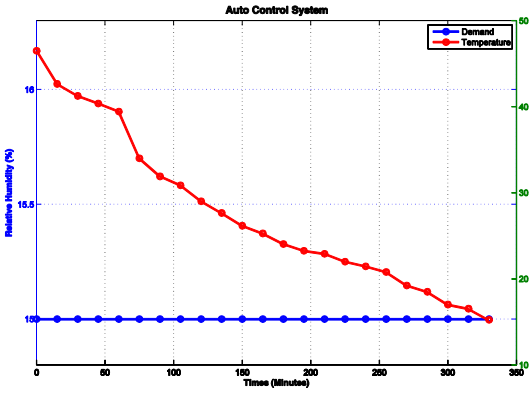

Fig. 12 %humidity of fruit dehydration machine Auto type

4.3 Energy charge analysis

Energy charge comparison is based on the total energy used by fruit dehydration machine [13] between manual and auto control system details of which are demonstrated below:

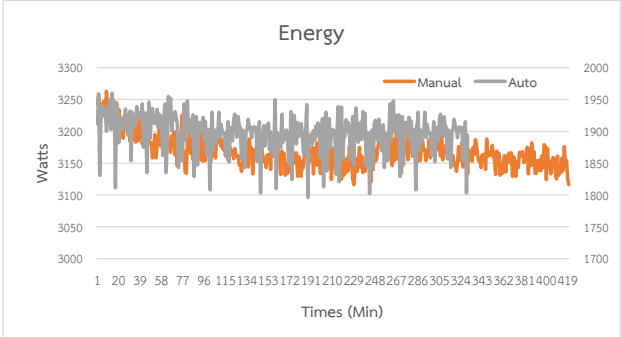

Fig. 13 Energy consumption of fruit dehydration machine

According to kWh and energy charge comparison demonstrated in Table 1, the researcher discovered that power consumption by auto control fruit dehydration machine was less than that of manual control system one. Data was also collected to analyze the operation of both types of dehydrator with manual and auto control system, respectively, it appeared that if the dehydrator is improved by being equipped with auto control system (Installation charge 30,000 baht), the breakeven point will be met after 3.33 years.

Table 1 Energy comparison

Energy cost	Estimates	Cost (Baht)
Manual system	22.18 kWh/unit	88.72
Auto system	10.44 kWh/unit	41.76
Reduced power charge	11.74 kWh/unit	46.96
Reduced power charge (month)	187.84 kWh/month	751.36
Reduced power charge (year)	2,254.08 kWh/year	9,016.32
Cost auto system	30,000 Baht	
Economical (%)	47.07 %	

Note : (1) Power charge used for calculation: 4 baht/kWh
(2) Frequency of machine usage: 4 time/week (16 time/month)

Table 2 Break-Even Point Analysis

Time (Year)	Total Cost (baht)	Energy Saving (baht)
1	30,000	9,016.32
2	30,000	18,032.64
3	30,000	27,048.96
4	30,000	36,065.28
5	30,000	45,081.60

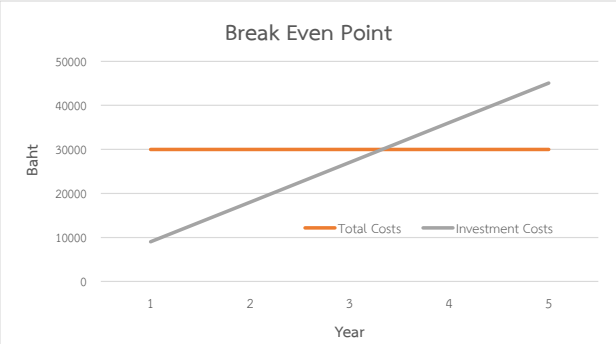

Fig. 14 Break-Even Point Analysis

5. Conclusion

The study and development of fruit dehydration machine by biomass energy aimed at improving control system of the dehydrator from original manual system which requires the operator to monitor the system and adjust direction of hot air for every 25 minutes; to the auto control system under which hot air direction is automatically adjusted based on the set point previously fixed. Testing results of the operation of both types of dehydrator revealed that fruit dehydration machine with auto control system took less drying time when compared to that of the dehydrator with manual control system for approximately 1.30 hours. With respect to energy charge used by each type of dehydrator, the one with auto control system could save electric charge for as much as 46.96 baht/time. If the operator conducts fruit dehydration 4 times a week, the electric charge will be reduced for 751.36 baht/month or 9,016.32 baht/year. With respect to the analysis of breakeven point of system improvement, it will take 3.33 years.

According to the study and development of fruit dehydration machine by biomass energy, the research really hopes that this research will be able to offer guideline for those interested in study and development of control system for fruit dehydrator and in further applying such control system to various types of dehydrator to achieve better efficiency and innovation.

6. Reference

[1] Office of Agricultural Economics, “Annual report 2561,” Phahonyothin road, Chatuchak district, Bangkok, 2561.

[2] Ministry of Agriculture and Cooperatives, “The Twelfth National Economic and Social Development (2560 - 2564),” (On-line), References http://www.oae.go.th/download/journal/development-plan2559.pdf, March 2561.

[3] Department of Agricultural Extension, “Implementation Manual for Agricultural Extension System 2560,” (On-line), References http://www.agriman.doae.go.th/large%20plot%2059/k1/10_2%20(2).pdf, March 2561.

[4] Phakdee Rattanamuk, “THAILAND 4.0 meets the needs of Thailand?,” Transcending the trap of Thailand 3.0, Bangkok : Intellectuals, EPPO, 2561.

[5] Phumsak Rasri, “Thailand’S Agriculture 4.0,” (On-line), References http://www.organicoard3.com/wpcontent/uploads/thailand_4.0.pdf, January 2561.

[6] Surasak Thiebrat, “Chilli and Garlic Drying by Using Waste Heat Recovery From Geothermal Power Plant,” Master. Engineering (Energy Technology), King Mongkut’s University of Technology Thonburi, 2540.
[7] Thaworn Ratrongmuang, “Drying of Agricultural Producs Using Heat Energy from Steam Boiler,” Master of Industrial Education Program, Department of Mechanical Engineering, King Mongkut’s University of Technology Thonburi, 2550.
[8] Puttinun Jaruwat, Pimol Wutisin, Chusak Chavapradit and Yongyut Kongsan, “Research Study on Continuous Type Longan Dryer,” Postharvest Engineering Research Group, Agricultural Engineering Research Institute (Aeri), Department of Agriculture, Bangkok, 2551.
[9] Maitri Naewbanij, Sriwai Singhagajen, Yongyut Kongsan and Supat nusawat, “Report of universal tray dryer,” Postharvest Engineering Research Group, Agricultural Engineering Research Institute (Aeri), Department of Agriculture, Bangkok, 2536.
[10] Siwalak Pathaveerat, Chusak Chavapradit, Nitad Tangpinitgun, Yongyut Kongsan and Supat nusawat, “Design and Test of Sweet Tamarind Dryer,” Postharvest Engineering Research Group, Agricultural Engineering Research Institute (Aeri), Department of Agriculture, Bangkok, 2537.
[11] P. Hayamin, C. Thongchaisuratkrul, Evaluation electricity production of solar cells 25 kW. Phayao Research Conference 6, pp.945-955, Phayao, Thailand, 26-27 January 2017.
[12] METROPOLITAN ELECTRICITY AUTHORITY, Electric Monthly Calculation, (On-line), References (https://www.mea.or.th/about-electric/116/280/form/11), December 2563.
[13] W. Pimonmart, S. Anake, S. parinee and T. Chalermwat, “Benefits of Roof-Mounted Solar Cells for Low-Cost Residential Buildings,” JARS: Journal of Architectural Research and Studies, Thammasat University, Vol.9, No.2, 2012.