Energy study of edamame freezing process at PT Mitratani Dua Tujuh Jember

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Abstract. Knowledge of the cooling load of products that will be stored frozen in cold storage needs to be known. The purpose of this research was to analyse the cooling load in cold storage, calculate the freezing time of the product, calculate the amount of heat in the vapor compression cycle and the coefficient of performance (COP). PT. Mitratani Dua Tujuh is a company engaged in the processing of frozen fast food and edamame as one of the leading frozen products in this company. The maximum capacity of cold storage used was 190 tons with an air speed of 0.9 m/s and used two compressors with R-404A refrigerant type. The results of the analysis found that the freezing time per package on the product was 5.28 hours. Cold storage cooler load of 55,432 kW or equivalent to 15.75 tons of refrigeration. The amount of heat in the compression cycle consisted of compression, condensation, expansion and evaporation were 6,45 kW, 34,17 kW, 17,18 kW and 27,72 kW, and the coefficient of performance (COP) was 1,237.

1. Introduction

The current healthy lifestyle of people was driving a positive trend in the development of frozen vegetable production using frozen preservation technology. This was to maintain freshness, nutrition, and taste and was able to be consumed at any time. The commodities that increased considerably were fresh edamame and frozen edamame for both exports and domestic markets [1].

Five countries exporting edamame products to Japan were Taiwan (44.1%), Thailand (27.6%, China (24,4%), Indonesia (3.8%) and Vietnam (0.1%). When compared to other countries, Indonesian export capacity was still very small, but the price of edamame products was better at 250 yen per 500 grams compared to Vietnam and China at 118 yen to 217 yen per 500 gram [2].

Jember Regency was the center of agriculture and plantation areas. Soybean was a major commodity that competed closely with corn production. However, currently in Jember Regency was developing edamame soybeans by providing a touch of technology to improve the competitiveness of edamame products. Edamame soybean export increased, from 2014 amounted of 4,096.18 tons with an export value of US $ 5,923,025 and in 2016 amounted of 5,000 tons with an export value of US $ 9,907,949 [3]. This increase in export value pushed PT Mitratani 27 Jember to increase the number of partner farmers and land.

Jember Regency contributed for more than 50% of Indonesia's average edamame soybean exports. This made the basis for researchers to study the energy requirements in the freezing process at PT Mitratani 27 Jember as a consequence of increased production for export needs [4]. Edamame freezing in principle was that the heat in the sample was taken until it reached freezing. This mechanism made material changes to be hampered and the storage life was relatively longer [5].

During the freezing, sensible heat of food ingredients or products was taken to lower the temperature of the product or food to the freezing point. In fresh food, heat generated from the respiration process was also taken. The taken heat must calculated to determine the appropriate freezer size. In the freezing process, latent heat of crystallization was taken from ice crystals formed. The latent heat of other food components such as fat was also taken before the fat solidified. Some foods contained large amounts of water, and water had a high specific heat (4200 J/Kg °K) [6]. In the freezing process, firstly, ice crystals formed which usually took place rapidly at temperatures below 0°C. The enlargement process of ice crystals which usually took place quickly at a temperature of -2°C to -7°C. At even lower temperatures, the enlargement of ice crystals was inhibited because the speed of ice crystal formation increased [7].

2. Literature review

2.1. Freezing time of edamame

The product stored in cold storage was edamame that had been frozen using Individual Quick Freezing (IQF) before. The freezing time of the product used to find out the product had been frozen. To find out how long it took to freeze the product using Equation (1).

$$t_F = \frac{\rho_f H_L}{T_F - T_a}\left(\frac{P.a}{h} + \frac{R.a^2}{k}\right) \tag{1}$$

2.2. Cooling load

The cooling load that must be overcome by the cooling machine came from several heat sources namely heat transfer, product heat load, thermal transmission load, equipment heat load, lighting heat load, and occupant heat load (people) from the heat source could be calculated, including :

$$\mathrm{Re_L} = \frac{\mathrm{Vs\ L}}{\mathrm{v}} = \frac{\mathrm{inertia}}{\mathrm{viscosity}} \tag{2}$$

The calculation of convection heat transfer began with finding the value of the Reynolds number (ReL). Heat the product load using Equation:

$$Q_1 = m \, . \, C_p (T_i - T_f) \tag{3}$$

Where: Q_1= heat of product temperature decrease (kJ), m = product mass (kg), Cp= product specific heat (kJ/kg°K), T_i= product initial temperature (°K), T_f = temperature of frozen product (°K)

$$Q_2 = m \, . \, H_L \tag{4}$$

Where: Q_2 = heat required for product freezing (kJ), m= product mass (kg), HL= latent heat of fusion (kJ / kg)

$$Q_3 = m \, . \, C_p (T_f - T_s) \tag{5}$$

Where: Q_3= heat to reduce temperature to freeze (kJ), m= mass of stored product (kg), Cp= product specific heat (kJ/kg°K), Tf= temperature of frozen product (°K), Ts = expected product temperature (° K). From Equations 3, 4 and 5 found out the total heat needed in the freezing process of product ingredients by adding up the three equations using Equation (6).

$$Q_T = Q_1 + Q_2 + Q_3 \tag{6}$$

Where: QT = total heat to freezing to storage temperature (kJ), Q_1= heat to decrease product temperature (kJ), Q_2= heat needed for freezing the product (kJ), Q_3= heat to reduce temperature to freeze storage (kJ).

2.3. The amount of heat in the compression cycle of steam and COP

The steam compression cycle included the components contained in cold storage. The amount of workload or heat on the components calculated including refrigerant mass flow, compressor working size, heat released by the condenser, heat on the expansion act, heat absorbed by the evaporator and calculation of the achievement coefficient (COP) using Equation (7).

$$\text{coefficient of performance (COP)} = \frac{h_2 - h_1}{h_3 - h_2} \tag{7}$$

3. Methodology

3.1. Tool and material

The material used was edamame in cold storage of PT Mitra Tani Dua Tujuh in Jember Regency. The tool used was cold storage with a steam compression cooling method, infrared thermometer, thermocouple, airflow meter, stopwatch, scale and roll meter.

3.2. Research methodology

Data collections used primary and secondary data from internal and external environment of the company. Primary data obtained by direct observation and direct interviews with parties involved in the company. Secondary data obtained from a variety of literature both from libraries and internet sites that were relevant to the issues raised and were accounted for.

3.2.1. Data collection. The data obtained were done by direct measurement of cold storage dimensions using a roller meter, temperature inside and outside the cold storage using a thermometer and wind speed inside and outside the room using an airflow meter. Measurement of product ingredients by preparing product ingredients in advance. Then measured the dimensions of the product and packaging using a meter roll, measure the initial temperature of the product and the end of the product using a thermocouple and measured the mass of the product and packaging. The measurement of loading and unloading time and the use of lights in cold storage were measured using a stopwatch. This data was also supported by conducting direct interviews with workers and people directly related to the process.

3.2.2. Measurement parameter. Measurement parameters in the analysis of cooling loads in cold storage included construction of cold storage, cold storage environment through measurements inside and outside the room using a thermometer and also measuring air velocity using an airflow meter. The parameters regarding the product measured included temperature, mass, dimensions and volume.

4. Experiment and results

Evaluations done included product data and cold storage rooms, refrigeration system data, cold storage construction data and electrical equipment and worker data. Products stored in cold storage were edamame, as for the data on the product and cold storage room as shown in Table 1.

Table 1. Data of cold storage and edamame products.

Data	Information
Maximum cold storage capacity	190 ton
Air velocity in cold storage	0.9 m/s
Cooling Method	Steam Compression
Weight of each edamame package	30 kg
Edamame product density	151.65 kg/m^3
Edamame product initial temperature	18 ºC
The final temperature of edamame storage	-20 ºC

4.1. The data of cold storage construction

The used Cold Storage was cold storage number 11 at PT. Mitratani Dua Tujuh. The dimension and the position of the cold storage can be seen in Figure 1 and Figure 2. The cold storage had a dimension of 20 m length, 10 m width, and 6 m height. The construction of floor, wall, and roof used in the cold storage was polyurethane foam of 150 mm thickness. The heat conductivity to the material of polyurethane foam was 0.026 W/mºK. In the front part of the cold storage, there was an anteroom. It is a room that functioned as the distribution place before and after inserting the green soybean into the cold storage so that the product's temperature had not changed much.

4.2. Freezing duration

The product kept in the cold storage was a frozen green soybean which was frozen by using Individual Quick Freezing (IQF) beforehand. The green soybean that passed the process of IQF was then packed in a plastic bag with diameter of 0.6 m and a height of 0.7 m. The product that was put into the cold storage was -18ºC in temperature. The material density was as much as 151.65 kg/m^3 which obtained from the result of the distribution of weight of each package and volume of packaging. The Plank Constanta used was cylindrical object so that P value of 1/4 and R value of 1/16 were obtained. The latent heat of green soybean fusion was 237 kJ/kg while the air heat conductivity of the cold storage, in which its room temperature was -20 ºC, was 0.0226 W/mºK. The results of the freezing time calculation obtained 5.28 hours.

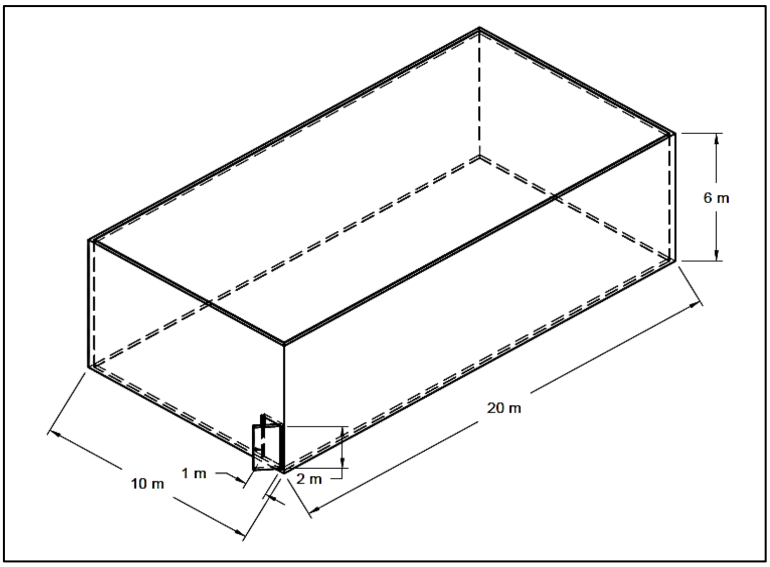

Figure 1. Dimension of cold storage (Scale 1: 400).

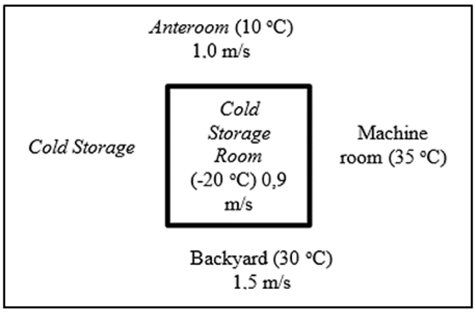

Figure 2. Layout of *cold storage.*

4.3. The calculation of cooling load

4.3.1. Heat transfer. Heat transferred from the place with high temperature to a place that had low temperature. The heat transfer through conduction could be known by looking at its value of thermal conductivity, while the convective heat transfer obtained from the value of Reynolds number (ReL) by using equation 2. The results of Reynolds number calculation showed that the characteristics of fluid flow were turbulent (ReL>300.000). After getting Reynolds number, the next step was looking for a Prandtl number (Pr). The value of Prandtl number from the result of the calculation was 0.71. The third step was looking for the price Nusselt number (NuL) by considering the price of Reynolds and Prandtl numbers and obtained the value of NuL number as much as 2.106,47. The value size of convective coefficients (h) in the cold storage by using the obtained values was as much as 2.38 $W/m^{2o}K$.

4.3.2. Product load heat. The essential calculation of heat load was product heat, this was due to the product heat load had higher value than other heat loads. The calculation of the product heat load only calculated the size of the sensible heat after freezing. It was due to the storage process of green soybean was done after the green soybean frozen in -18 ºC or 255 ºK temperature. The product temperature was expected as much as -20ºC or 253ºK. The specific heat of the green soybean as much as 3.198,648 J/kgºK or equal to 3,198648 kJ/kgºK. The number of green soybean stored in the cold storage was 190.000 kg. The calculation of the product heat load was done by using Equation (5). The results of the calculation showed that the product heat load and the product heat load per time unit as much as 959.594,4 kL and 50,448 kW respectively.

4.3.3. Thermal transmission load. Before calculating the size of the thermal transmission load of the wall, floor, and roof of the cold storage, the value of convective coefficient (h) on each part was determined beforehand. The assumptions used to determine the value was: the surface of the plate was flat, the steady state air condition and radiation aspect were ignored. The value of Reynolds, Prandtl, and Nusselt numbers was found out before conducting the calculation process of convective coefficient. The outdoor convective coefficient (h) could be found like finding the convective coefficient inside the cold storage (h_1). The value of outdoor convective coefficient (h_0) based on the result of the calculation can be seen in Table 2.

The value of thermal heat in Table 3 of each part of the roof, wall, and floor of the cold storage was different. This was due to the difference of the surface area material and the temperature of outside air that influenced the value of outdoor convective coefficient.

Table 2. Outdoor convective heat coefficient.

Thermal Transmission	Coefficient Value (h_o) (W/m^{o}K)
Back wall	3.60
Anteroom wall (front)	2.71
Machine room wall (right)	4.02
Left wall (other *cold storage*)	-
Roof	3.14
Floor	-

Table 3. Load heat thermal transmission.

Thermal Transmission	Thermal Heat Value (Q_t) (kW)
Back wall	0.464
Anteroom wall (front)	0.274
Machine room wall (right)	1.025
Left wall (other cold storage)	0.620
Roof	1.537
Floor	1.034
Total	4.955

4.3.4. Heat burden of equipment, lighting and workers. In this research the calculations of heat load of equipment, lighting and workers were presented in Table 4. The equipment heat load in this case was the motor from the fan. There were 8 fans in the cold storage in which each fan had a power of 1.14 Kw with usage time for 22.5 hours per day. Equipment heat load based on the results of the calculation obtained 0.011 kW.

The lightings used in this cold storage were 6 unit of mercury lamps with a power of 100 W for each lamp. This lighting lamp functioned to ease the workers in inserting, moving or removing the products. Based on the results of the calculation obtained the lighting heat load was 0.001 kW.

The workers heat load was the size of heat generated by the workers while they were in the cold storage. The workers who worked in the cold storage were 3 workers with average working time in cold storage were 2 hours per day. The total heat load obtained from the result of the addition of product heat load, thermal transmission heat load, equipment heat load, lighting heat load and workers heat load. Based on the results of all of the calculations, the total heat load was as much as 55.432 kW or equivalent to 15.75 tons of refrigeration.

Table 4. Load heat of equipment, lighting, and workers.

Load Type	Heat (kW)
Equipment	0.011
Lighting	0.001
Workers	55.432

4.3.5. Coefficient of Performance (COP) of vapor and nil compression cycle. The calculation of vapor compression consisted of some stages covered the process of compression, condensation, expansion, and evaporation. The results obtained from the compression process produced 6.45 kW heat. In the process of condensation, where the refrigerant gas was pressurized and had a high temperature, produced heating value of 34.17 kW. Then the pressure of the refrigerant liquid was reduced by using a check valve (expansion valve). When pressure reduction happened, the temperature also decreased and the quality of refrigerant gas increased, it happened because with the decrease of pressure and temperature, some of the liquid refrigerant turned into gas. In the expansion process, the value of heat obtained and calculated as much as 17.18 kW. The evaporation process happened at the same temperature, where only the phase of liquid refrigerant to gas changed. Latent heat of evaporation was taken from the environment so environmental cooling occurred. The size of cooling occurred expressed in cooling effect (ton refrigeration). In this process the heat produced as much as 27.72 kW and the heat absorbed by the compressor was the heat generated from the product, thermal transmission, equipment, lighting, and workers. Coefficient of Performance (COP) was a coefficient for the performance of refrigeration cycle and it was expressed in a certain comparison between the heat absorbed by the evaporator and the performance of the compressor. COP value obtained based on the calculation and reading p-h refrigerant diagram 404A obtained is 1,237.

5. Conclusions
The conclusion of this research is cold storage refrigerant load is 55.432 kW or equivalent to 15.75 tons of refrigeration, edamame freezing time is 5.28 hours, the amount of heat in the vapor compression cycle consisting of compression, condensation, expansion and evaporation are 6.45 kW, 34.17 kW, 17.18 kW and 27.72 kW, respectively, and coefficient of Performance (COP) is 1.237.

6. References
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