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Designing and Manufacturing the Cryoconcentration Equipment (Cold Concentrator) and Apply It to Concentrate a High-quality Product from Dragon (*Hylocereus costaricensis*) Fruit Juice

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ABSTRACT

Dragon fruit *(Hylocereus costaricensis)* juice is a nutrient-rich drink that can be easily infected by environmental microorganisms, causing fermentation, spoilage, and a short shelf-life. Fruits and other foods are preserved by cold storage and thermal or vacuum concentration methods that are energy-intensive or quickly reduce the product's quality. The cryoconcentration method used in dragon fruit is one of the reasonable ways to preserve vitamins, bioactive compounds, and nutritional ingredients. However, widespread use or production of equipment specifically designed for cold concentrators has yet to be general. This study aims to calculate, design, and manufacture the cryoconcentration equipment named CCE-03. The manufactured equipment is 5 L of material per batch capacity, with a –10 to –35°C concentration ambient, a concentrating time of 1.5 to 6 hours, and a defrosting temperature of 10 to 25°C. The equipment works stably and is controlled by an automatic measuring device operated via a computer. The concentrating process takes 1.6 hours, and the product's energy cost is 0.48 kWh/L. The product concentration is 46.6%, and the loss of vitamin C content is 11.3%. The concentrated dragon juice is high-quality.

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1. Introduction

Thermal concentration (normal concentration) is commonly used in food production to concentrate liquid foods. In the concentration, heat is supplied to increase the temperature of liquid foods to the boiling point and to make water evaporate. When the water in the solution evaporates, the solution loses its solvent. Then, the concentration of the solution increases with the heating time. However, when the concentration increases, the boiling temperature of the solution also increases [1]. Under atmospheric pressure conditions, the solution boiling temperature is higher than 100°C and depends on the solvent concentration in the solution. In this case, heat-sensitive compounds, such as pigments, flavors, vitamins, and bioactive compounds, can be destroyed to varying degrees in the hot concentration process. Thus, it is not suitable for liquid foods containing the compounds. A vacuum concentration process is used to reduce compound destruction from heat and oxygen. The process can reduce the boiling temperature and the interaction between liquid foods and oxygen. However, the process can partly prevent the destruction.

One of the problems that researchers have addressed is how to concentrate liquid foods, especially heat-sensitive foods like fruit juices, in which pigment, flavors, vitamins, and bioactive compounds are maintained [2], [3]. The suitable method is the concentration process at low temperatures, called cryoconcentration (cold concentration or freeze concentration) [4]. However, the cryoconcentration process is limitedly applied because of the complexity of the fundamentals of calculating, designing, manufacturing, and operating [5]. Cryoconcentration has been applied to concentrate high-value food products such as coffee solutions, fruit juice [6], [7], and milk [8]. The process of cryoconcentration depends on the ability to separate the ice crystals from the concentrated solution. Therefore, developing ice crystals to huge sizes obeys the Ostwald ripening mechanism [9].

The separation of inorganic salts from their aqueous solution using eutectic cryoconcentration technology is characterized by the simultaneous crystallization of both the solute and ice [10]. The phase diagram of the water-NaCl solution [11], [12] (Figure 1) has been used as the fundamentals for freezing and freeze-drying because of its generality. Similarly, the diagram can be used for making the cold concentrator in cold concentration. To analyze the concentration process, the diagram shows liquid and solid phases. The above region of the IBCS curve line is the solution liquid phase, and below is the solid region containing ice and salt. The IBC line indicates the crystallizing curve of the solvent; the CS is that of the solute (salt); at C, the eutectic point, both the solvent and solute are crystallized, and it indicates the lowest temperature for crystallizing the entire solution. In the cold concentration method, a refrigeration system removes heat from the salt solution to cool it (A to B point, Figure 1). The initial concentration and temperature of the solution are C_A and T_A, respectively. In the cooling process, its temperature decreases from T_A to T_B, and the C_A is constant, bringing the solution temperature to the crystallizing temperature (T_B) of the solvent in the solution (at B, the solvent has been crystallized).

When the solvent is crystallized from the liquid phase to the solid phase and separated from the solution, the concentration of the solution increases, and the solvent crystallizing temperature in the solution rises. The crystallization process of the solvent obeyed the line BC. The increase in solution concentration leads to a decrease in the crystallizing temperature of the solvent in the solution, and at the C point, the solvent has completely crystallized.

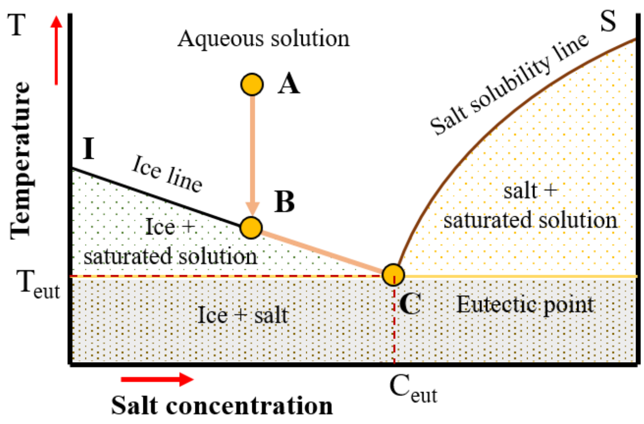

Figure 1. *Phase diagram of water – NaCl solution.*

The solution states changes in cold concentration. IBC and CS lines show the crystallizing curve of the solvent and the solute (salt), respectively; C, the eutectic point, the solvent and solute are crystallized. It is the lowest temperature for crystallizing the entire solution.

In cryoconcentration, the solution state should not decrease to the C point; the concentration reaches the eutectic concentration (C_{eut}). The concentration will stop when the solution concentration reaches the technological requirement, C_R, at a certain point in Section BC. At atmospheric pressure, the crystallization temperature of the solvent, water in solution, is below 0°C. Then, all pigments, smells, vitamins, biological compounds, etc., in the food solution are completely preserved [2], [13]. The fundamentals of cold concentration have been found, but the implementation and manufacturing of the equipment for production applications have not received full attention. Therefore, in this study, we will present the design and manufacture of the equipment used for concentrating fruit juice to produce products retaining their original natural properties [1], [2], [13].

2. Materials and Methods

2.1. Materials

The Dragon fruits (*Hylocereus costaricensis*) were collected from Ninh Thuan and Binh Thuan provinces and analyzed the chemical ingredients at the B210 laboratory. The fruit juice was used as material and slowly frozen for calculating, designing, and manufacturing the cold concentration equipment. The red-fleshed dragon fruits were harvested and transported to the laboratory, where the materials were peeled, cut into 8 pieces, and put into a freezing chamber at -12 °C for 14 hours. After that, the frozen materials were defrosted in a cylindrical device. After thawing, the materials formed a suspension solution that was filtered and pressed to obtain pure dragon fruit juice.

The material nutrient ingredients were analyzed. Total protein, water, and fat content in the material were determined by Kjeldahl [14], AOAC Official 934.06 [15], and Soxhlet methods, respectively. Fiber, ash, iron, carotene, and ascorbic acid were analyzed using AOAC Official methods: 2011.25, 940.26, 2015.01, 2005.07-2005, and 2012.21, respectively [15].

2.2. Calculating methods

The research problem is calculating, designing, and manufacturing a cold concentration system with a capacity of 5 liters of dragon fruit juice per batch.

2.2.1. *Initial parameters for calculating and designing*

Equipment capacity: V_M (L/batch);

Initial dry matter concentration of dragon fruit juice: x_i (%);

Concentration of qualified product: x_e (%);

Initial temperature of dragon fruit juice solution– room temperature: T_i = 25°C;

Final temperature of dragon fruit juice solution: T_e = –27°C.

2.2.2. *Mass balance calculation*

Equipment capacity calculated as mass:

$$G_i = \frac{V_M}{\rho_S}, \qquad \text{kg/batch} \tag{1}$$

Where: ρ_S (kg/m^3): specific mass of pre-concentration dragon fruit juice solution:

$$\frac{1}{\rho_S} = \sum_{j=1}^{n} \frac{x_j}{\rho_j} \tag{2}$$

x_j, ρ_j (kg/m^3): mass ratio and specific mass of substrate j in the solution, respectively.

Mass balance equation:

$$\begin{cases} G_i = G_{ic} + G_e \\ G_i x_i = G_e x_e \end{cases} \tag{3}$$

Where: G_i (kg) – mass of initial solution that need to be concentrated;

x_i (%) – percent concentration of initial solution;

G_e (kg) – mass of concentrated product in a batch;

x_e (%) – product concentration;

G_{ic} (kg) – mass of ice crystals separating from the solution in a batch.

2.2.3. *Energy balance calculation*

Degree of freezing temperature reduction in the dragon fruit juice solution [16]:

$$\Delta T_S = T_{cr}(Solution) - T_{cr}(water) = -K_{cr} \times C_m \tag{4}$$

Where: T_{cr}(water) = 0 °C – freezing temperature of water at the pressure P_a = 1 at;

K_{cr} – constant of freezing solution;

C_m – molar concentration.

$$C_m = \frac{n}{M_w}.1000 \left(\frac{mol}{1000g}\right) \tag{5}$$

M_w (g) – mas of water solvent in the solution.

n (mol) – number of solute moles in solution

$$n = \frac{m_{dr}}{M_{dr}} \quad (6)$$

$$M_{dr} = \sum_{j=1}^{n} x_j M_j \quad (7)$$

Where: m_{dr} (g) and M_{dr} (g/mol) – mass and average molar mass of dry matter or solute in concentrated solution, respectively; x_j – mass ratio of the j^{th} substance in the dry or solute matter of the concentrated solution; T_{cr} (Solution) (°C) – crystallizing temperature of the product at 45% concentration.

Energy balance equation:

$$\sum Q_{in} = \sum Q_{out} \quad (8)$$

Where: $\sum Q_{in}$ (kW) – total capacity of inlet heat of the concentration system;

$\sum Q_{out}$ (kW) – total capacity of outlet heat of the concentration system;

$$\sum Q_{in} = K \times \left(\frac{Q_1 + Q_2 + Q_3}{\tau} + Q_4 \right), \text{kW} \quad (9)$$

$$\sum Q_{out} = Q_o^{comp}, \text{kW} \quad (10)$$

Q_1 (kJ) – removing heat to decrease the initial temperature, T_p, to the crystallizing temperature, T_{cr}, was determined by:

$$Q_1 = G_i C_s (T_p - T_{cr}) = G_w C_w (T_p - T_{cr}) + G_{dr} C_{dr} (T_p - T_{cr}) \quad (11)$$

Where: C_w, C_{dr} (kJ.kg^{-1}.K^{-1}) – specific heat of water and dry matter in the dragon juice solution, respectively.

Q_2 (kJ) – removing heat to crystalize and separate water (solvent) from the solution to increase the concentration.

$$Q_2 = G_{ic}.L \quad (12)$$

Where: L (kJ/kg) – Latent heat of freezing.

Q_3 (kJ) – removing heat to decrease the solution temperature from T_{cr} to T_e was determined by:

$$Q_3 = Q_{31} + Q_{32} + Q_{33} \quad (13)$$

Where: Q_{31} (kJ) – removing heat from unfrozen water

$$Q_{31} = (G_w - G_{ic}) C'_w (T_{cr} - T_e) \quad (14)$$

Q_{32} (kJ) – removing heat from frozen water

$$Q_{32} = G_{ic} C_{ic} (T_{cr} - T_e) \quad (15)$$

Q_{33} (kJ) – removing heat from dry matters

$$Q_{33} = G_{dr} C_{dr} (T_{cr} - T_e) \quad (16)$$

Where: C'_w, C_{ic} (kJ.kg^{-1}.K^{-1}) – specific heat of unfrozen and frozen water in the dragon solution, respectively.

Q_4 (kW) – losing heat through the walls of the concentration device.

$$Q_4 = k_{loss} \times \left(\frac{Q_1 + Q_2 + Q_3}{\tau} \right) \quad (17)$$

Where: k_{loss} – losing heat coefficient; τ (h) – time of cooling the concentrated solution.

The cooling capacity of the refrigerator needed to cool the concentrated solution is:

$$Q_0^{comp} = K.\left(\left(\frac{Q_1 + Q_2 + Q_3}{\tau}\right) + Q_4\right), kW \tag{18}$$

2.3. Designing and manufacturing cold concentration equipment

After receiving the cold concentration equipment technological data, drawings were created to aid the manufacturing process [13], [16], [17]. To make the cryoconcentration equipment, we used AutoCAD software version 2018 (Autodesk Inc., US) to assemble it. For each part, detailed technical drawings were made. Additionally, we employed various mechanical processing techniques such as milling, planing, bending, grinding, mounding, welding, and drilling for building the system.

2.4. Quality assessment of cold concentration equipment

The experimental method was used to evaluate the quality of the manufactured cold concentration equipment, including its stability, energy cost, solvent separation ability, and the quality of the concentrated product. To simplify the calculation and measurement, the three outcome indicators of the cold concentration were the energy cost y_1 (kWh/kg), the moisture of the concentrated product y_2 (%), and vitamin C loss y_3 (%) [17], [18]. These parameters were compared to those of the control method, thermal concentration. Take 15 liters of dragon fruit juice with 10% dry matter divided into three samples, 5 liters each. These three samples were concentrated using three different methods: Samples 1, 2, and 3 were focused on cold, vacuum, and thermal concentrations, respectively. The concentrated product was measured for outcome parameters after being concentrated for 1.8 hours.

3. Results and discussion

3.1. Initial parameters needed for calculating and designing

The *Hylocereus costaricensis* juice raw material was slowly frozen. Then, the material was analyzed for dry matter concentration, chemical composition, and physical and thermal parameters at laboratory B108 (Faculty of Chemical and Food Technology, Ho Chi Minh City University of Technology Education); the received results served as the initial parameters for calculating and designing, and were presented in Table 1 and Table 2.

Table 1. *Nutrient ingredients of dargon fruits*

Ingredients (in 100g fruit)		Species		
		Hylocereus megacanthus	***Hylocereus undatas***	***Hylocereus megalanthus***
Water	(%)	83	89	85
Protein	(g)	0.193 ± 0.035	0.5	0.4
Fat	(g)	0.410 ± 0.200	0.1	0.1
Fiber (g)		0.800 ± 0.100	0.3	0.5
Ash	(g)	0.610 ± 0.070	0.5	0.4
Calcium	(mg)	7.550 ± 1.250	6.0	10.0
Phosphorus	(mg)	33.150 ± 2.950	19.0	16.0
Iron	(mg)	0.600 ± 0.050	0.4	0.3
Carotene	(mg)	0.009 ± 0.004	ND	ND
Thiamine	(mg)	0.355 ± 0.075	0	0
Riboflavin	(mg)	0.365 ± 0.085	0	0
Niacin	(mg)	0.364 ± 0.067	0.2	0.2
Ascorbic acid	(mg)	8.500 ± 0.500	25	4

Notes: ND: non-detective value

Table 1 indicated the initial concentration of dragon fruit juice is x_i = 10% (the percentage of dry matter in 100g of dragon fruit juice). Based on the technological requirements, the cold-concentrated product must reach the concentration x_e = 45%. The dry matter ingredients (Table 2) did not show the micro-nutrients such as minerals or vitamins (mainly vitamin C) because they are too small and simplified for calculating and designing and were added to the sucrose ingredient.

Table 2. *Chemcal parameters of 100 g dragon fruit juice produced by slow freezing*

Components	water (x_1)	Dry matter		
		Glucose (x_2)	Fructose (x_3)	Sucrose (x_4)
content (%)	90	6.8	2.1	1.1

The material was slowly frozen, leading to the ice crystals in the dragon fruit flesh becoming large and tearing the cell membrane of the flesh [12]. When melting, the ice will cause the cell fluid to flow out. The receiving capacity of the dragon fruit flesh is 98%, which no other method can reach. The product-obtaining norm is 1.3 (1.3 kg of dragon fruit flesh can produce 1 liter of *Hylocereus costaricensis* juice).

Table 3. *Initial and thermo-physical parameters necessary for calculating and designing*

No.	Parameter	Symbol	Unit	Value
1	Required capacity of the device	V_M	Litters solution/ batch	5
2	Initial concentration	x_i	%	10
3	Require concentration of product	x_e	%	45
4	Duration of a cold concentrating batch	τ	h	1.35
5	Water specific mass	ρ_w	Kg/m^3	1000
6	Glucose specific mass	$\rho_{glucose}$	Kg/m^3	1540
7	Fructose specific mass	$\rho_{fructose}$	Kg/m^3	1690
8	Sucrose specific mass	$\rho_{sucrose}$	Kg/m^3	1690
9	Specific heat of water in the dragon fruit juice solution (above 0°C)	C_w	kJ.kg^{-1}.K^{-1}	4.1673
10	Specific heat of dry matter in the dragon fruit juice solution	C_{dr}	kJ.kg^{-1}.K^{-1}	1.5168
11	Specific heat of uncrystallized water in the dragon fruit juice solution (below 0°C)	C'_w	kJ.kg^{-1}.K^{-1}	4.5020
12	Specific heat of ice crystals in the dragon fruit juice solution	C_{ic}	kJ.kg^{-1}.K^{-1}	1.9572
13	Latent heat of freezing	L	kJ/kg	333.58
14	constant of freezing solution	K_{cr}	-	1.84

3.2. Calculating and designing the cold concentration equipment

The equipment was designed with two cold concentration tanks with the capacity V_M = 5 L solution/batch to fulfill the efficient concentration without interruption and to shorten concentration time.

When the first tank was working, the solenoid valve that supplied refrigerant to the evaporator in the tank was opened, and that of the valve of the second tank. Then, the dragon solution was cooled and

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frozen in the cooling process. Water in the solution was crystallized, separated from the solution, and stuck to the surface of the evaporator heat exchange tubes, leading to a rapid decrease in the rate of heat exchange in the evaporator. At that moment, the solenoid valve in the first tank was closed, and the valve in the second tank was opened to provide refrigerant to the second tank's evaporator. Meanwhile, the pumping of the juice solution into the first tank was stopped. The solution was then pumped into the second tank, allowing the solution's cold concentration to progress continuously.

Hot water was pumped into the tank to defrost ice stuck on the evaporator's heat exchange tubes while the first tank stopped cooling. The hot water was released from the tank after all the ice had drained, and the concentrated solution was transported back to the first tank. When the ice was separated from the solution and struck the surface of the evaporator of the second tank, the hot water was pumped into the second tank to defrost the ice. The process was carried out similar to that of the first tank.

When the dragon fruit juice solution had reached the requirement concentration, the concentration process ended, and the product was taken out for storage.

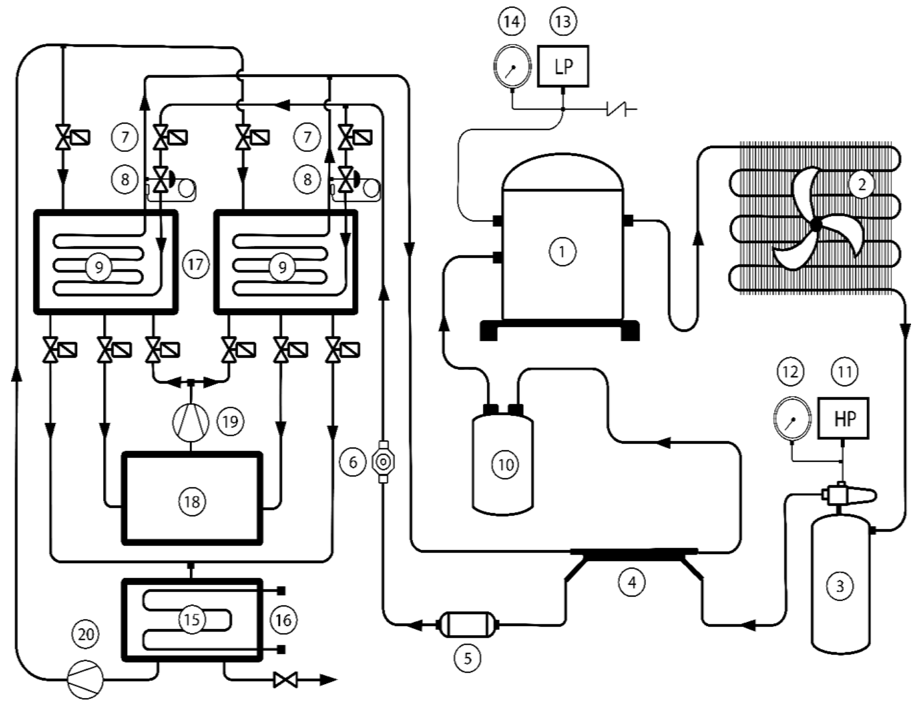

Figure 2. *Principle diagram of cryoconcentration equipment used for designing and manufacturing*.

(1) Compressor of refrigeration; (2) Condenser; (3): High-pressure tank; (4): Heat recovery device; (5) Filter; (6): Gas eye; (7): Solenoid valve; (8): Expansion valve; (9): Evaporator; (10) Liquid separator; (11) High-pressure relay; (12) High-pressure gauge; (13) Low-pressure relay; (14) Low-pressure gauge; (15) Hot water tank; (16) Power supply; (17) Two cold concentration tanks, the first and second tanks are on the left and righ-hands, respectively; (18) Concentrated solution tank circulating the solution with the first and second tanks; (19) Pumping circulating concentrated solution; (20) Circulating hot water pump.

Applying the calculation method presented in item 2.2, the necessary parameters, presented in Table 2 and Table 3, were used for calculating and designing the cold concentration equipment with the working principle shown in Figure 2 and summarized in Table 4.

3.3. Manufacturing of cold concentration equipment

From the calculating and designing results shown in Table 4, the AutoCAD software was used to build the necessary technological drawings for manufacturing.

From the calculating and designing results shown in Table 4, the AutoCAD software was used to build the necessary technological drawings for manufacturing. After designing the technical drawings of the cold concentrator, the mechanical processes described in item 2.3 were utilized for its manufacture. Figure 3 illustrated the outcome of the cold concentration equipment.

Table 4. *Calculation and design results of cold concentration equipment with capacity of V_M L/batch*

Parameter	Equation	Unit	Result
Equipment productivity, calculated by mass, G_i	(1)	Kg/batch	5.2
Specific mass of pre-concentrated dragon fruit juice solution, ρ_S	(2)	Kg/m^3	1040
Mass of concentrated product per batch, G_e	(3)	Kg/ batch	1.16
Mass of ice separated from the concentrated solution, G_{ic}	(3)	Kg/ batch	4.04
Average molecular mass of the dry matter in the solution, M_{dr}	(7)	g/mol	197.82
Molar concentration C_m corresponds to the initial solution x_i = 10%	(5) and (6)	Mol/1000g	0.562
Molar concentration C_m corresponding to vehicle product solution x_e = 45%	(5) and (6)	Mol/1000g	4.140
Degree of freezing temperature reduction in the dragon fruit juice solution, ΔT_S	(4)	^{0}C	-7.6
Removing heat to decrease the initial temperature, T_p, to the crystallizing temperature, T_{cr}, Q_1	(11)	kJ	662.36
Removing heat to crystalize and separate water (solvent) from the solution to increase the solution concentration, Q_2	(12)	kJ	1347.7
Removing heat to decrease the solution temperature from T_{cr} to T_e, Q_3	(13), (14), (15), and (16)	kJ	224.6
Losing heat through the walls of the concentration device, Q_4	(17)	kJ	558.7
Cooling capacity of the refrigerator needed to cool the concentrated solution, Q_o^{Comp}	(8), (9), (10), and (18)	kW	1.014
Engine power of the refrigeration compressor, N_{comp}	-	kW	1.113
Loading heat load of refrigerant condenser in R404A refrigeration system, Q_K	-	kW	1.73
Expansion valve with a narrow cross-section for the refrigerant passing through, F	-	mm^2	3.69×10^{-3}
Volume of the cold concentration tanks (volumes of two tanks were equal) containing the evaporator and V_M volume of the dragon fruit juice solution to be concentrated, V_{Eq}	-	m^3	11.9×10^{-3}
Dimensions of cold concentration tank:			
- Length	-	mm	250
- Width	-	mm	200
- Height	-	mm	250
Volume of hot water tank supplying for defrosting ice, V_{heat}	-	m^3	0.331×10^{-3}
Heating capacity to heat water for defrosting, P_{heat}	-	kW	0.85
Diameter of the suction pipe from the evaporator to the refrigeration compressor, d_1	-	mm	12
Diameter of the pipe pushing the liquid from the compressor to the condenser, d_2	-	mm	10
Capacity of the pump supplying concentrated solution to the concentration tank, $N_{pump\ solution}$	-	W	60
Capacity of the hot water supply pump for defrosting of the concentrator, $N_{pump\ water}$	-	W	45

Technical parameters of cold concentration equipment CCE-03:

- Maximum productivity of the Equipment: 5L/batch.
- Environmental temperature to cool the concentrated juice solution: -10 to -35°C.
- Adjustable concentration time: 1.5 to 6 hours.
- Defrost temperature: 10 to 25°C.
- Automatic measuring equipment controlled by a program programmed on a computer.

3.4. The stability and quality of cryoconcentration equiment CCE-03

Figure 3. *Cryoconcentration equiment CCE-02.*

Figure 3 showed that the cold concentration equipment CCE-03 has been designed and manufactured. Then, the stability of working, energy cost, solvent-separating ability of the equipment, and concentrated product quality were assessed. Table 5 showed the energy cost y_1 (kWh/L of product), dry matter concentration y_2 (%), and losss of vitamin C y_3 (%), respectively.

From the results of Table 5, the graph was presented in Figure 4. It can be observed that the energy cost for producing 1 liter of the product was higher using the cold concentration method than using the heat and vacuum concentration methods. However, the differences are insignificant in actual work when calculating the cost norms for making one liter of the product.

In our study, the concentration of the product could reach 50%, similar to the other findings that the concentration of products is 45%. Besides, another author found that vitamin C is maintained in cryoconcentration and that the thermal concentration is not [2], [3]. The findings are compatible with our findings. These results indicated that, in terms of thermal concentration, the product was of inferior quality in terms of bioactive compounds. The vacuum concentration method can significantly reduce the quality of the product. In contrast, the product preserved almost all original properties of the raw materials and exhibited superior quality.

The CCE-03 cold concentration equipment (Figure 3) was successfully manufactured, operates stably, and produces high-quality concentrated product. This device is suitable for industrial applications.

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Table 5. *Changes in energy cost, dry matter concentration, and los of vitamin C of concentrated products by time*

outcome indicator	Time (min)										Method
	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	
y_1 (kWh/L)	0	0.06	0.12	0.18	0.24	0.3	0.36	0.42	0.48	0.54	Cold concentration
y_2 (%)	10.0	12.5	15.5	19.3	24.1	30.0	37.4	46.6	58.1	72.4	
y_3 (%)	0.0	10.2	10.3	10.5	10.7	10.9	11.1	11.3	11.5	11.7	
y_1 (kWh/L)	0	0.07	0.14	0.21	0.28	0.35	0.42	0.49	0.56	0.63	Vacuum concentration
y_2 (%)	10.0	12.3	15.2	18.8	23.2	28.6	35.3	43.5	53.7	66.2	
y_3 (%)	0.	11.9	14.2	17.0	20.3	24.2	28.9	34.5	041.2	49.2	
y_1 (kWh/L)	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	thermal concentration
y_2 (%)	10.0	11.9	14.0	16.7	19.7	23.4	27.7	32.9	39.0	46.2	
y_3 (%)	0.0	12.9	16.7	21.6	27.8	36.0	46.5	60.0	77.5	100	

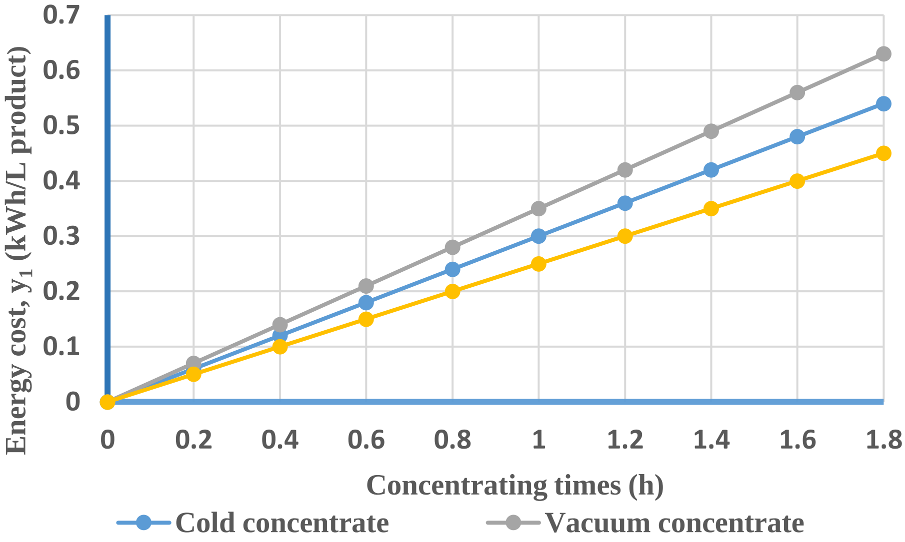

Figure 4. *Time dependence of energy cost calculated for a litter of the concentrated products*

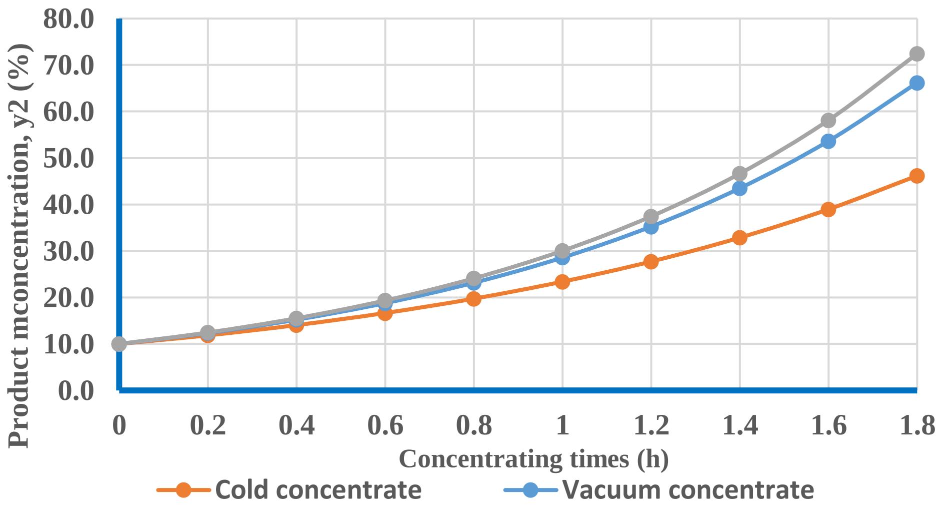

Figure 5. *Time dependence of energy cost calculated for a litter of the concentrated products*

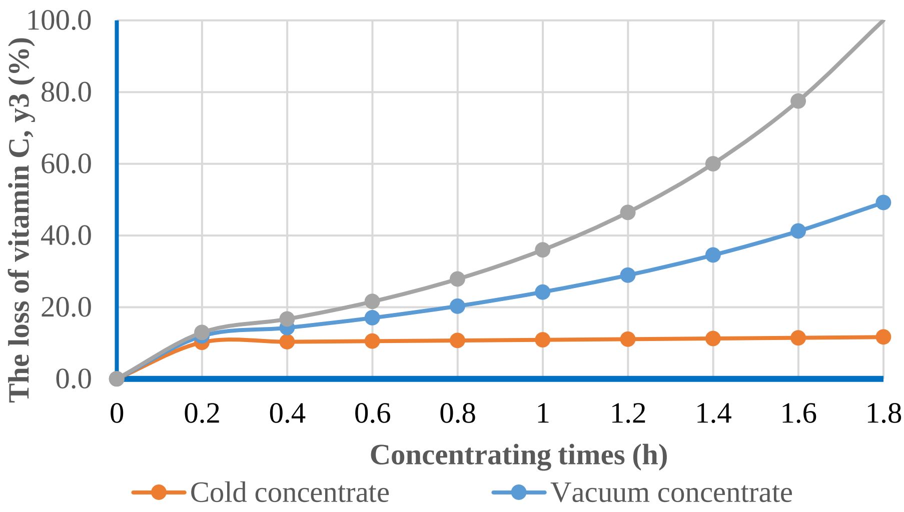

Figure 6. *Time dependence of vitamin C losing of the concentrated products*

4. Conclusions

In this research, the cryoconcentration equipment CCE-03 is successfully manufactured with a maximum capacity of 5 L/batch. The temperature for cooling the concentrated dragon fruit juice solution was -10 to -35°C; the concentration duration and the defrost temperature can be adjusted from 1.5 to 6 hours and 10 to 25°C, respectively. The equipment can be automatically controlled and measured by a computer program. The equipment is operated with stable working, giving a high-quality, concentrated product. After the concentrating process, the loss of vitamin C fluctuates small and almost constant (10.2% to 11.7%). After 1.6 hours of concentration, the energy cost is 0.48 kWh/L of product, the dry matter concentration reaches the requirements of 46.6%, and the loss of vitamin C content is 11.3%. The product shows high quality compared to that obtained by other concentration methods.

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Conflict of Interest

The authors declare no conflict of interest

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