A Study of Solar Energy Storage from Sugar Mixture

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Title	A Study of Solar Energy Storage from Sugar Mixture
By	Miss Suchanun Wisutthimateekorn
Field of Study	Petrochemical Engineering
Advisor	Asst. Prof. Dr. Nuttapol Lerkkasemsan

Accepted by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering).

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Abstract

This thesis studies solar energy storage by using all-glass evacuated solar collector tube. Advantage of this collector is preventing heat loss because inside the tube is vacuum. Phase change materials (PCMs) is used as material for storage heat from the solar collector. PCMs is good for collect energy because it can storage both sensible heat from changing of temperature and latent heat from changing of state of substance. From the experiment, the temperature range of water is 60 to 100 degrees Celsius and factors that affect the water temperature are solar radiation and wind speed. In this experiment, sugar mixtures are used as PCMs because it has high specific heat and latent heat. The sugars studied was sucrose (S), fructose (F), glucose (G) and sugar alcohol which are xylitol (X) and erythritol (E). Theses sugar will be mixed into two, three and four components. The eutectic temperature of sugar mixtures can be found by using Differential Scanning Calorimetry (DSC) and compared with the experiment. In this study, about 3 PCMs mixtures which are G-F, E-X and X-F were used, as well as eutectic temperature of the PCMs are 93, 86 and 76 degrees Celsius respectively. The result of the phase change material which suitable for the temperature range of interest is xylitol – erythritol because it can store heat better than other sugar mixture.

Keywords: phase change material, eutectic temperature

เรื่อง	การศึกษาการเก็บพลังงานแสงอาทิตย์โดยใช้สารผสมจากน้ำตาล
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บทคัดย่อ

ปริญญานิพนธ์นี้ได้ถูกจัดทำขึ้นโดยมีจุดประสงค์เพื่อที่จะศึกษาการเก็บพลังงานจากแสงอาทิตย์โดยใช้หลอดแก้วสุญญากาศโดยจะใช้วัสดุเปลี่ยนสถานะในการเก็บพลังงานความร้อนซึ่งสามารถกักเก็บพลังงานได้มากเนื่องจากมีทั้งค่าความร้อนสัมผัสที่เกิดจากการเปลี่ยนอุณหภูมิของสารและค่าความร้อนแฝงซึ่งเกิดจากการเปลี่ยนสถานะของสาร จากการทดลองเครื่องทำความร้อนที่ใช้หลอดแก้วสุญญากาศนั้นสามารถทำน้ำร้อนได้ช่วงอุณหภูมิ 60 ถึง 100 องศาเซลซียส ซึ่งปัจจัยที่มีผลต่ออุณหภูมิของน้ำคือความเข้มแสงอาทิตย์และความเร็วลมตามลำดับ ส่วนวัสดุเปลี่ยนสถานะจะเลือกใช้สารผสมของน้ำตาลเนื่องจากน้ำตาลมีค่าความร้อนแฝงสูงซึ่งน้ำตาลที่นำมาศึกษาได้แก่ ซูโครส, ฟรักโตสและกลูโคส และใช้น้ำตาลแอลกอฮอล์ ได้แก่ ไซลิทอลและอีรีทรีทอล ในการศึกษานี้จะทดลองสารสอง สาม และสี่องค์ประกอบ อุณหภูมิยูเทคติคสามารถหาได้โดยใช้เครื่อง Differential Scanning Calorimetry (DSC) และนำมาเปรียบเทียบกับค่าจากการทดลอง สำหรับวัสดุเปลี่ยนสารที่จะนำมาทดลองเก็บความร้อนจากน้ำจะใช้ 3 สาร คือ ซูโครส-ฟรักโตส, อีรีทรีทอล-ไซลิทอล และ ไซลิทอล-ฟรักโตส ซึ่งมีอุณหภูมิยูเทคติคคือ 93, 86 และ 76 องศาเซลเซียสตามลำดับ ผลจากการทดลองพบว่า วัสดุเปลี่ยนสารที่เหมาะสมกับช่วงอุณหภูมิที่สนใจคือ สารผสมระหว่างไซลิทอลและฟรักโตส เพราะสามารถเก็บความร้อนได้ดีกว่าสารผมน้ำตาลตัวอื่นๆ

คำสำคัญ: วัสดุเปลี่ยนสถานะ, อุณหภูมิยูเทคติค

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Table of Contents

List of Figures

List of Tables

NOMENCLATURE

Cp	Specific heat capacity	J/kg K
m	Mass	kg
$\Delta_{fus}H$ or L	Heat of fusion	kJ/kg
x	Mass fraction	
T	Temperature	°C
Q	Heat energy	kJ

CHAPTER I

INTRODUCTION

1.1 Background

Global warming and rising energy demand over time make "solar energy" which it is the renewable energy, free of pollution and more widely used. At present, the growth rate of various sectors of the Thai economy is constantly increasing, whether in the industrial, commercial, transportation, agricultural and residential sectors. As a result, the energy consumption continues to increase. Therefore, the development of renewable energy is necessary to reduce the amount of energy consumed and reduce global warming.

From the map of the solar potential of Thailand (1999). It found that distribution of solar radiation intensity in different areas in each month of the country. Influenced by the northeast monsoon and the southwest monsoon. Most of the country receives the highest solar radiation in April and May, ranging from 20 to 24 MJ / m^2-day. The average daily solar radiation of the country is 18.2 MJ / m^2-day. The results show that Thailand has a relatively high solar energy potential[1].

At present, Solar energy applications are classified into 3 types: solar power to generate electricity, solar energy to produce heat and solar cooling technology. In this study, we will study solar energy to produce heat which we can keep heat in a manifold. There are substances in a manifold that use heat storage called phase change material (PCMs). The system converts solar energy into shortwave radiation into heat energy through a solar collector. Based on the principle of light when light incident on the object, there are 4 types of optical phenomena: absorption, emission, reflection, and transmission. The heat has ranges of temperature from 40 to 1500 degrees Celsius which depend on the characteristics of the solar collector.

Nowadays, the solar collector has many types such as focusing solar collector, flat plate solar collector and evacuated tubular collector. We will choose the solar collector is an all glass evacuated tubular collector that can produce temperatures of water about 90-200 degrees Celsius. The advantages of the evacuated tubular collector are that it is a vacuum between a layer of glass, thus preventing heat loss. For installing solar collectors in Thailand, turn the machine to the south and place the tilt at a 45° to the horizontal plane.

For the working fluid used in evacuated tubular collectors, there are many types, such as water or ethanol. In this case, water is used for working fluid.

Phase change material (PCMs) in a tank will use sugar mixture for storage heat at the temperature range from solar collector because of its high heat capacity. In this work use sugars that is sucrose, glucose, fructose and sugar alcohol that is Erythritol (Ery), and Xylitol (Xyl).

1.2 Objectives

1.2.1 Study about temperature range of solar collector in Thailand

1.2.2 To determine the eutectic temperature of sugar mixtures

1.2.3 To determine the phase change materials which suitable for the temperature range of interest

1.3 Scopes of Work

1.3.1 Type of solar collector

1.3.2 Phase change material (PCMs) that is sugar mixtures

1.4 Expected Outputs

1.4.1 Determine the temperature range of solar collector

1.4.1 Determine the eutectic temperature of sugar mixtures

1.4.2 Determine the phase change materials which suitable

CHAPTER II

Theory and Literature Reviews

2.1. Solar radiation

Solar Radiation is the energy emitted by the sun. The incidence of atmospheric radiation is called Extraterrestrial Solar Radiation, which consists of a short range of 290-300 nm to 97 percent. Extraterrestrial radiation passing through the atmosphere to the Earth's surface is disseminated and absorbed by gas molecules, dust particles, and clouds in the atmosphere. Solar radiation has 2 types:

1. Direct solar radiation (G_D): the radiation that reaches the surface of the Earth.

2. Diffuse solar radiation (G_d): the radiation that spreads in the sky.

Solar Radiation can be calculated from the equation as follows:

$$G_{solar} = G_D cos\theta + G_d \quad (1)$$

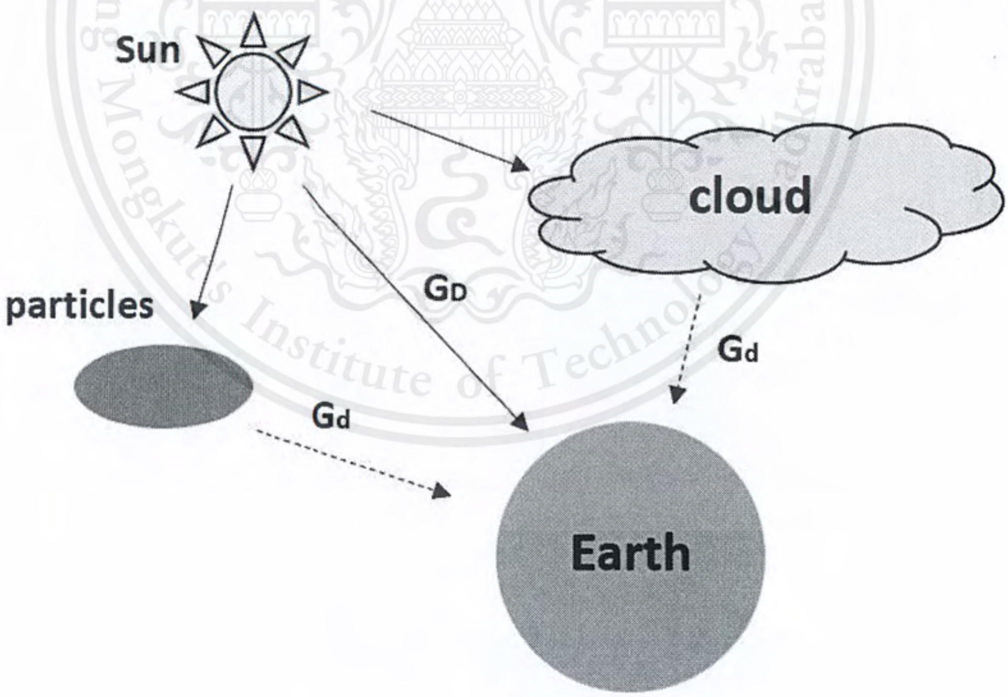

Figure 1 Type of solar radiation

2.2 Solar collector

The principle of a solar collector is to absorb solar energy and convert it into heat. Then the heat is transferred to the fluid flowing through the collector. Most solar collectors use a flat plate solar collector and evacuated tubular collector.

2.2.1 Flat plate collector

Flat plate collectors are popular for generating heat at low or medium temperatures which consist of a large plate for absorb heat and usually a large plate is copper or aluminium as they are good conduction.

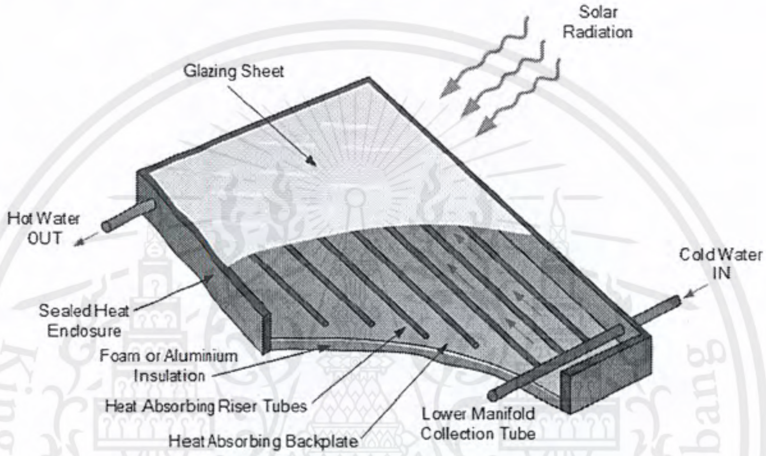

Figure 2 Schematic diagram of a Flat plate collectors

(Source: http://www.alternative-energy-tutorials.com/solar-hot-water/flat-plate-collector.html)

Evacuated tubular collector has high efficiency in heat transfer and generating heat at high temperature because it has a vacuum region between the glass tube which prevent heat loss. The type of glass used is borosilicate, which it has heat-resistant, low coefficient of expansion. When used at high temperatures, the shape of the glass will not change. And also, resistant to chemical corrosion of various types. The most widely used solar tubes are those with the diameter of the outer tube is 0.058 m, the diameter of the inner tube is 0.047 m, the glass tube thickness is 0.0016 m and the tube length is 1.8 m [2]. Evacuated tubular collectors has 2 types;

2.2.2. All glass evacuated tubular collectors

This collector consists of double glass tube which region between the tube is vacuum. Borosilicate is used to produce the tube because it can use in high temperature.

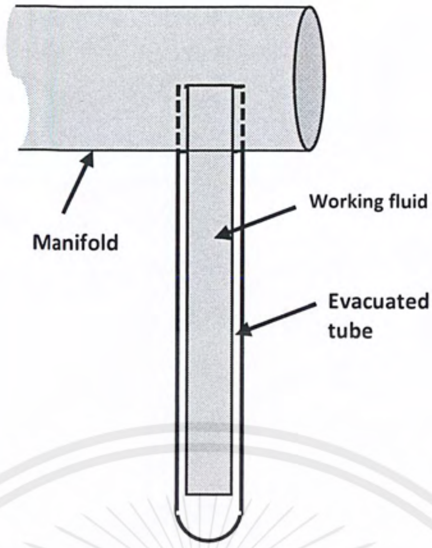

Figure 3 Schematic diagram of the all glass evacuated tubular collectors

2.2.3. Heat pipe Evacuated tubular collectors

This collector has a heat pipe which is placed in a vacuum glass tube as shown in Fig.3. In the heat pipe, there is a small amount of fluid that will evaporate and condense. In this cycle, solar will cause the fluid evaporates. Then the vapor will rise upward to the heat sink region will release the latent heat, then the vapor will condense and return back to the solar collector and the process is repeated That is thermosyphon [3].

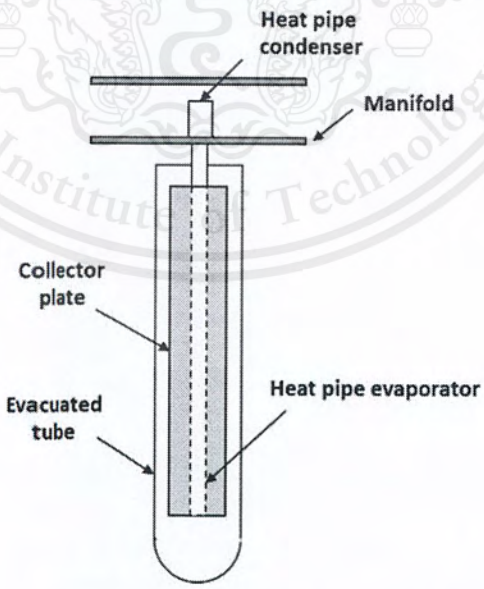

Figure 4 Schematic diagram of the heat pipe Evacuated tubular collectors

2.3. Thermal Energy Storage Material: TES

The thermal energy storage system stores the heat in the phase change material at daytime for use it at night. There are many types of heat storage, including Sensible heat, Latent heat and Chemical heat shown in figure 5.

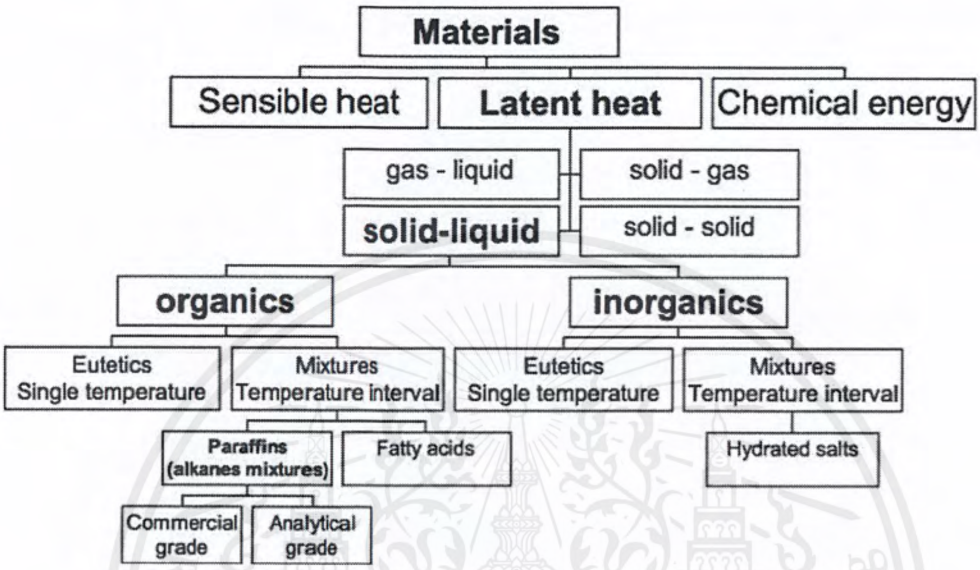

Figure 5 Classification of energy storage materials [4]

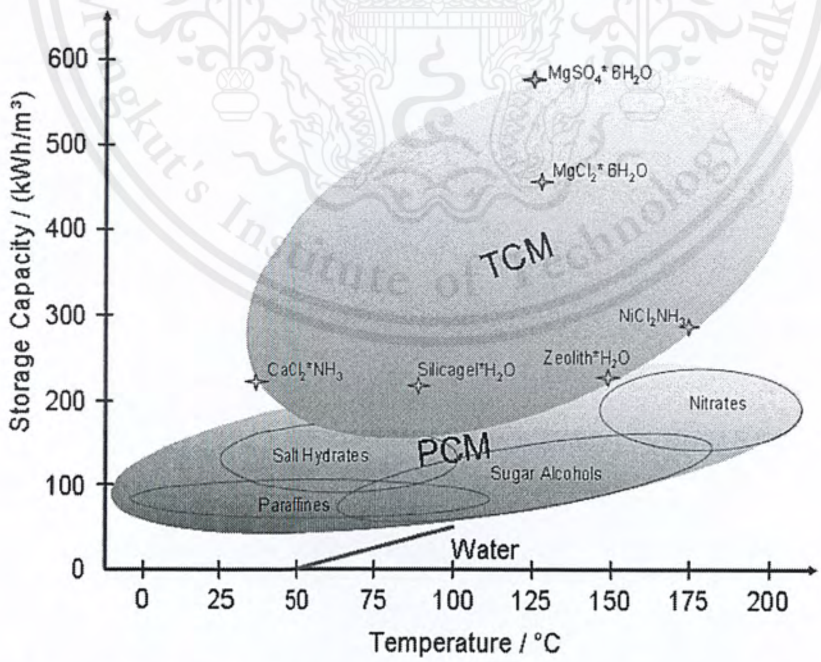

Figure 6 The ability to store heat energy with temperature range used to change the phase [5].

Figure 6 shows the ability to store heat energy from chemical energy materials that can store heat more than latent heat material. However, there are more complex systems that are not popular.

2.4. Phase change material (PCMs)

For latent heat, it uses phase change material (PCMs) for store heat from water which it has many types such as paraffin, non-paraffin, and eutectic. Therefore, the selection of PCMs must have the physical and chemical properties suitable for the application used as follows [6].

1. Melting point: PCM should have a melting point near the temperature range of evacuated tubular collectors

2. Density: High density of PCM improve the density of energy storage which will reduce the volume of a solar collector.

3. Latent heat of fusion: PCM should have a very high latent heat of fusion.

4. Specific heat (Cp): PCM should have high specific heat because it makes high sensible heat.

5. Thermal conductivity (k): PCM should have high Thermal conductivity

In this study, Sugars is used as a phase change material which have the following properties:

1. Sucrose ($C_{12}H_{22}O_{11}$)

- Molecular weight = 342.297 g/mol
- Melting point = 186 °C
- Specific heat capacity = 1.234 J/kg K
- Heat of fusion = 126.6 kJ/kg

2. Fructose

- Molecular weight = 180 g/mol
- Melting point = 103 °C
- Specific heat capacity = 1.117 J/kg K
- Heat of fusion = 154.1 kJ/kg

3. Glucose

- Molecular weight = 180 g/mol
- Melting point = 146 °C

- Specific heat capacity = 1.228 J/kg K
- Heat of fusion = 185.4 kJ/kg

4. Erythritol
- Molecular weight = 122.11 g/mol
- Melting point = 118 °C
- Specific heat capacity = 1.399 J/kg K
- Heat of fusion = 340 kJ/kg

5. Xylitol
- Molecular weight = 152.15 g/mol
- Melting point = 95.1 °C
- Specific heat capacity = 1.301 J/kg K
- Heat of fusion = 1 kJ/kg

2.5. Eutectic system

A system in which each of the substances dissolved in the liquid state at any ratio. But it is completely separate in solid state. If the amount of B is mixed, the melting point will be lower and lower. When the amount of B increases until one of the lowest points is called the eutectic point and when adding B more, the value of the melting point will be higher. This eutectic mixture has the same properties as pure compounds in the melt that is molten at constant temperature. Both substances are alternate structures of substances between A and B, called eutectic structures, as shown in Figure 7.

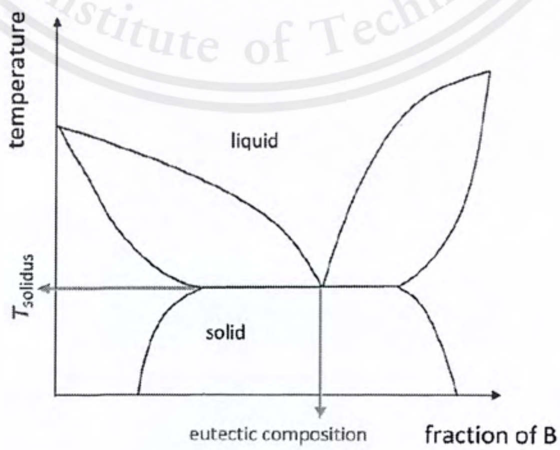

Figure 7 Eutectic point in phase diagram

2.6. Related research

Papadimitratos et al.[7] study on phase change materials (PCMs) within the evacuated tubular collector by using Tritriacontane and Erythritol, which have a eutectic temperature are 72 and 118 degrees Celsius respectively. For the result, it can be improving the efficiency of normal and stagnation mode are 26% and 66% respectively.

Palomo Del Barrio et al.[8] study on phase change materials (PCMs) at low to medium temperature by using sugar alcohol. There are adonitol-erythritol (30 mol% of erythritol), arabitol-erythritol (40 mol %of erythritol), xylitol-erythritol (36 mol% of erythritol) and arabitol-xylitol (56 mol% of xylitol) which have a melting temperature are 87, 86, 82 and 77 degrees Celsius respectively.

Diarce et al.[9] study on new eutectic mixtures of sugar alcohol for phase change materials (PCMs) in 50 to 90 degrees Celsius. There are erythritol-xylitol, erythritol -sorbitol and xylitol-sorbitol which have a melting temperature are 83.9, 86.6 and 74.9 degrees Celsius respectively. For the result is suitable for temperature range.

Kelly and Brown[10] study on mixtures of sucrose, glucose and fructose in two and three component systems. For the results, melting temperature of sucrose-glucose is 137 °C (0.3 mass fraction of sucrose), sucrose-fructose is 37 °C (0.3 mass fraction of sucrose), glucose-fructose is 93.2 °C (0.27 mass fraction of glucose) and sucrose-glucose-fructose is 93 °C (0.175 mass fraction of sucrose, 0.225 mass fraction of glucose.

Mahfuz et al. 2014 [11] study on phase change materials (PCMs) because high energy storage capacity and isothermal during discharging and changing which use paraffin wax as PCMs in shell and tube TES system. For the result in flow rate 0.033 kg/min and 0.167 kg/min, energy efficiencies are 63.88% and 77.41% respectively. But exergy analysis, efficiencies are 9.58% and 6.02% respectively.

2.7. Calculation

2.7.1. Calculate specific heat capacity of sugar mixtures [12]

$$Cp\,mix = \left(\frac{m1}{m\,mix}\right) Cp1 + \left(\frac{m2}{m\,mix}\right) Cp2 + \ldots \qquad (2)$$

2.7.2. Calculate heat of fusion of sugar mixtures [13]

$$(\Delta_{fus}H)_{mix} = x_1\Delta_{fus}H_1 + x_2\Delta_{fus}H_2 + \ldots \quad (3)$$

2.7.3. Calculate mass of sugar mixture.

$$Q = mC_p\Delta T + mL + mC_p\Delta T$$

$$mC_{p,water}\Delta T = m\left(C_{p,sugar}\Delta T + L + C_{p,sugar}\Delta T\right) \quad (4)$$

2.7.4. Calculate heat energy of water.

$$Q = mC_p\Delta T \quad (5)$$

CHAPTER III

RESEARCH METHODOLOGY

The aim of this part is to calculate efficiency of evacuated tubular collectors and use PCMs to storage heat of water in range of temperature from solar collector in Thailand. In this work have 4 steps as follow:

3.1 Study on renewable energy about that used in nowadays and solar collector

Study renewable energy about solar energy that be produced heat by using solar collector. And study about solar collector such as

- Type of solar collector
- Properties of working fluid
- Phase change material

3.2 Produce the thermal energy storage system and record parameters

All glass evacuated tubular collectors are used in thermal energy storage. In this system following figure 8 consist of

- Manifold 80 L
- Stainless tank 80 L
- All glass evacuated tubular collectors 8 tube

In this experiment will be record parameters are solar radiation, Air speed, ambient temperature and %RH (humidity).

3.3 Eutectic temperature of sugar mixtures

1. Experiment for different molar fraction
2. Differential Scanning Calorimetry (DSC)

3.4 Calculate properties of sugar mixtures

1. Specific heat capacity
2. Heat of fusion

3.5 Experiment about phase change materials

1. Calculate properties of sugar mixtures
2. Prepare sugar mixtures in Aluminum foil bag (3-inch x 9-inch)

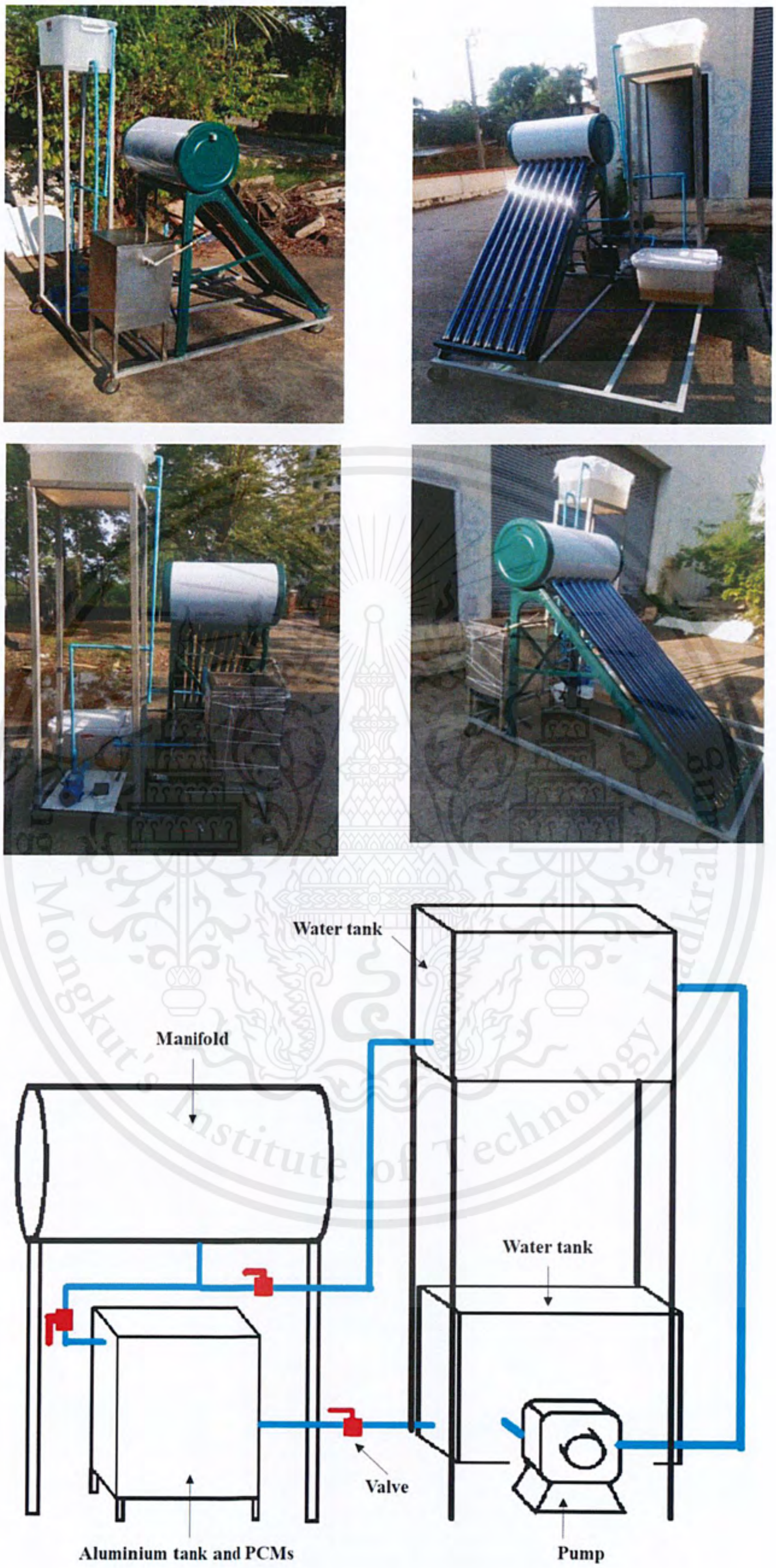

Figure 8 Thermal energy storage system

Figure 9 Aluminum foil bag

3. Experiment 2 parts;

- Part 1: Pour hot water in PCMs tank and record temperature of water and PCMs in 2.30 hour.
- Part 2: Take PCMs which in liquid phase into cold water tank and record temperature of water and PCMs in 20 minutes.

3.6 Calculate the value from experiment

1. The most important factor affecting the water temperature in solar collector
2. Heat energy of water in 2 parts

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Solar collector

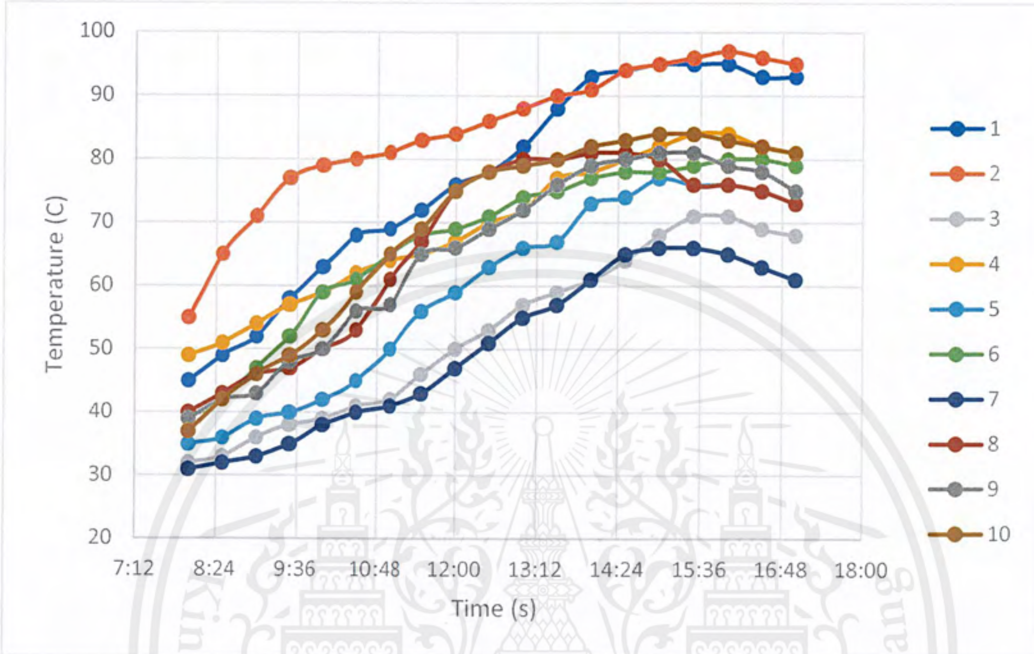

Figure 10 Graph between temperature of water and time in 10 days

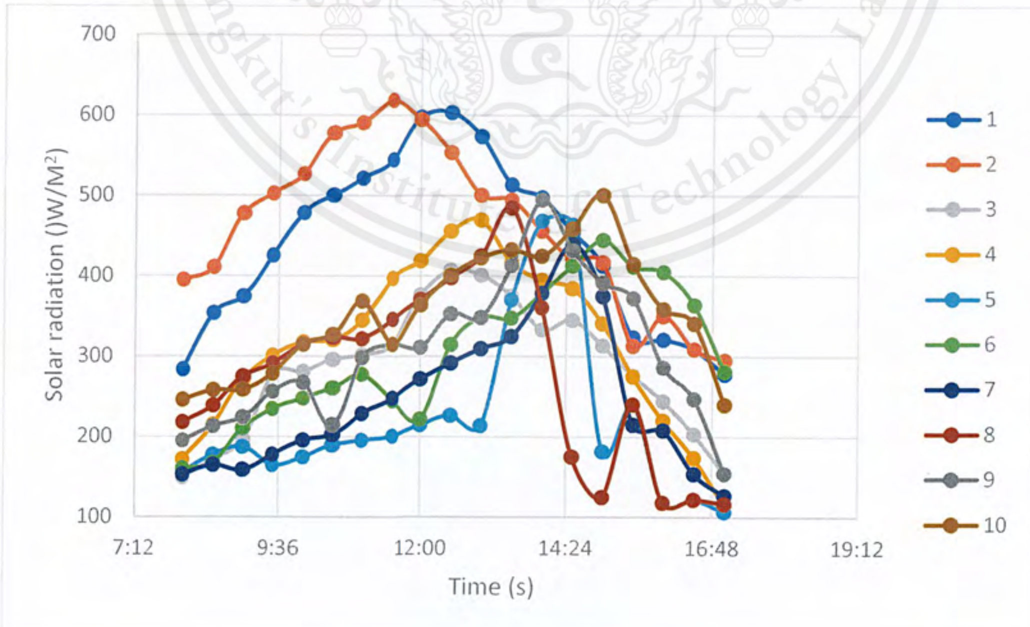

Figure 11 Graph between solar radiation and time in 10 days

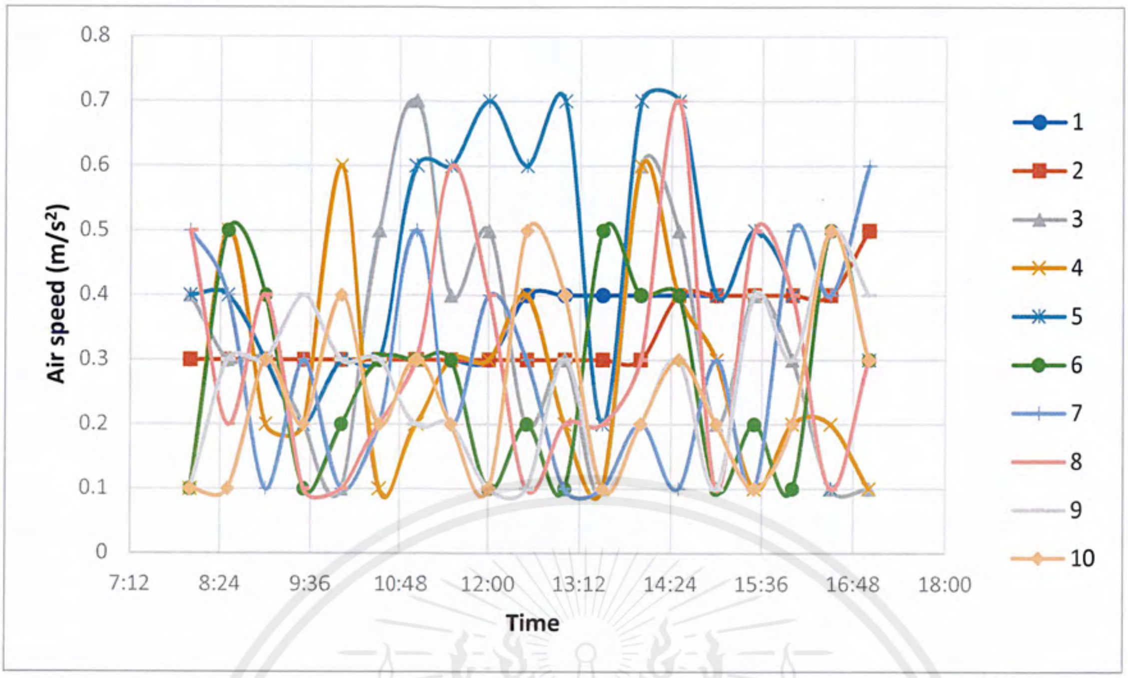

Figure 12 Graph between wind speed and time in 10 days

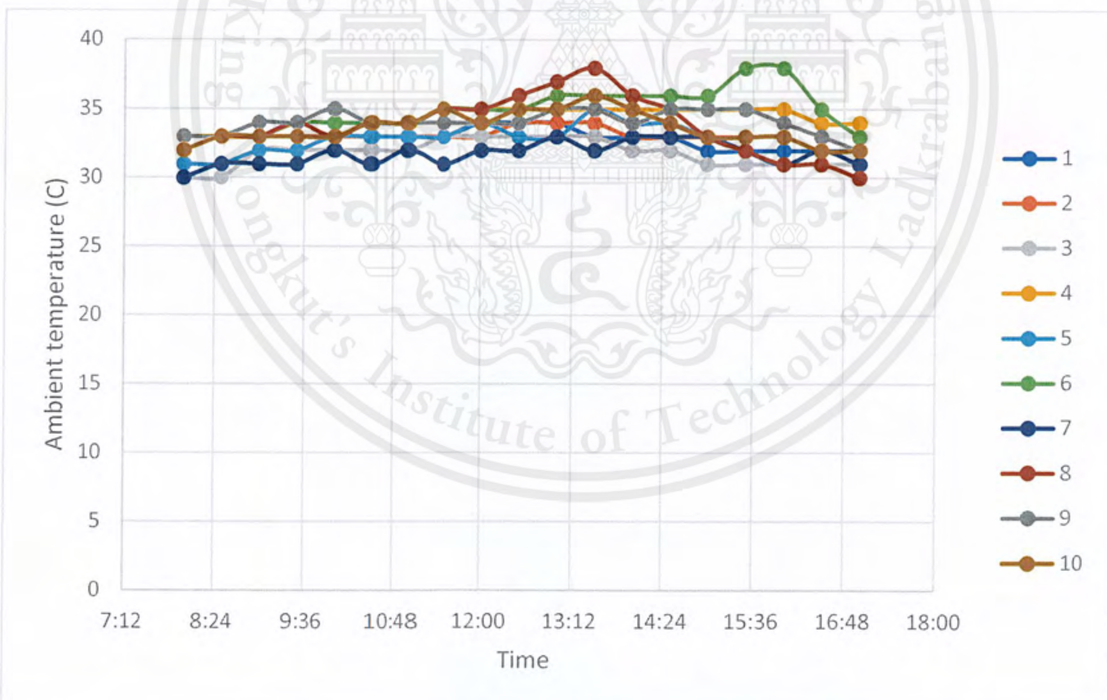

Figure 13 Graph between ambient temperature and time in 10 days

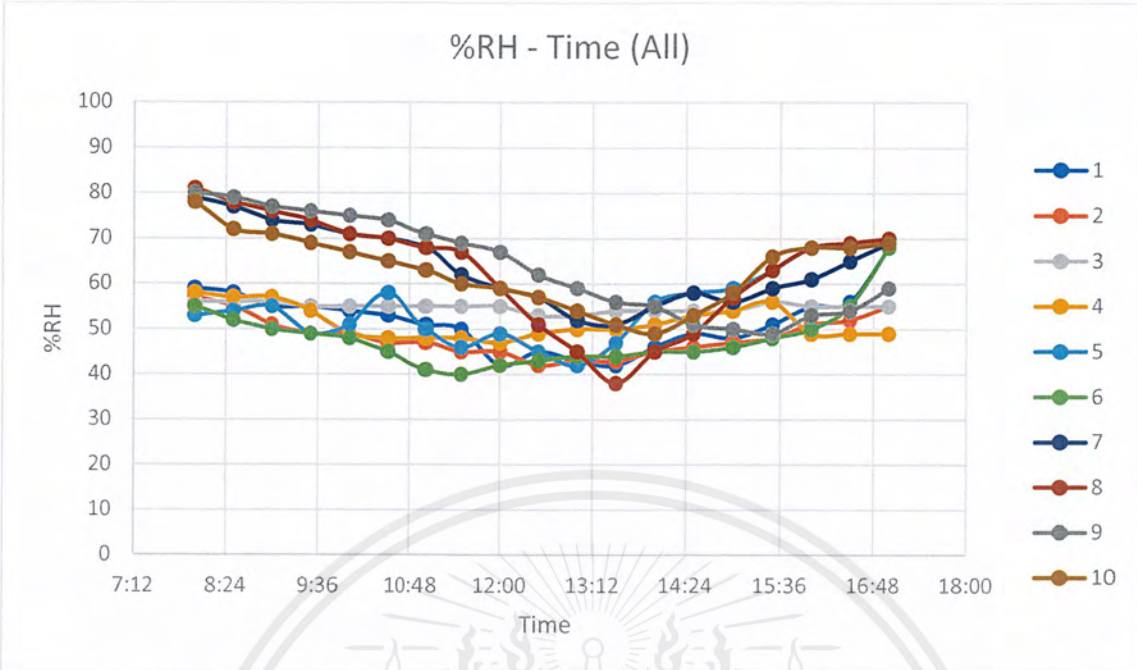

Figure 14 Graph between %RH and time in 10 days

From the result, it was found that ambient temperature and% RH almost did not affect water temperature. Observed from each day when the temperature of the water changes the ambient temperature and the% RH has little change. But the factors that affect the water temperature are solar radiation and wind speed. It was found that the day with very high solar radiation and low wind speed would result in high water temperature.

Heat energy of solar collector which determine from the lowest to the highest temperature of the water as follow

Table 1 Heat energy of solar collector in each day.

Day	Heat energy (kJ)
1	8400
2	6720
3	6048
4	5544
5	7056
6	6552
7	5880
8	6720
9	7056
10	7896

4.2 Eutectic temperature of sugar mixtures

1. Sucrose + Fructose

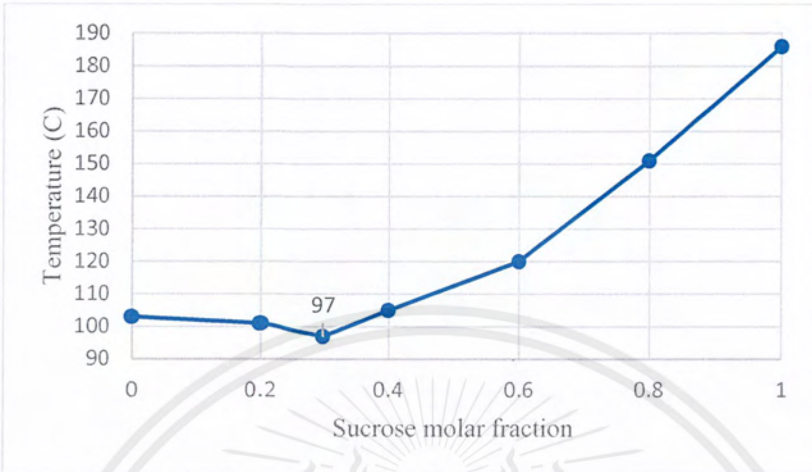

Figure 15 Phase diagram of the sucrose - fructose system from experiment

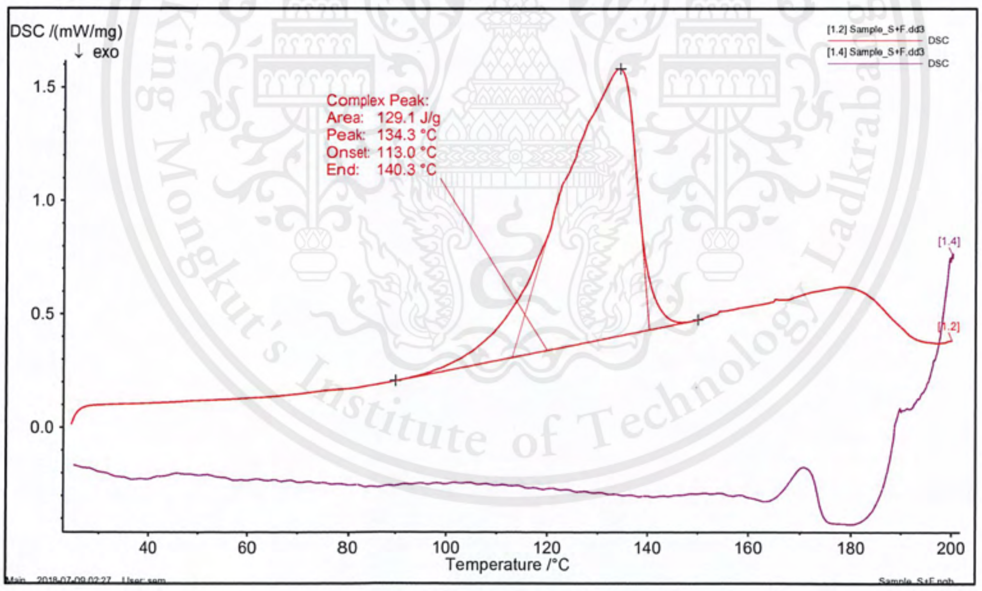

Figure 16 DSC curve of the sucrose - fructose system

Sucrose - Fructose system has a eutectic temperature from experiment is 97 °C which it has a mass fraction of sucrose and fructose are 0.3 and 0.7 respectively. For DSC, this system has a melting temperature is 113-140.3 °C.

2. Glucose + Fructose

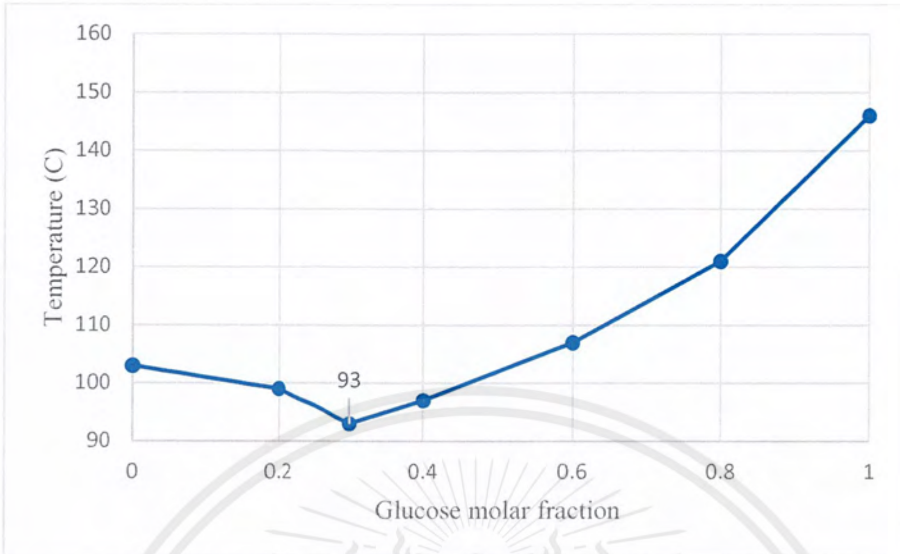

Figure 17 Phase diagram of the glucose - fructose system from experiment

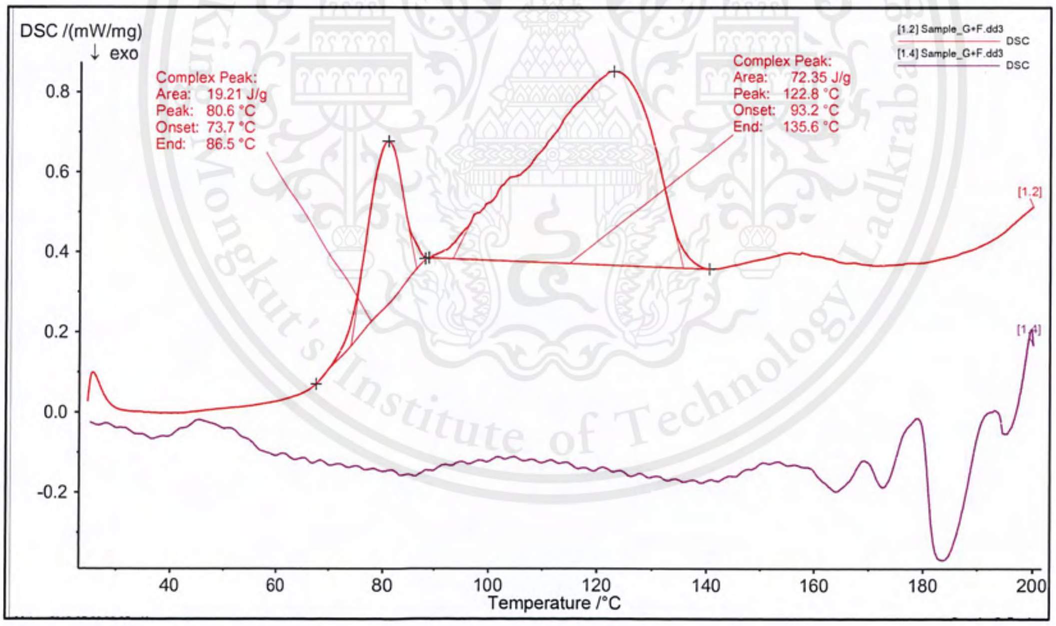

Figure 18 DSC curve of the glucose - fructose system

Glucose - Fructose system has a eutectic temperature from experiment is 93 °C which it has a mass fraction of glucose and fructose are 0.3 and 0.7 respectively. For DSC, this system has a melting temperature is 93.2-135.6 °C.

3. Erythritol + Xylitol

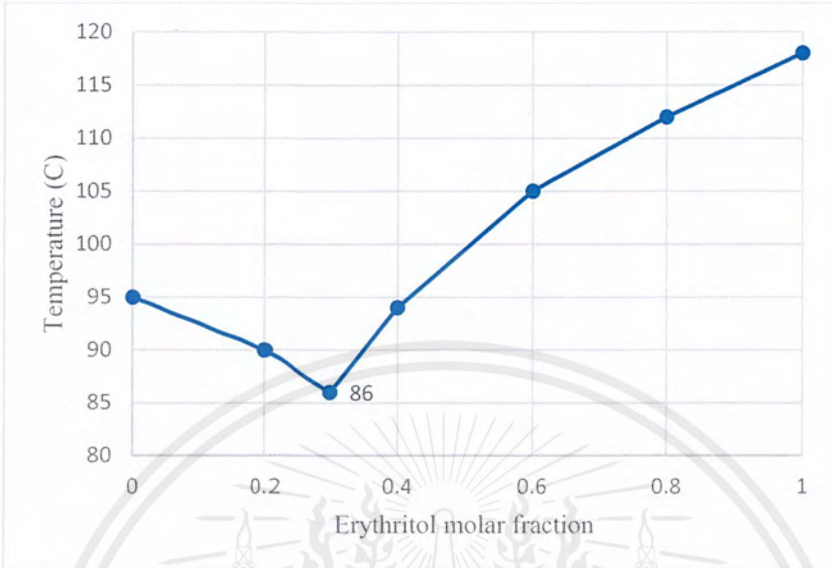

Figure 19 Phase diagram of the erythritol - xylitol system from experiment

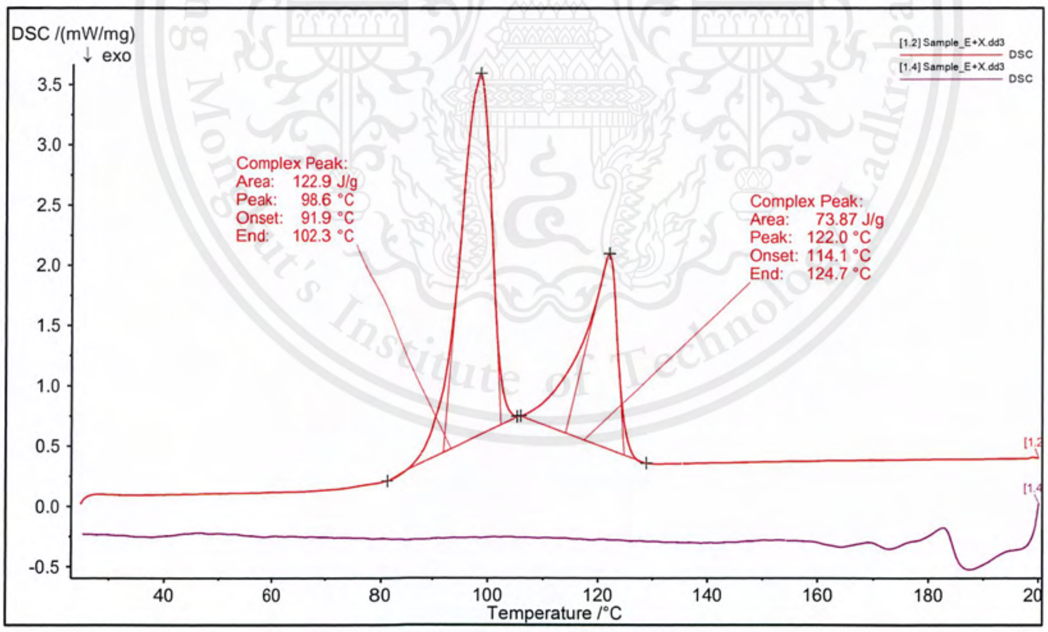

Figure 20 DSC curve of the erythritol - xylitol system

Erythritol - Xylitol system has a eutectic temperature from experiment is 86 °C which it has a mass fraction of erythritol and xylitol are 0.3 and 0.7 respectively. For DSC, this system has a melting temperature : 91.9-102.3 °C.

4. Xylitol + Fructose

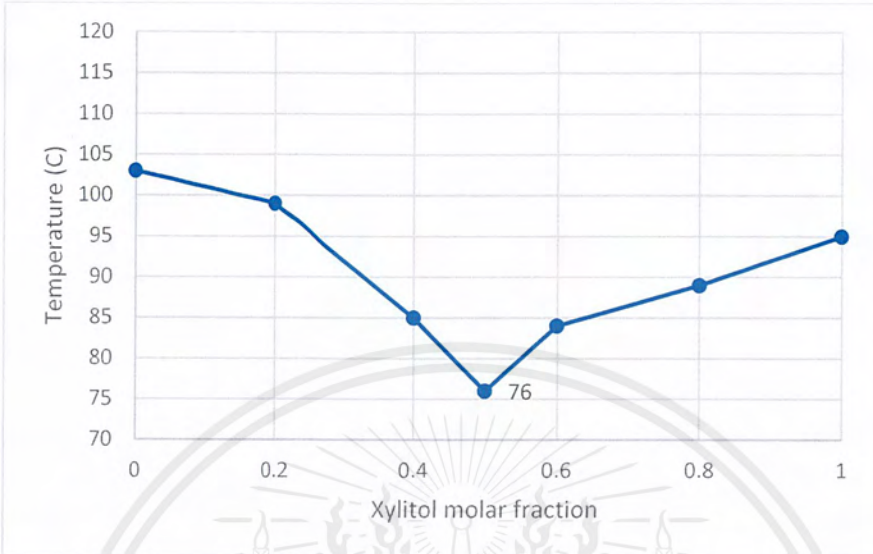

Figure 21 Phase diagram of the xylitol - fructose system from experiment

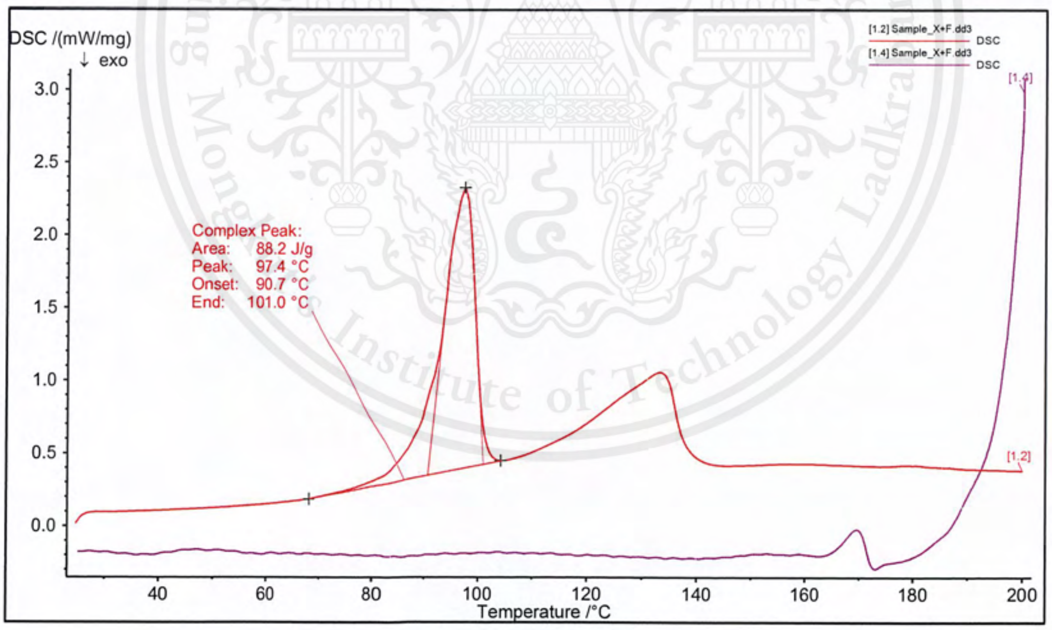

Figure 22 DSC curve of the xylitol - fructose system

Xylitol - Fructose system has a eutectic temperature from experiment is 76 °C which it has a mass fraction of xylitol and fructose are 0.5 and 0.5 respectively. For DSC, this system has a melting temperature : 90.7-101.0 °C

5. Sucrose + Glucose + Fructose

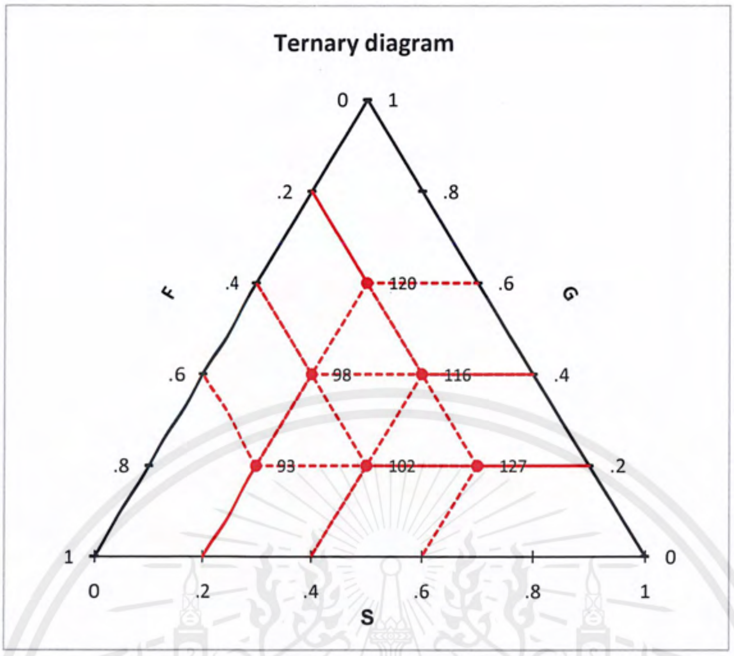

Figure 23 Ternary diagram of the sucrose - glucose - fructose system from experiment

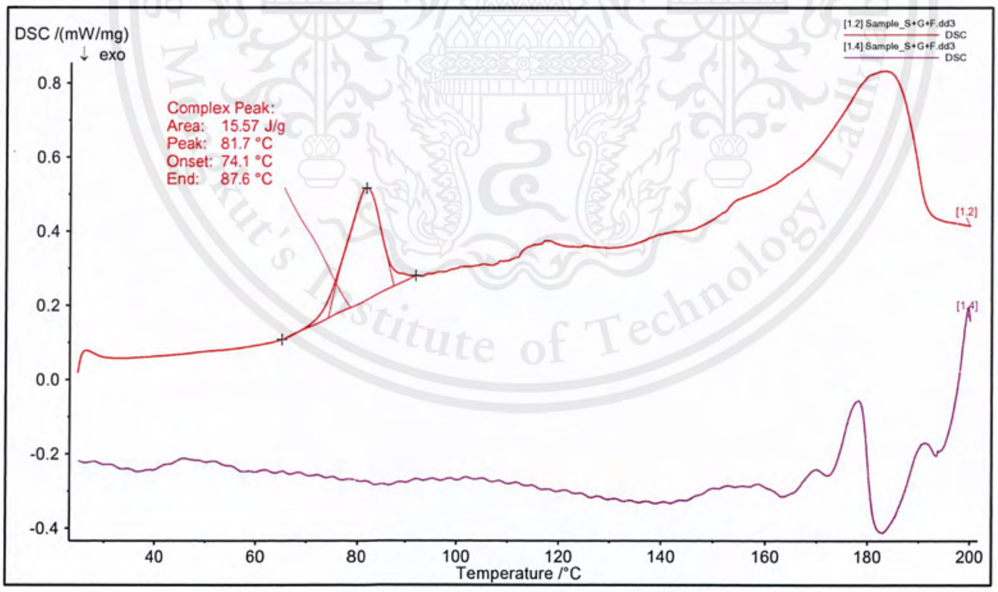

Figure 24 DSC curve of the sucrose - glucose - fructose system

Sucrose - Glucose - Fructose system has a eutectic temperature from experiment is 93 °C which it has a mass fraction of sucrose, glucose and fructose are 0.2, 0.2 and 0.6 respectively. For DSC, this system has a melting temperature : 74.1-87.6 °C

6. Erythritol + Xylitol + Fructose

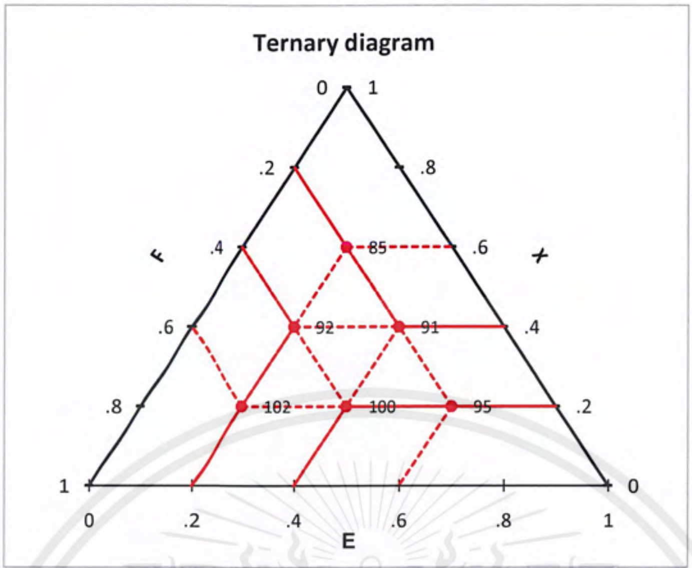

Figure **25** Ternary diagram of the erythritol - xylitol - fructose system from experiment

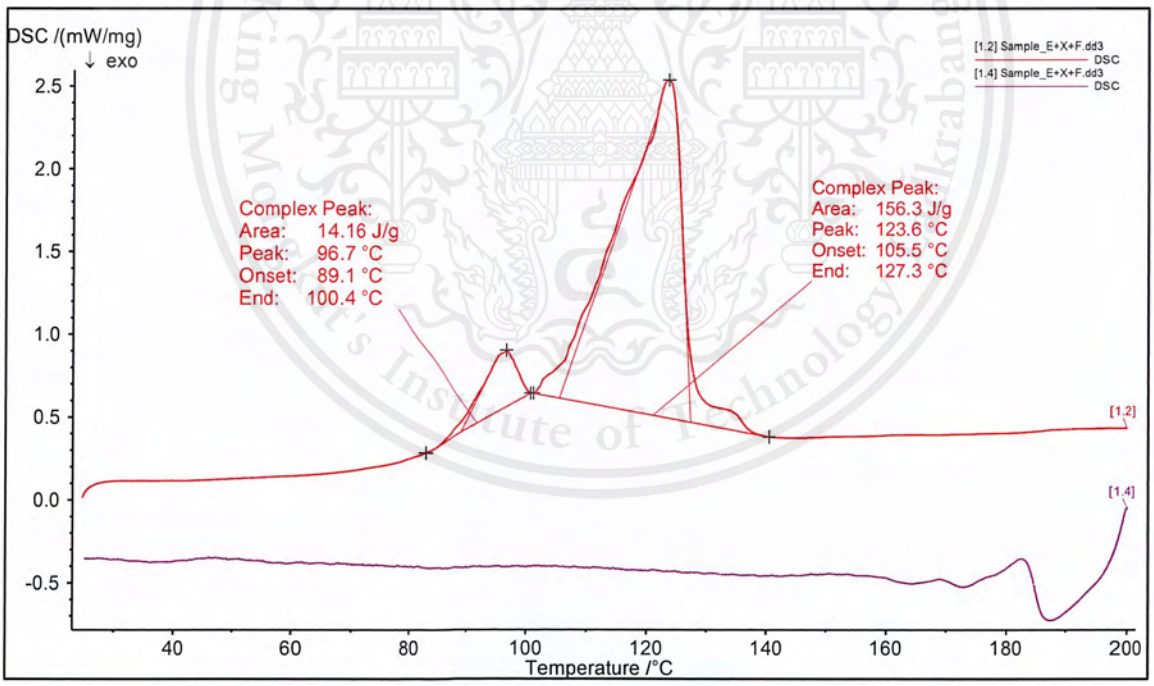

Figure 26 DSC curve of the erythritol - xylitol - fructose system

Erythritol - Xylitol - Fructose system has a eutectic temperature from experiment is 85 °C which it has a mass fraction of erythritol, xylitol and fructose are 0.2, 0.6 and 0.2 respectively. For DSC, this system has a melting temperature : 89.1-100.4 °C

7. Erythritol + Xylitol + Fructose + Glucose

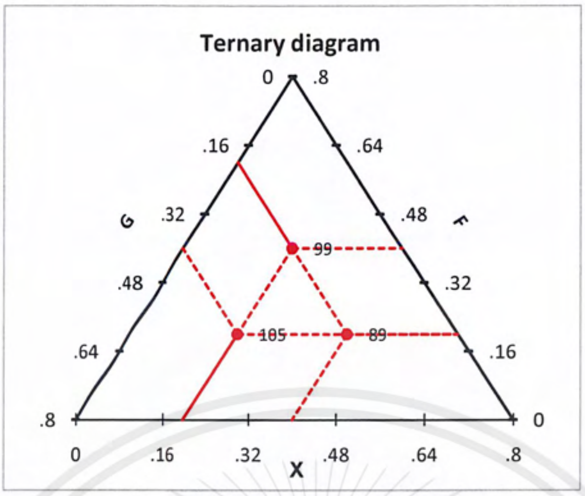

Figure 27 Ternary diagram of the erythritol - xylitol - fructose - glucose system from experiment (E = 0.2)

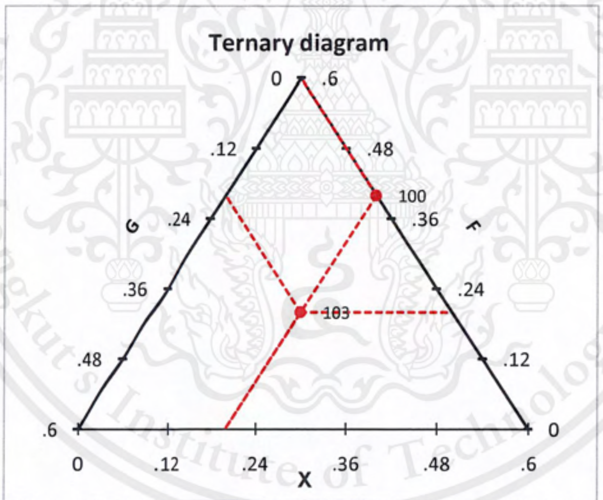

Figure 28 Ternary diagram of the erythritol - xylitol - fructose - glucose system from experiment (E = 0.4)

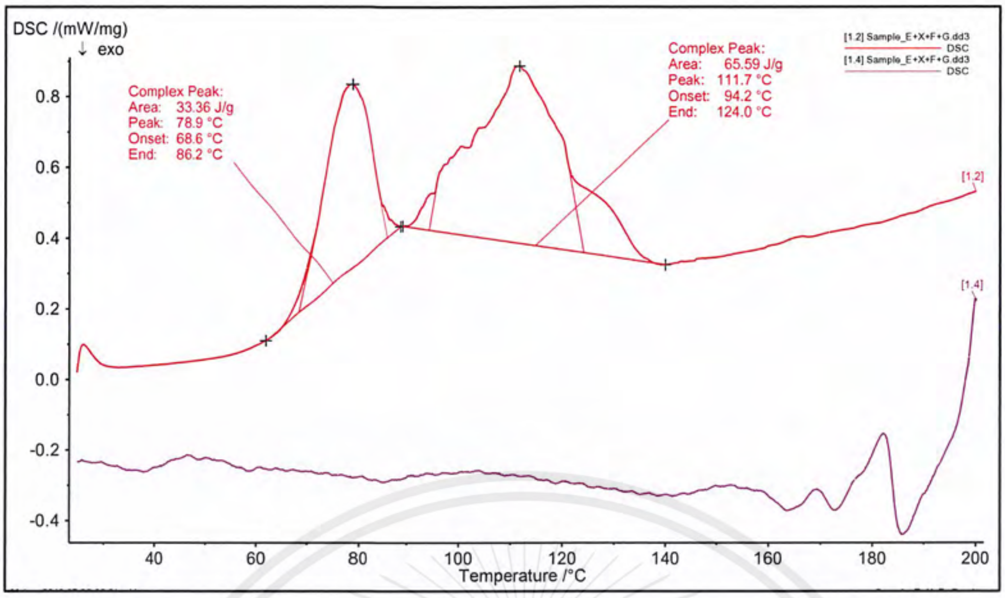

Figure 29 DSC curve of the erythritol - xylitol - fructose - glucose system

Erythritol - Xylitol - Fructose – Glucose system has a eutectic temperature from experiment is 89 °C which it has a mass fraction of erythritol, xylitol, fructose and glucose are 0.2, 0.4, 0.2 and 0.2 respectively. For DSC, this system has a melting temperature : 94.2 °C

Table 2 Eutectic temperature of each sugar mixture

Sugar mixtures	**mass fraction**	**Eutectic temperature from Experiment: started to melt (°C)**	**Eutectic temperature from DSC: started to melt (°C)**
Sucrose + Fructose	S = 0.3, F = 0.7	97	113
Glucose + Fructose	G = 0.3, F = 0.7	93	93.2
Erythritol + Xylitol	E = 0.3, X = 0.7	86	91.9
Xylitol + Fructose	X = 0.5, F = 0.5	76	90.7
Sucrose + Glucose + Fructose	S = 0.2, F = 0.6, G = 0.2	93	74.1
Erythritol + Xylitol + Fructose	E = 0.2, X = 0.6, F = 0.2	85	89.1
Erythritol + Xylitol + Fructose + Glucose	E = 0.2, X = 0.4, F = 0.2, G = 0.2	89	94.2

The result is the cause of the deviation between the eutectic temperature obtained from the experiment and the DSC analysis because the mixture may be impure or not mix well.

4.3 Properties of sugar mixtures

In this study will choose sugar mixtures are Glucose – Fructose, Erythritol – Xylitol and Xylitol – Fructose which have a eutectic temperature are 93, 86 and 79 degree Celsius respectively following table 1.

Table 3 Eutectic temperature and mass fraction of sugar mixtures

Sugar mixtures	**Mass fraction**	**Eutectic temperature (°C)**
Glucose + Fructose	G = 0.3, F = 0.7	93
Erythritol + Xylitol	E = 0.3, X = 0.7	86
Xylitol + Fructose	X = 0.5, F = 0.5	76

Table 4 Specific heat capacity and enthalpy of fusion of sugar mixture

Sugar mixtures	**Cp mix (kJ/kg K)**	**Enthalpy of fusion mix (KJ/kg)**
Glucose + Fructose	1.15	162.55
Erythritol + Xylitol	1.33	275.39
Xylitol + Fructose	1.21	202.55

Table 5 Mass of PCMs for water 3 L

Sugar mixtures	**Mass (kg)**
Glucose + Fructose	1.47
Erythritol + Xylitol	0.96
Xylitol + Fructose	1.24

4.4 Phase change materials

Part 1: PCMs storage heat from hot water

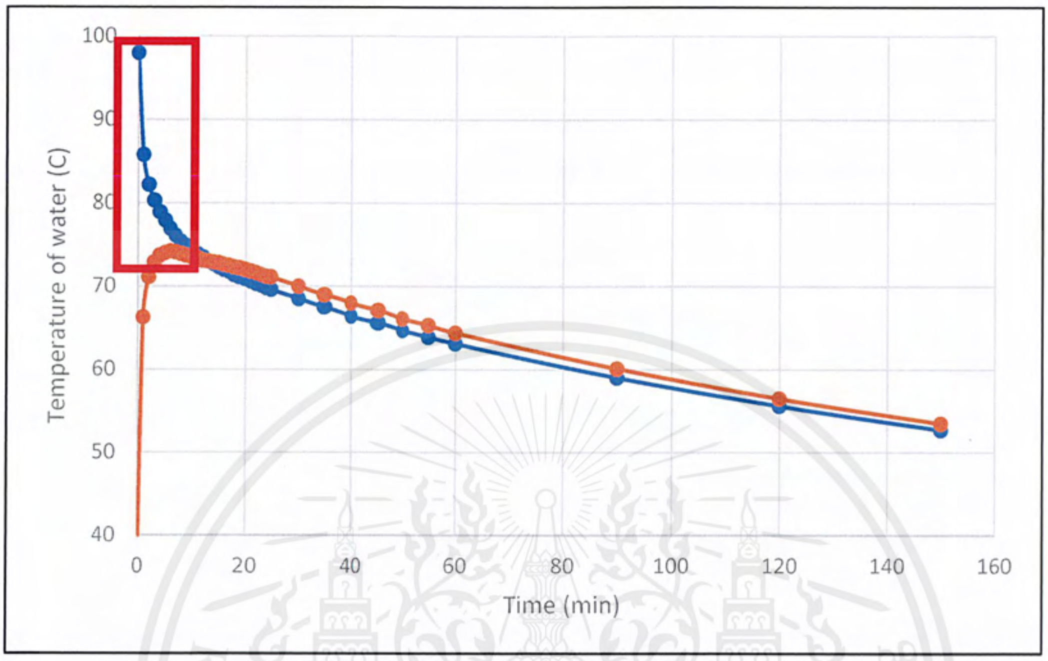

Figure 30 Graph between temperature and time of G+F (Part 1)

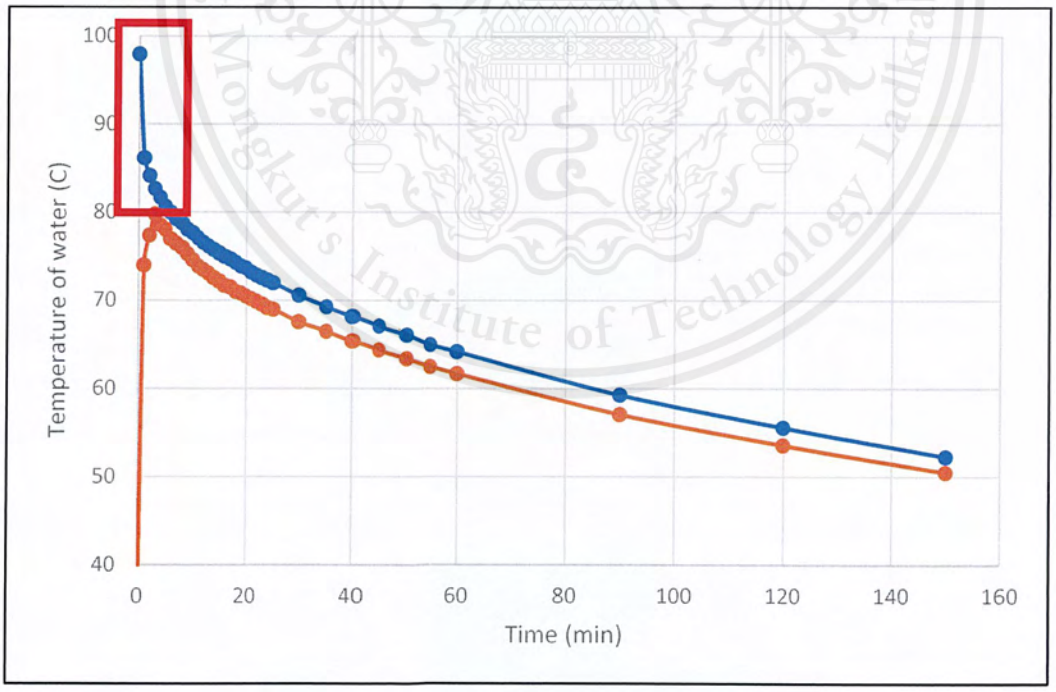

Figure 31 Graph between temperature and time of E+X (Part 1)

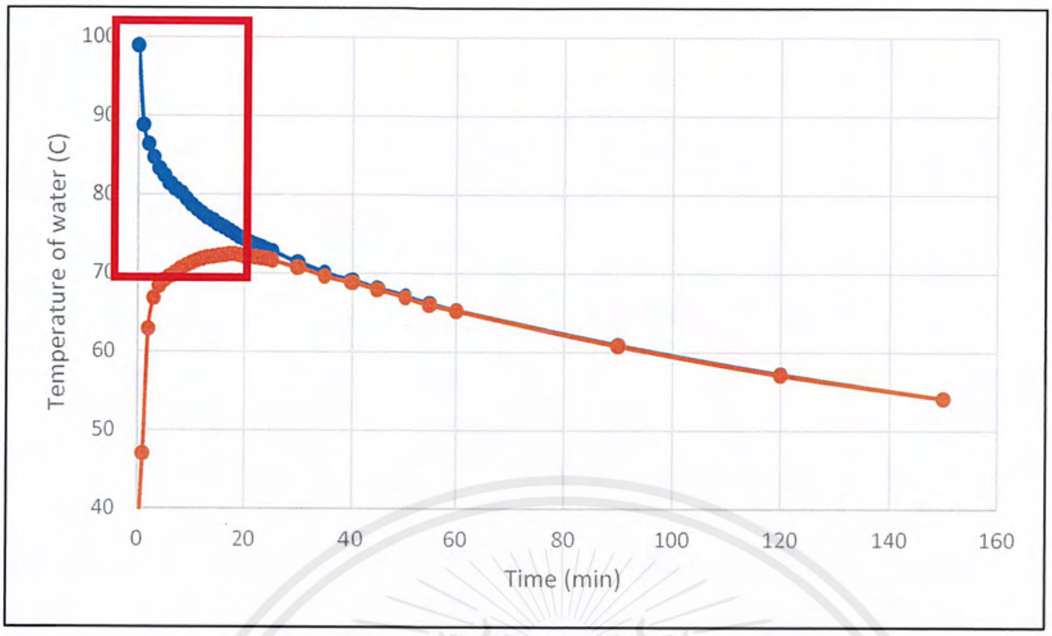

Figure 32 Graph between temperature and time of X+F (Part 1)

The heat energy of water is calculated from the maximum water temperature to the maximum temperature of the sugar mixture, which is the heat energy lost to the sugar mixtures.

Heat energy of water lost to sugar mixture in the glucose-fructose (fig.18) is 299.88 kJ, erythritol-xylitol (fig.19) is 229.32 kJ and xylitol-fructose (fig.20) is 333.90 kJ.

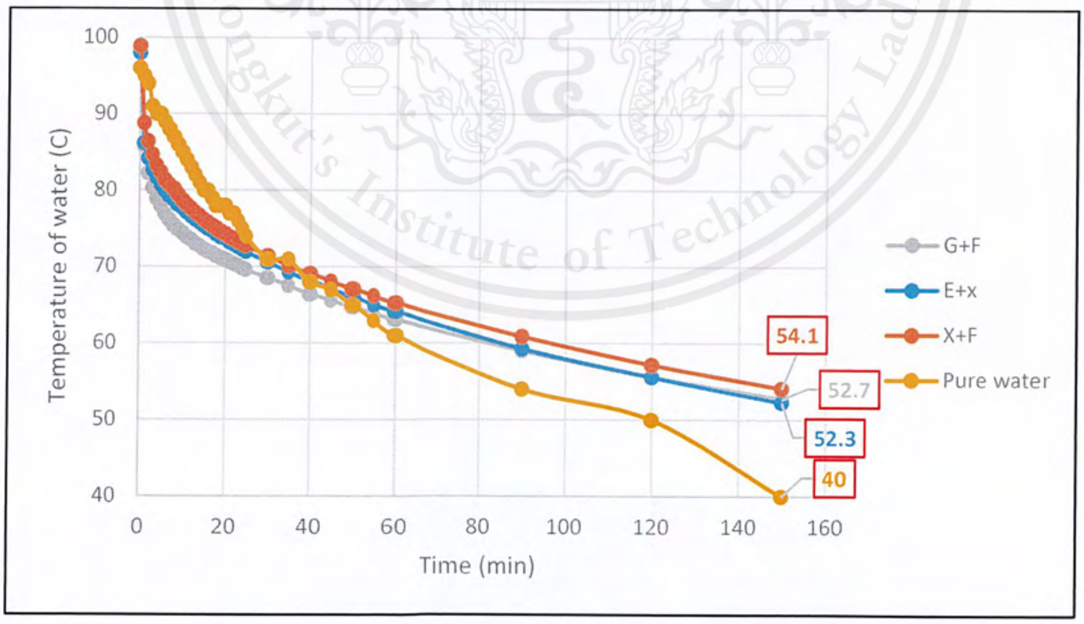

Figure 33 Graph between temperature of water in each sugar mixtures and time (Part 1)

The temperature at 150 min in glucose – fructose, erythritol – xylitol, xylitol – fructose and pure water are 52.7 ℃ , 52.3 ℃ , 54.1 ℃ and 40 ℃ respectively. Heat energy of water in glucose – fructose is -570.78 kJ, erythritol – xylitol is -575.82 kJ, xylitol – fructose is -553.14 kJ and pure water is -693.00 kJ

From calculation, Xylitol-Fructose can store heat from water better than other sugar mixtures because this mixture can receive the most heat from water.

Part 2: Heat cold water by using PCMs

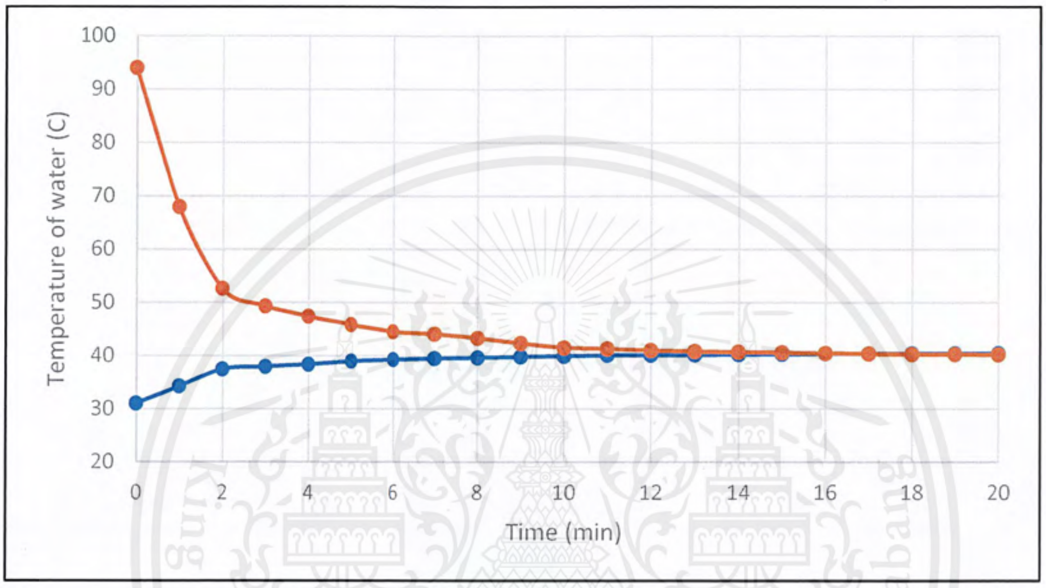

Figure 34 Graph between temperature and time of G+F (Part 2)

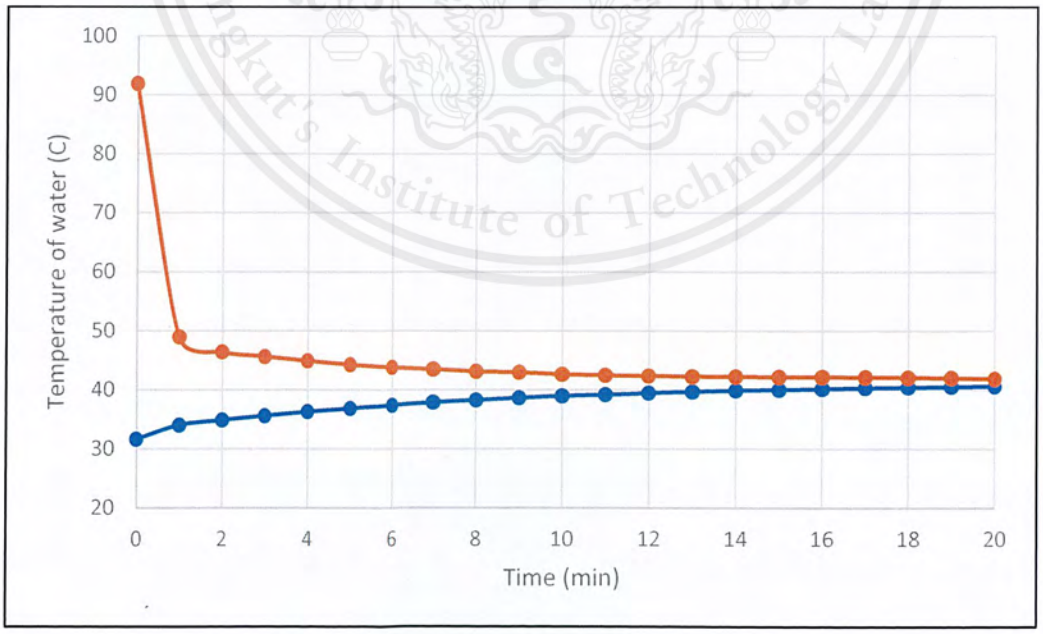

Figure 35 Graph between temperature and time of E+X (Part 2)

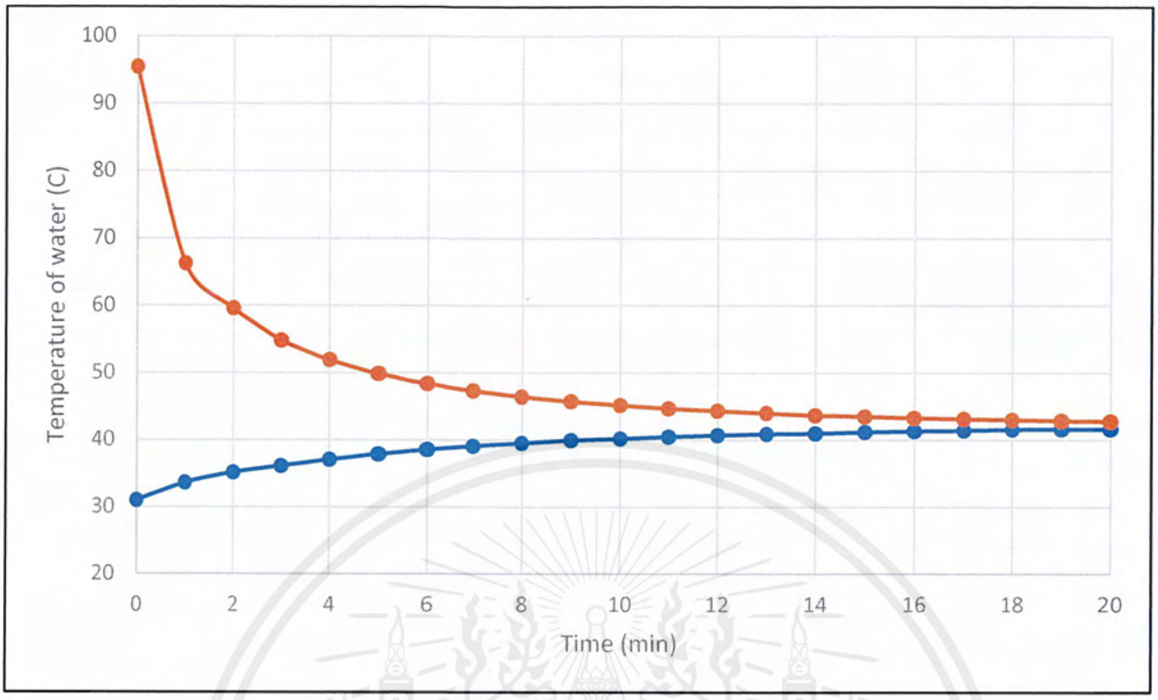

Figure 36 Graph between temperature and time of X+F (Part 2)

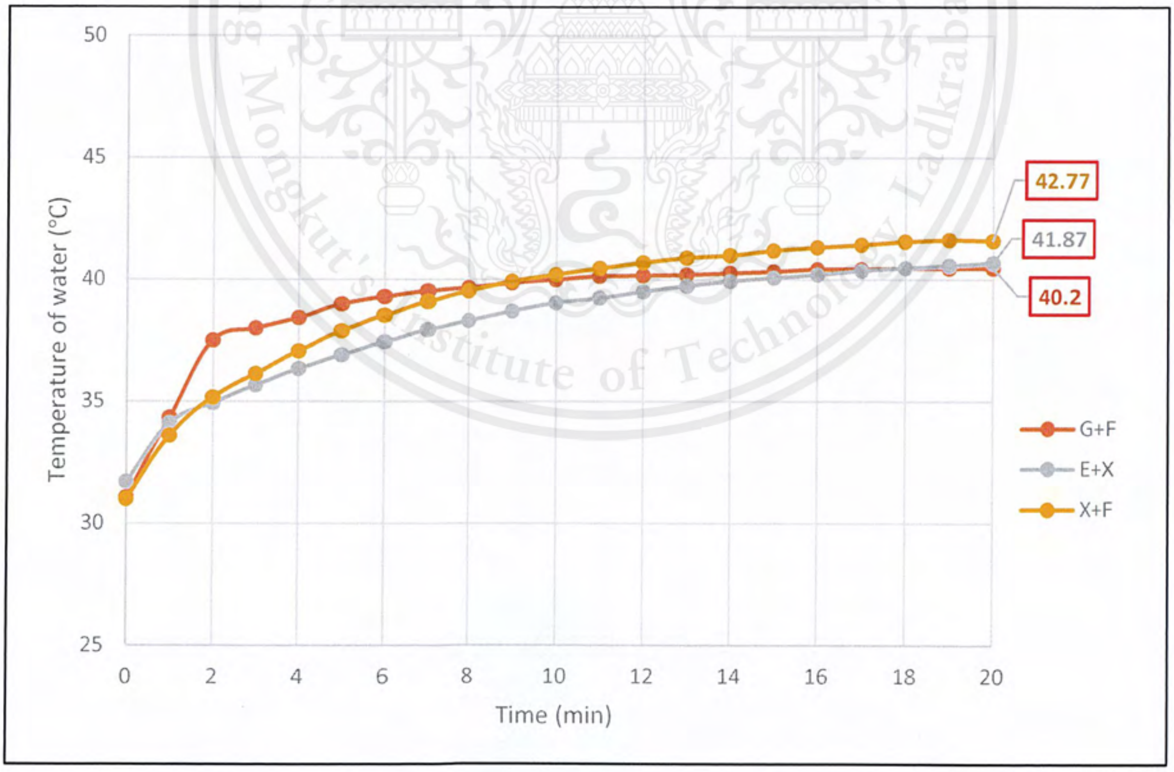

Figure 37 Graph between temperature of water in each mixtures and time (Part 2)

The temperature at 20 min in glucose – fructose, erythritol – xylitol and xylitol – fructose are 40.47 °C , 40.67 °C and 40.47 °C respectively. Heat energy of water in glucose – fructose is 119.32 kJ, erythritol – xylitol is 113.02 kJ and xylitol – fructose is 133.56 kJ

For melt fraction of each mixture which glucose – fructose is 77.75 %, erythritol – xylitol is 63.95 % and xylitol – fructose is 86.15 %.

From the calculation of heat energy of water and melt fraction, xylitol-fructose can store heat from water better than other sugar mixtures because this compound has melt fraction more than other sugar mixtures.

CHAPTER V

CONCLUSION

5.1 Solar collector

- The range of temperature of water from solar collector is 60-100 degrees Celsius.
- The important factor affecting the water temperature is the solar radiation and wind speed.

5.2 Phase change materials

- Sugar mixtures, it started to melt at temperature as follow
  1. sucrose-fructose is 97 °C from experiment and 117 °C from DSC with mass fraction is S = 0.3, F = 0.7
  2. glucose-fructose is 93 °C from experiment and 93.2 °C from DSC with mass fraction is G = 0.3, F = 0.7
  3. erythritol-xylitol is 86 °C from experiment and 91.9 °C from DSC with mass fraction is E = 0.3, F = 0.7
  4. xylitol-fructose is 76 °C from experiment and 90.7 °C from DSC with mass fraction is E = 0.5, F = 0.5
  5. sucrose-glucose-fructose is 93 °C from experiment and 74.1 °C from DSC with mass fraction is S = 0.2, G = 0.2, F = 0.6
  6. erythritol-xylitol-fructose is 85 °C from experiment and 89.1 °C from DSC with mass fraction is E = 0.2, X = 0.6, F = 0.2
  7. erythritol-xylitol-fructose-glucose is 89 °C from experiment and 94.2 °C from DSC with mass fraction is E = 0.2, X = 0.4, F = 0.2, G = 0.2
- Xylitol – Fructose can store heat from the solar collector at a temperature range of 60-100 degrees Celsius better than other sugar mixtures.

Suggestions

1. Determine the relationship between the factors that affect the water temperature.
2. Using other mixtures which have melting temperature are lower or higher.
3. Change the shape of bag for increase surface area.

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Appendix

Appendix A

Properties of sugar mixture

1. Melting point of each sugar mixtures

Table A1 Melting point of Sucrose + Fructose

S	F	melting point (°C)
0	1	103
0.2	0.8	101
0.3	0.7	97
0.4	0.6	105
0.6	0.4	120
0.8	0.2	151
1	0	186

Table A2 Melting point of Glucose + Fructose

G	F	melting point (°C)
0	1	103
0.2	0.8	99
0.3	0.7	93
0.4	0.6	97
0.6	0.4	107
0.8	0.2	121
1	0	146

Table A3 Melting point of Erythritol + Xylitol

E	X	melting point (°C)
0	1	95
0.2	0.8	90
0.3	0.7	86
0.4	0.6	94
0.6	0.4	105
0.8	0.2	112
1	0	118

Table A4 Melting point of Xylitol + Fructose

S	F	melting point (°C)
0	1	103
0.2	0.8	99
0.4	0.6	85
0.5	0.5	76
0.6	0.4	84
0.8	0.2	89
1	0	95

Table A5 Melting point of Sucrose + Fructose + Glucose

S	G	F	melting point (°C)
0.2	0.2	0.6	93
0.2	0.4	0.4	98
0.2	0.6	0.2	120
0.4	0.4	0.2	116
0.4	0.2	0.4	102
0.6	0.2	0.2	127

Table A6 Melting point of Erythritol + Xylitol + Fructose

S	G	F	melting point (°C)
0.2	0.2	0.6	102
0.2	0.4	0.4	92
0.2	0.6	0.2	85
0.4	0.4	0.2	91
0.4	0.2	0.4	100
0.6	0.2	0.2	95

Table A7 Melting point of Erythritol + Xylitol + Fructose + Glucose

E	X	F	G	melting point (°C)
0.2	0.2	0.2	0.4	105
0.2	0.2	0.4	0.2	99
0.2	0.4	0.2	0.2	89
0.4	0.2	0.2	0.2	103

Table A8 Specific heat capacity (J/kg K) and heat of fusion (kJ/kg) of substance

Substance / Properties	**Fructose**	**Glucose**	**Erythritol**	**Xylitol**
Melting point (°C)	103	146	118.8	95.1
Cp (J/kg K)	1.1167	1.2278	1.399	1.3013
Heat of fusion (kJ/kg)	154.1	185.4	340	251

2. Calculate specific heat capacity of sugar mixtures

$$Cp\ mix = \left(\frac{m1}{m\ mix}\right) Cp1 + \left(\frac{m2}{m\ mix}\right) Cp2 + \ldots \tag{A1}$$

- Glucose + Fructose (G = 0.3, F = 0.7) in 1000 g

$$Cp\ mix = \left(\frac{300}{1000}\right) 1.2278 + \left(\frac{700}{1000}\right) 1.1167$$

$$Cp\ mix = 1.15 \quad kJ/kg \cdot K$$

- Xylitol + Fructose (X = 0.5, F = 0.5) in 1000 g

$$Cp\ mix = \left(\frac{500}{1000}\right) 1.3013 + \left(\frac{500}{1000}\right) 1.1167$$

$$Cp\ mix = 1.21 \quad kJ/kg \cdot K$$

- Erythritol + Xylitol (E = 0.3, X = 0.7) in 1000 g

$$Cp\ mix = \left(\frac{300}{1000}\right) 1.399 + \left(\frac{700}{1000}\right) 1.3013$$

$$Cp\ mix = 1.33 \quad kJ/kg \cdot K$$

3. Calculate heat of fusion of sugar mixtures

$$(\Delta_{fus}H)_{mix} = x_1\Delta_{fus}H_1 + x_2\Delta_{fus}H_2 + \ldots \tag{A2}$$

- Glucose + Fructose (G = 0.3, F = 0.7) in 1000 g

$$(\Delta_{fus}H)_{mix} = 0.3(185.4) + 0.7(154.1)$$

$$(\Delta_{fus}H)_{mix} = 162.55 \quad kJ/kg$$

- Xylitol + Fructose (X = 0.5, F = 0.5) in 1000 g

$$(\Delta_{fus}H)_{mix} = (0.5)251 + (0.5)154.1$$

$$(\Delta_{fus}H)_{mix} = 202.55 \quad kJ/kg$$

- Erythritol + Xylitol (E = 0.3, X = 0.7) in 1000 g

$$(\Delta_{fus}H)_{mix} = 0.3(340) + 0.7(251)$$

$$(\Delta_{fus}H)_{mix} = 275.39 \quad kJ/kg$$

4. Calculate mass of sugar mixtures:

$$Q = mC_p\Delta T + mL + mC_p\Delta T$$
$$mC_{p,water}\Delta T = m\left(C_{p,sugar}\Delta T + L + C_{p,sugar}\Delta T\right) \quad \text{(A3)}$$

Given m_{water}= 3 kg, $\Delta T_{water,exp}$ = 98-70 = 28 °C, $C_{p,water}$ = 4.2 kJ/kg and $T_{sugar,exp}$ = 98 °C

- Glucose + Fructose;

$$mC_{p,water}\Delta T = m\left(C_{p,sugar}\Delta T + L + C_{p,sugar}\Delta T\right)$$
$$3 \times 4.2 \times 30 = m(1.1467(93.2 - 30) + 162.55 + 1.1467(98 - 93.2))$$
$$m = 1.47 \quad kg$$
$$\therefore m_{glucose} = 0.3 \times 1.47 \approx 0.44 \ kg$$
$$m_{fructose} = 0.7 \times 1.47 \approx 1.03 \ kg$$

- Xylitol + Fructose;

$$mC_{p,water}\Delta T = m\left(C_{p,sugar}\Delta T + L + C_{p,sugar}\Delta T\right)$$
$$3 \times 4.2 \times 30 = m(1.21(76 - 30) + 202.55 + 1.21(98 - 76))$$
$$m = 1.24 \quad kg$$
$$\therefore m_{xylitol} = 0.5 \times 1.24 \approx 0.62 \ kg$$
$$m_{fructose} = 0.5 \times 1.24 \approx 0.62 \ kg$$

- Erythritol + Xylitol;

$$mC_{p,water}\Delta T = m\left(C_{p,sugar}\Delta T + L + C_{p,sugar}\Delta T\right)$$
$$3 \times 4.2 \times 30 = m(1.33(86 - 30) + 275.39 + 1.33(98 - 86))$$
$$m = 0.96 \quad kg$$
$$\therefore m_{erythritol} = 0.3 \times 0.96 \approx 0.3 \ kg$$
$$m_{xylitol} = 0.7 \times 0.96 \approx 0.66 \ kg$$

Appendix B
Experiment

Table B1 Data of temperature of water in solar collector on 26 April to 5 May, 2018

No.	1				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	45	284	0.3	33	59
8:30	49	354	0.3	33	58
9:00	52	375	0.3	33	55
9:30	58	426	0.3	33	55
10:00	63	479	0.3	33	54
10:30	68	501	0.3	33	53
11:00	69	522	0.3	33	51
11:30	72	545	0.3	33	50
12:00	76	598	0.3	34	42
12:30	78	604	0.4	34	45
13:00	82	574	0.4	34	43
13:30	88	514	0.4	33	42
14:00	93	498	0.4	33	46
14:30	94	455	0.4	33	49
15:00	95	413	0.4	32	48
15:30	95	324	0.4	32	51
16:00	95	321	0.4	32	55
16:30	93	309	0.4	32	56
17:00	93	278	0.5	32	68

No.	2				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	55	395	0.3	33	57
8:30	65	411	0.3	33	55
9:00	71	478	0.3	33	51
9:30	77	503	0.3	33	49
10:00	79	527	0.3	33	49
10:30	80	578	0.3	33	47
11:00	81	591	0.3	33	47
11:30	83	619	0.3	33	45
12:00	84	595	0.3	33	45
12:30	86	554	0.3	34	42
13:00	88	501	0.3	34	43
13:30	90	495	0.3	34	43
14:00	91	456	0.3	33	45
14:30	94	421	0.4	33	46
15:00	95	417	0.4	33	47
15:30	96	350	0.4	33	48
16:00	97	313	0.4	33	51
16:30	96	309	0.4	32	52
17:00	95	295	0.5	32	55

No.	3				
Time	T (°C)	I (w/m²)	V_{air} (m/s²)	Tair (°C)	%RH
8:00	32	149	0.4	30	56
8:30	33	172	0.3	30	56
9:00	36	196	0.3	32	56
9:30	38	278	0.2	32	55
10:00	39	243	0.1	32	55
10:30	41	296	0.5	32	55
11:00	42	211	0.8	32	55
11:30	46	315	1.2	33	55
12:00	50	376	0.7	33	55
12:30	53	407	0.2	33	53
13:00	57	305	0.3	33	53
13:30	59	298	0.1	33	54
14:00	61	333	0.6	32	54
14:30	64	345	0.5	32	54
15:00	68	313	0.2	31	54
15:30	71	276	0.4	31	56
16:00	71	244	0.3	31	55
16:30	69	203	0.1	31	55
17:00	68	154	0.1	31	55

No.	4				
Time	T (°C)	I (w/m²)	V_{air} (m/s²)	Tair (°C)	%RH
8:00	49	172	0.1	33	58
8:30	51	215	0.5	33	57
9:00	54	272	0.2	33	57
9:30	57	301	0.2	34	54
10:00	59	318	0.6	34	49
10:30	62	321	0.1	34	48
11:00	64	345	0.2	34	48
11:30	65	397	0.3	35	48
12:00	67	419	0.3	35	47
12:30	70	456	0.4	35	49
13:00	72	461	0.2	35	50
13:30	77	417	0.1	35	50
14:00	78	395	0.6	35	51
14:30	80	385	0.4	35	53
15:00	82	341	0.3	35	54
15:30	84	275	0.1	35	56
16:00	84	220	0.2	35	49
16:30	82	174	0.2	34	49
17:00	81	115	0.1	34	49

No.	5				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	35	156	0.4	31	53
8:30	36	178	0.4	31	54
9:00	39	188	0.3	32	55
9:30	40	165	0.2	32	49
10:00	42	175	0.3	33	51
10:30	45	190	0.3	33	58
11:00	50	196	0.6	33	50
11:30	56	201	0.6	33	46
12:00	59	215	0.7	34	49
12:30	63	227	0.6	33	45
13:00	66	214	1.1	33	42
13:30	67	371	0.2	35	47
14:00	73	488	0.9	34	56
14:30	74	464	0.7	34	58
15:00	77	182	0.4	33	59
15:30	76	240	0.5	32	63
16:00	76	118	0.4	31	68
16:30	75	122	0.1	31	69
17:00	73	107	0.3	30	70

No.	6				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	39	161	0.1	32	55
8:30	42	167	0.5	33	52
9:00	47	211	0.4	33	50
9:30	52	235	0.1	34	49
10:00	59	248	0.2	34	48
10:30	61	261	0.3	34	45
11:00	65	278	0.3	34	41
11:30	68	245	0.3	35	40
12:00	69	222	0.1	35	42
12:30	71	315	0.2	35	43
13:00	74	349	0.1	36	44
13:30	75	348	0.5	36	44
14:00	77	379	0.4	36	45
14:30	78	413	0.4	36	45
15:00	78	445	0.1	36	46
15:30	79	412	0.2	38	48
16:00	80	405	0.1	40	50
16:30	80	364	0.5	35	55
17:00	79	281	0.3	33	68

No.	7				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	31	153	0.5	30	79
8:30	32	165	0.4	31	77
9:00	33	159	0.1	31	74
9:30	35	178	0.3	31	73
10:00	38	196	0.1	32	71
10:30	40	203	0.2	31	70
11:00	41	229	0.5	32	68
11:30	43	248	0.2	31	62
12:00	47	272	0.4	32	59
12:30	51	292	0.3	32	57
13:00	55	310	0.1	33	52
13:30	57	325	0.1	32	51
14:00	61	379	0.2	33	55
14:30	65	440	0.1	33	58
15:00	66	375	0.3	33	56
15:30	66	215	0.1	32	59
16:00	65	208	0.5	31	61
16:30	63	154	0.4	32	65
17:00	61	127	0.6	31	69

No.	8				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	40	218	0.5	32	81
8:30	43	239	0.2	33	78
9:00	46	275	0.4	33	76
9:30	47	291	0.1	34	74
10:00	50	315	0.1	33	71
10:30	53	324	0.2	34	70
11:00	61	322	0.3	34	68
11:30	67	346	0.6	35	67
12:00	75	371	0.4	35	59
12:30	78	398	0.1	36	51
13:00	80	425	0.2	37	45
13:30	80	485	0.2	38	38
14:00	81	361	0.3	36	45
14:30	81	175	0.9	35	49
15:00	80	125	0.1	33	57
15:30	76	240	0.5	32	63
16:00	76	118	0.4	31	68
16:30	75	122	0.1	31	69
17:00	73	107	0.3	30	70

No.	9				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	39	195	0.1	33	80
8:30	42	213	0.3	33	79
9:00	43	224	0.3	34	77
9:30	48	256	0.4	34	76
10:00	50	267	0.3	35	75
10:30	56	215	0.3	34	74
11:00	57	298	0.2	34	71
11:30	65	315	0.2	34	69
12:00	66	311	0.1	34	67
12:30	69	353	0.1	34	62
13:00	72	348	0.3	35	59
13:30	76	386	0.1	35	56
14:00	79	412	0.2	34	55
14:30	80	385	0.3	35	51
15:00	81	391	0.1	35	50
15:30	81	372	0.4	35	49
16:00	79	286	0.3	34	53
16:30	78	247	0.5	33	54
17:00	75	154	0.4	32	59

No.	10				
Time	T (°C)	I (w/m^2)	V_{air} (m/s^2)	Tair (°C)	%RH
8:00	37	246	0.1	32	78
8:30	42	258	0.1	33	72
9:00	46	259	0.3	33	71
9:30	49	279	0.2	33	69
10:00	53	316	0.4	33	67
10:30	59	327	0.2	34	65
11:00	65	369	0.3	34	63
11:30	69	315	0.2	35	60
12:00	75	364	0.1	34	59
12:30	78	401	0.5	35	57
13:00	79	423	0.4	35	54
13:30	80	433	0.1	36	51
14:00	82	425	0.2	35	49
14:30	83	459	0.3	34	53
15:00	84	495	0.2	33	58
15:30	84	415	0.1	33	66
16:00	83	359	0.2	33	68
16:30	82	341	0.5	32	68
17:00	81	240	0.3	32	69

Table B2 Data of temperature of water (3 L)

Time (min)	Temperature of water in tank (°C)	
	Experiment 1	Experiment 2
0	96	96
1	95	95
2	92	94
3	90	91
4	89	90
5	88	90
6	88	89
7	87	88
8	86	87
9	85	86
10	85	85
11	84	84
12	83	83
13	82	82
14	82	81
15	81	80
16	80	80
17	80	79
18	79	78
19	79	78
20	78	78
21	78	77
22	77	77
23	77	76
24	76	75
25	75	74
30	72	71
35	71	71
40	69	68
45	68	67
50	66	65
55	64	63
60	62	61
90	55	54
120	50	50
150	41	40

Part 1 : PCMs storage heat from hot water (3 L)

Table B3 Data of temperature with phase change material (Glucose + Fructose)

Time (min)	Temperature (°C)	
	Water	PCMs
0	98	34
1	85.8	66.3
2	82.2	71.1
3	80.3	72.9
4	78.9	73.7
5	77.9	74
6	76.9	74.2
7	76.1	74.1
8	75.4	73.9
9	74.9	73.7
10	74.4	73.5
11	73.9	73.4
12	73.5	73.1
13	73	73
14	72.7	72.9
15	72.3	72.8
16	72	72.6
17	71.8	72.5
18	71.4	72.3
19	71.1	72.2
20	70.9	72
21	70.6	71.8
22	70.3	71.6
23	70.1	71.4
24	69.8	71.2
25	69.6	71.1
30	68.5	70
35	67.5	69
40	66.4	68
45	65.6	67.1
50	64.7	66.1
55	63.9	65.3
60	63.1	64.4
90	59	60.1
120	55.6	56.5
150	52.7	53.5

Table B4 Data of temperature with phase change material (Xylitol + Fructose)

Time (min)	Temperature (°C)	
	Water	PCMs
0	98.9	34.3
1	88.8	47
2	86.4	62.9
3	84.7	66.8
4	83.3	68.3
5	82.4	69.1
6	81.4	69.6
7	80.7	70.1
8	80.2	70.6
9	79.4	71
10	78.7	71.3
11	78.1	71.6
12	77.6	71.8
13	77.1	72
14	76.7	72.1
15	76.2	72.2
16	75.8	72.3
17	75.4	72.4
18	75	72.4
19	74.6	72.3
20	74.3	72.1
21	73.9	72.1
22	73.6	72
23	73.3	71.9
24	73	71.8
25	72.8	71.6
30	71.4	70.7
35	70.1	69.6
40	69.1	68.8
45	68.1	67.9
50	67.1	66.9
55	66.2	66
60	65.3	65.2
90	60.9	60.8
120	57.2	57.1
150	54.1	54.1

Table B5 Data of temperature with phase change material (Erythritol + Xylitol)

Time (min)	Temperature (°C)	
	Water	PCMs
0	98	30
1	86.2	74
2	84.2	77.4
3	82.7	79.8
4	81.7	78.6
5	80.7	78.1
6	80	77
7	79.3	76.5
8	78.8	76
9	78.1	75.3
10	77.7	74.6
11	77.1	73.9
12	76.6	73.5
13	76.2	73.1
14	75.8	72.6
15	75.4	72.2
16	75	71.7
17	74.7	71.5
18	74.3	71
19	73.9	70.8
20	73.7	70.5
21	73.2	70.2
22	72.9	69.9
23	72.6	69.6
24	72.3	69.2
25	72	69
30	70.6	67.6
35	69.3	66.5
40	68.2	65.4
45	67.1	64.4
50	66.1	63.4
55	65	62.5
60	64.2	61.7
90	59.3	57.1
120	55.6	53.6
150	52.3	50.5

Part 2: Heat cold water by using PCMs

Table B6 Data of water temperature with phase change material **(Glucose + Fructose)**

Time (min)	Temperature of water (°C)		
	1	2	3
0	30	33.2	30
1	34	34.8	34.2
2	38.7	36.6	37.2
3	38.9	37.6	37.5
4	39	38.2	38.1
5	39.4	38.8	38.8
6	39.7	39.2	39
7	39.9	39.5	39.2
8	40.2	39.7	39.1
9	40.4	40	39.2
10	40.6	40.1	39.3
11	40.6	40.3	39.5
12	40.7	40.3	39.5
13	40.7	40.4	39.5
14	40.7	40.5	39.6
15	40.8	40.6	39.6
16	41	40.7	39.6
17	41	40.7	39.6
18	41	40.7	39.7
19	41	40.7	39.7
20	41	40.7	39.7

Table B7 Data of PCMs temperature with phase change material **(Glucose + Fructose)**

Time (min)	Temperature of PCMs (°C)		
	1	2	3
0	94	93.1	95
1	65	71	68
2	45	61	52
3	42	55.1	51
4	41.5	51.7	49
5	41.2	49.4	47
6	41	47.7	45
7	40.9	46.4	45
8	40.8	45.2	44
9	40.8	44.3	42
10	40.7	43.5	40.5
11	40.7	43	40.3
12	40.7	42.3	40.2

13	40.5	42	40.2
14	40.5	41.6	40.1
15	40.5	41.3	40.1
16	40.5	41.1	40
17	40.4	40.9	39.9
18	40.4	40.7	39.8
19	40.4	40.7	39.8
20	40.3	40.6	39.7

Table B8 Data of water temperature with phase change material **(Erythritol + Xylitol)**

Time (min)	Temperature of water (°C)		
	1	2	3
0	31.1	32.8	31.2
1	33.2	35.3	33.8
2	33.6	36.6	34.6
3	33.9	37.6	35.5
4	34.4	38.4	36.2
5	34.9	39	36.8
6	35.3	39.6	37.4
7	35.8	40	38
8	36.3	40.3	38.3
9	36.7	40.6	38.8
10	37	40.9	39.2
11	37.3	41	39.4
12	37.6	41.2	39.7
13	37.9	41.4	39.9
14	38.1	41.6	40.1
15	38.3	41.7	40.2
16	38.5	41.7	40.4
17	38.7	41.9	40.5
18	38.8	42	40.6
19	39	42.1	40.6
20	39.1	42.1	40.8

Table B9 Data of PCMs temperature with phase change material **(Erythritol + Xylitol)**

Time (min)	Temperature of PCMs (°C)		
	1	2	3
0	90.4	93.7	91.8
1	58.4	44.8	43.8
2	53.2	45.4	40.7
3	50.3	45.1	41.6

4	48.3	44.3	42.2
5	46.6	43.9	42.4
6	45.5	43.6	42.4
7	44.7	43.2	42.6
8	44.1	42.9	42.5
9	43.7	42.7	42.5
10	43.3	42.5	42.2
11	43.1	42.3	42.1
12	43	42.1	42.1
13	42.8	42.1	42
14	42.8	42	42
15	42.9	41.9	41.8
16	43	41.8	41.9
17	43	41.7	41.8
18	42.9	41.7	41.8
19	43	41.7	41.4
20	42.9	41.6	41.1

Table B10 Data of water temperature with phase change material **(Xylitol + Fructose)**

Time (min)	Temperature of water (°C)		
	1	2	3
0	30.8	31.4	30.8
1	35.2	33.1	32.5
2	35.9	36.5	33.1
3	36.7	37.8	33.9
4	37.6	38.8	34.8
5	38.3	39.7	35.7
6	38.9	40.4	36.3
7	39.4	41	36.9
8	39.7	41.4	37.5
9	40.1	41.7	38
10	40.3	42	38.3
11	40.6	42.2	38.6
12	40.8	42.4	38.9
13	40.9	42.6	39.2
14	41	42.6	39.4
15	41.2	42.8	39.6
16	41.3	42.9	39.8
17	41.4	42.9	40
18	41.5	43	40.2
19	41.6	43.1	40.2
20	41.5	43	40.3

Table B11 Data of PCMs temperature with phase change material **(Xylitol + Fructose)**

Time (min)	Temperature of PCMs (°C)		
	1	2	3
0	95.3	93.3	97.7
1	82.2	56.6	59.9
2	77.9	51.7	49.1
3	71.5	47.6	45.3
4	66.3	45.6	43.8
5	62.1	44.5	43
6	58.9	43.8	42.5
7	56.3	43.5	42.2
8	54.2	43.1	42
9	52.5	42.9	41.8
10	51	42.7	41.8
11	49.8	42.7	41.6
12	48.8	42.6	41.6
13	47.9	42.5	41.6
14	47.1	42.4	41.6
15	46.5	42.4	41.6
16	45.9	42.4	41.6
17	45.5	42.4	41.6
18	45.1	42.4	41.6
19	44.7	42.4	41.5
20	44.4	42.4	41.5

Calculate heat energy of water

Part 1

G+F : $Q = mC_p\Delta T$

$Q = 3\times4.2\times(74.2\text{-}98)$

$Q = -299.88$ kJ

E+X : $Q = mC_p\Delta T$

$Q = 3\times4.2\times(79.8 - 98)$

$Q = -229.32$ kJ

X+F : $Q = mC_p\Delta T$

$Q = 3\times4.2\times(72.4\text{-}98.9)$

$Q = -333.9$ kJ

Part 2

G+F : $Q = mC\_p\ \Delta T$

$Q=3\times4.2\times(40.2\text{-}31.07)$

$Q = 115.04$ kJ

$Q = m(C_p\Delta T+L+C_p\Delta T)$

$115.04 = m(1.15(93\text{-}94.03)+162.55+1.15(40.2\text{-}93))$

$115.04 = 100.65m$

$m = 1.143$

melt fraction= $\left(\frac{1.143}{1.47}\right)\times100 = 77.75$ %

E+X : $Q = mC_p\Delta T$

$Q = 3\times4.2\times(41.87\text{-}31.7)$

$Q = 128.14$ kJ

$Q = m(C_p\Delta T+L+C_p\Delta T)$

$128.14 = m(1.33(86\text{-}92)+275.39+1.33(41.87\text{-}86))$

$128.14 = 208.72m$

$m = 0.61$

melt fraction= $\left(\frac{0.61}{0.96}\right)\times100 = 63.95$ %

X+F : $Q = mC_p\Delta T$

$Q = 3\times4.2\times(42.77\text{-}31.0)$

$Q = 148.3$ kJ

$Q = m(C_p\Delta T+L+C_p\Delta T)$

$148.3 = m(1.21(76\text{-}95.43)+202.55+1.21(42.77\text{-}76))$

$148.3 = 138.83m$

$m = 1.068$

melt fraction= $\left(\frac{1.068}{1.24}\right)\times100 = 86.15$ %

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