CHAPTER 1

INTRODUCTION

1.1. Background of Study

Currently, there is much effort in using renewable energy like solar energy, wind energy, biomass and geothermal heat as well as in using waste heat for the production of electricity. The Organic Rankine Cycle (ORC) is a promising process for conversion of low and medium temperature heat to electricity. Instead of using water, refrigerant is used as working fluid for this system.

The hot water from geothermal reservoir is used to heat a secondary fluid which will vaporize and used to turn the turbine. This hot water never comes in contact with the turbine. The geothermal water and working fluid are each confined in separate circulating systems and never come in contact with other. The reason is using this organic working fluid is because they can vaporize below the boiling point of water.

Unfortunately, the temperature from hot spring Sungai Klas is categories as low temperature which is about 95^0C. Here, the application of solar energy is used to increase the temperature. By using solar water heater, it is believe that the temperature can increase above the boiling point of water. The low temperature heat is converted into useful work which can itself be converted into electricity.

Furthermore, in low temperature system, large heat exchanger areas are required to extract some amount of energy. These factors impose limits on exploiting the low temperature geothermal resources and emphasize the necessity of optimum, cost effective design of ORC power cycle.

1.2. Problem Statement

Over the last century, the industrial development has grown too fast. The increasing multiplications of energy consuming have caused an important growth of the energy demand. Unfortunately, this demand like fossil fuel can causes many serious problems such as global warming and atmospheric pollution. In order to reduce this problem, new energy conversion technologies to produce electricity without generating environmental pollution are required. Furthermore, the supply of fossil fuel will decrease. Therefore, we should find alternative energy to replace this fuel.

There are many hot spring places in Malaysia and most of them are develop for recreation. Instead of using these places as a recreation, this thermal energy source also can be used for power generation. Hot spring areas mostly are geometrically located at isolated area. Related to this reason, it is suggested that this place can have its own generator to produce electricity.

1.3. Objective

The objectives of this project are to find the alternative energy that can be developed to produce electricity. Hot spring is one of the usable energy which can be utilized as power generator. This project is aim to produce electricity and be able to support garden lamp during night at Resident Sungai Klah. This place was selected as it is able to produce enough hot springs and the temperature is suitable for this project.

1.4. Scope of Study

In order to achieve this objective, a few tasks and research need to be carried out by collecting all technical details. This research was divided into three parts which are:

- Working fluid selection
- Study the performance of solar water heater and its efficiency
- Analysis of a solar water heater combine with the organic rankine cycle

CHAPTER 2

LITERATURE REVIEW

2.1. Case Study

2.1.1. Chena Hot Spring Resort, Fairbank, Alaska

Chena Hot Springs is the lowest temperature geothermal resource to be used for commercial power production in the world. The challenge for moderate temperature small scale geothermal development has been to bring the cost down to a level where it is economical to develop small geothermal fields. Because the geothermal water at Chena Hot Springs never reaches the boiling point of water, traditional steam driven turbine cannot be used. Instead a secondary fluid, R-134a, which has a lower boiling point than water passes through a heat exchanger with 165°F water from geothermal wells. Heat from the geothermal water causes the R-134a to flash to vapor which then drives the turbine. Because this is a closed loop system virtually nothing is emitted to the atmosphere. Moderate temperature is by far the most common geothermal resource and most geothermal power plants in the future will be binary cycle plants. [1]

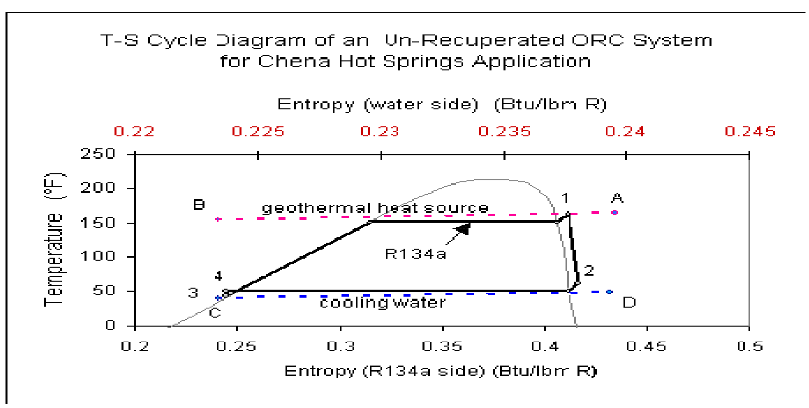


Figure1: Temperature – entropy diagram of the proposed Chena Hot Spring ORC unit

2.1.2. The Altheim Project, Upper Austria

Altheim is a municipality in the Upper Austrian "Inn region" with 5000 inhabitants and encloses an area of about 22 km^2. The decision to construct a geothermal heat supply, for environmental reasons, was made by the municipal council in January 1989. The district heating system is fed by 106^0 C geothermal fluids flowing from an aquifer about 2300 m deep. Since 1989, efforts were undertaken by the municipality to supply 10 MWe of thermal heat to a district heating network. In order to keep the water balance in the Malm aquifer, an injection drill hole was required. The new idea was to use the income from power production to finance the injection drill hole. A binary cycle or Organic Rankine Cycle (ORC) turbogenerator was proposed. [2] The Altheim project is challenging from the ORC point of view, both because of the low temperature of the heat source and the fact that the well head and the turbogenerator are placed within the town, near the town hall. Hence, very efficient silencing is required and the use of a flammable working fluid was excluded for safety reasons. As a working fluid, a harmless fluorocarbon was selected instead. A total power of 1000 kWe was generated during the test run, and it is presently operating at about 500 kWe. The ORC is cooled by the water from a nearby canal. After use, the geothermal water is pumped back at a temperature of 70^0C to the deep geothermal Malm-aquifer, allowing a sustained exploitation of the system. As a result, the balance of the water in the Malm reservoir is maintained.

Comparison of 1989 and Present State			
	1989	Present State	Reduction
CO_2	11,150,000 kg	3,094,000 kg	72%
NO_2	8,000 kg	2,600 kg	67%
SO_2	32,200 kg	11,200 kg	65%
CO	411,000 kg	173,000 kg	58%
Fossil Fuel Savings: 2,500 t/year			

Figure 2: Reduction of air pollution, greenhouse gas and saving of fossil fuel by using geothermal energy for heat supply

2.1.3. Combined Heat and Power Plant Neustadt – Glewe, Germany

Since 1995, the geothermal doublet in Neustadt- Glewe provides brine at 98^{0}C for a district heating system. The brine is produced from a 2100 to 2300 m (6890 to 7546 ft) deep sandstone aquifer. In the summer of 2003, the heating plant was extended by a binary-cycle (Organic Rankine Cycle, ORC) and in November of 2003, the first German geothermal power plant was connected to the grid, providing 210 kWe gross capacities.

The power plant is a simple Organic Rankine Cycle (ORC) using n-Perfluorpentane (C5F12) as working fluid. An additional pump was installed in the geothermal loop to control the mass flow rate fed to the power plant and to overcome the pressure losses of the brine in the heat exchanging equipment of the power plant. [3]

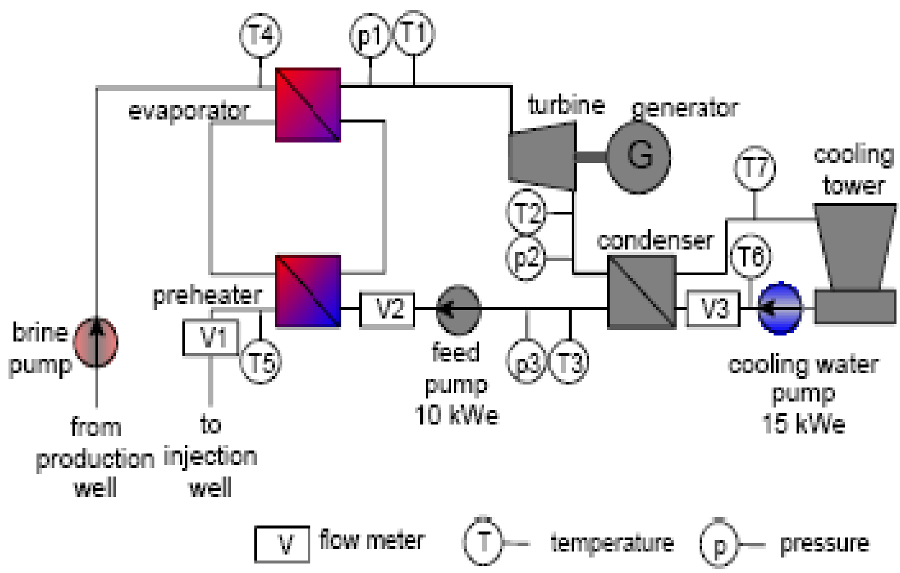


Figure 3: Schematic setup of Neustadt-Glewe power plant with positions of measuring equipment installed in the plant

2.2. Hot Spring

Table 1: Data from different location of hot spring [4]

Location	Temperature (^{0}C)	Discharge (l/sec)
Felda Sg Kelah, Sungkai	98	3.00
Ulu S. Periah, Sg Siput, Ipoh	51	0.08
Tambun Hot Spring, Ipoh	65	20

Most of the hot springs in Perak are manifest themselves as pools, or puddles of hot water. The pools are generally fed by two or more distinct streams or jets issuing from fractures and crevices in the bottom of the pool. Gas bubbles are observed ascending through the supernatant hot water.

The spring discharges are observed to range from less than 0.1 to 20 liters/sec. Higher flow rate is noted at Tambun which has an estimated flow of 20 liters/sec. In the meanwhile, spring at Sg Siput is about 0.08 liters/sec. Among these three locations, temperature of hot spring Sg Kelah is the higher with 98^{0}C.

Hot spring Sg Kelah is still undeveloped and close to an oil palm land scheme. Water comes out along joints and fractures in sandstone and this is one of the hottest encountered so far. The spring extends for about 50 meters along the stream bed.

2.3. Organic Rankine Cycle

Since the hot spring never reaches the boiling point of water, the steam turbine cannot be used. Besides, disadvantage of using the water-steam mixture is that superheated steam has to be used, otherwise the moisture content after expansion might be too high, which would erode the turbine blades. Instead of water, an organic fluid can be used.

Advantage of organic fluid is the fact that they do not need to be superheated, as with steam, as they do not forms liquid droplets upon expansion in the turbine. This prevents erosion of the turbine blades and provides design flexibility on the heat exchangers. Since superheating is not necessary, resulting in a higher efficiency of the cycle. This is called an Organic Rankine Cycle. [5] For this project, refrigerant (organic fluid) was selected as the working fluid. Further calculations have to be made to determine which refrigerant is suitable for this system.

Refrigerant, which has a lower boiling point than water passes through a heat exchanger that contain hot water from geothermal wells. Heat from hot water causes refrigerant to flash to vapor which then drive the turbine. This is a closed loop system thus; nothing is emitted to the atmosphere. [6]

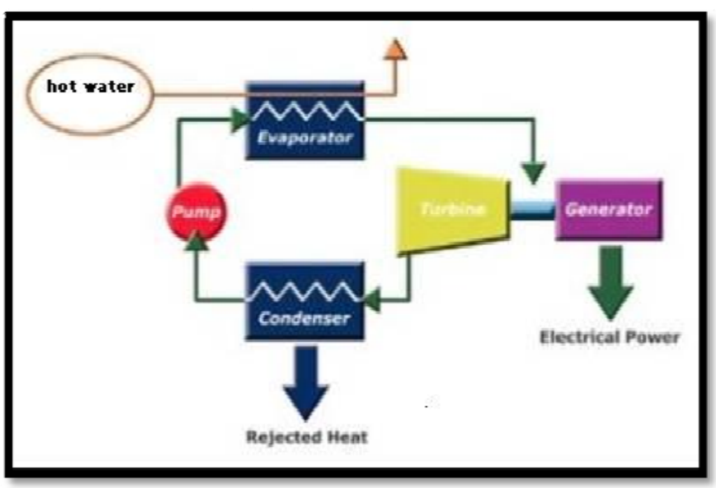


Figure 4: Close Loop Cycle for Organic Rankine Cycle

2.4. Working Principle

1) Hot water enters evaporator at certain temperature. After the hot water runs through the evaporator, it is returned to the geothermal reservoir via injection pump and injection well system.
2) The evaporator shell is filled with refrigerant. The hot water is not enough to boil water, but it is hot enough to boil the refrigerant which has lower boiling point. Hot water will transfer heat energy to the refrigerant and it begins to boil and vaporize.
3) Once there is adequate evaporation of the refrigerant, the vapor is routed to the turbine.
4) The vapor is expanded through the turbine nozzle, causing the turbine blades to turn at certain rpm. The turbine is connected to a generator and producing electricity.
5) Cooling water in condenser will re condenses the vapor refrigerant back to a liquid. Same as evaporator, the condenser only allows heat transfer to occur between the refrigerant (in tube shell) and the cold water (in the tube within condenser). The two liquids never actually come in contact.
6) The pump pushed the liquid refrigerant back over to the evaporator, so the cycle can start again.

2.5. Working Fluid

The selection of the working fluid is of key importance in low temperature Rankine Cycles. Because of the low temperature, heat transfer inefficiencies are highly prejudicial to the efficiency. These inefficiencies depend very strongly on the thermodynamic characteristics of the fluid and on the operating conditions.

Optimal characteristics of the working fluid:

- Isentropic saturation vapor curve.

  Since the purpose of the ORC focuses on the recovery of low grade heat power, a superheated approach like the traditional Rankine cycle is not appropriate. Therefore, a small superheating at the exhaust of the evaporator will always be preferred, which has consequences on the optimal thermodynamic properties of the fluid.

- Low freezing point, high stability temperature

  Unlike water, organic fluids usually suffer chemical deteriorations and decomposition at high temperatures. The maximum hot source temperature is thus limited by the chemical stability of the working fluid. The freezing point has to be lower than the lowest temperature in the cycle.

- High heat of vaporisation and density

  A fluid with a high latent heat and density will absorb more energy from the source in the evaporator and thus reduce the required flow rate, the size of the facility, and the pump consumption.

- Low environmental impact

  The main parameters are the Ozone depleting potential (ODP) and greenhouse warming potential (GWP).

- Safety

  The fluid has to be noncorrosive, nonflammable, and nontoxic. Depending on the location of the facility, this parameter can be of very high importance (e.g. an ammonia cycle will not be installed in a dwelling without any precaution). The ASHRAE safety classification of the refrigerant is a good indicator of the dangerousness level of the fluid.

- Good availability and low cost

  Traditional refrigerants used in ORC are expensive. This cost could be reduced by a more massive production of those refrigerants, or by the use of low cost hydrocarbons.

- Acceptable pressures

  Very high pressures have a negative impact on the reliability of the cycle. They lead to the need of more resistant and more expensive facilities.

2.6. Solar water heater

Because of the low temperature of hot spring, solar water heater is added to increase the temperature of this geothermal water. Solar water heating is water heated by the use of solar energy. Solar heating systems are generally composed of solar thermal collectors, a water storage tank or another point of usage, interconnecting pipes and a fluid system to move the heat from the collector to the tank. This thermodynamic approach is distinct from semiconductor photovoltaic (PV) cells that generate electricity from light. Solar water heating deals with the direct heating of liquids by the sun where no electricity is directly generated. A solar water heating system may use electricity for pumping the fluid, and have a reservoir or tank for heat storage. [7]

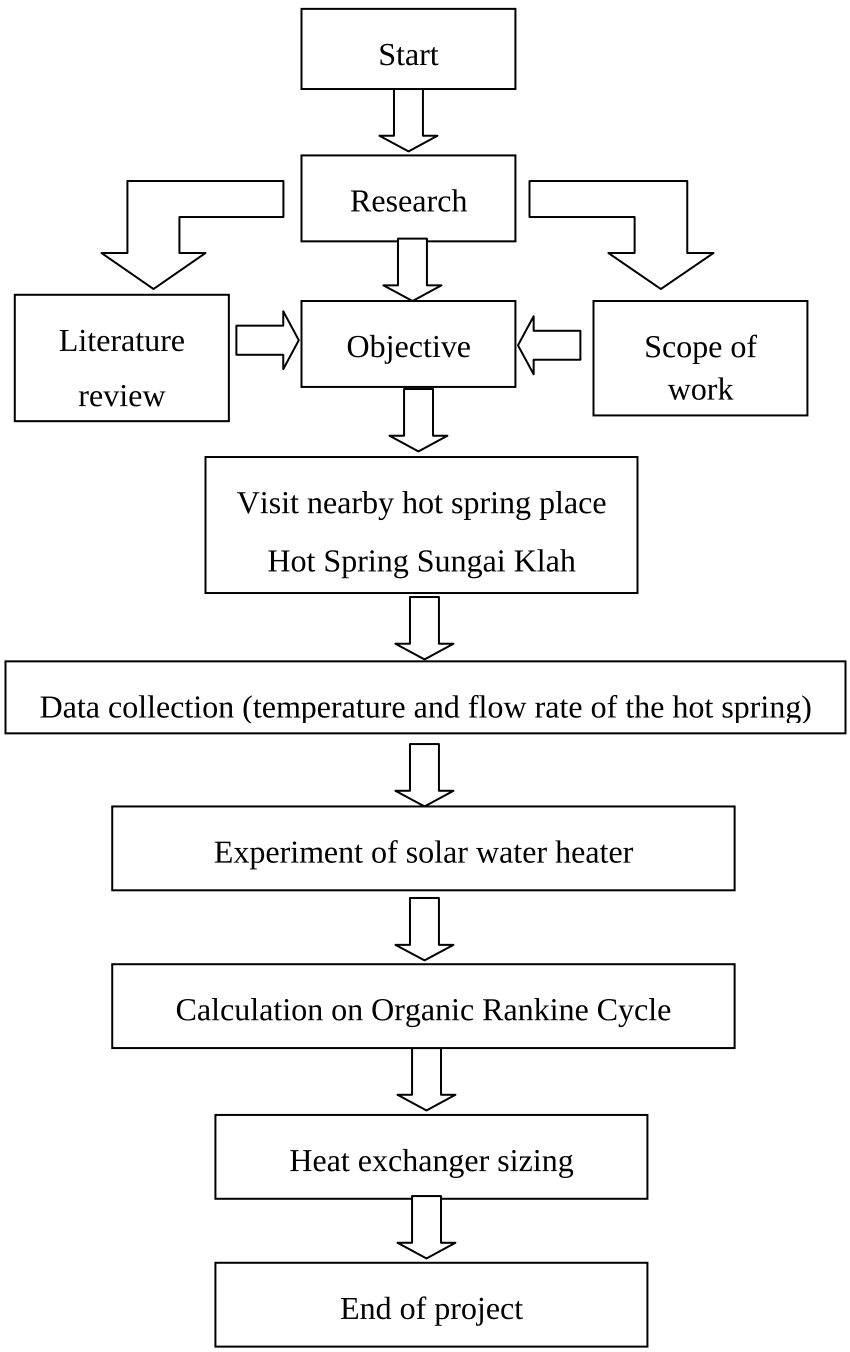
Figure 5: Tube collector solar water heater

CHAPTER 3

METHODOLOGY

3.1. Project Flow

In completing this project, some tasks and methodology have been allocated. The project flow is shown as below.



3.2. Project Activities

3.2.1. Research of the project

Research was done from internet and article which is related to geothermal energy. After done some research, system for generate power have been selected as a title for this project. This system is basically using heat from hot spring to generate electricity that can be used in that particular area. In this case, Perkampungan Sungai Klah was selected as research area. The author also needs to study about this system which already exists in other country.

3.2.2. Power Consumption

In order to estimate how much electrical power need for street lamp, calculation on electrical consumption have to carry out.

Table 2: Power consumption for street lamp [8]

Street lamp type	Traditional 400W Mercury-vapor Lamp
Brand	(Philips)
Voltage	AC 220V
Power consumption per year (365 days)	2312.64 KWH
Life span for continuous lighting for 12 hours/day	6,000 hours (Approx. 1.5 years)

3.2.3. Make a Visit

Visit to one of the hot spring place is required in order to collect all necessary data. The author was chosen Sungai Kelah as the location for this project. The author met Mr Haridas, which is the representative from Felda Residence Hot Spring Sungai Klah and he showed the location of hot spring with high temperature.

Figure 6: Measuring the temperature of hot spring source

Figure 7: Steam waste from hot spring

3.2.4. Collection of Data

All data have to collect before start designing the system. Data from hot spring such as the temperature of hot spring, location, and properties have to be taken. For working fluid, in this case refrigerant is to be selected. All the properties such as boiling point, entropy at certain temperature and the behavior of the fluid have to be considered. Selection of refrigerant will be discussed in result and discussion part.

Some assumptions have to make in order to carry out the calculation.

Table 3: Specifications of the Organic Rankine cycle considered [9]

Hot spring inlet temperature	106 ^{0}C
Hot spring outlet temperature	70 ^{0}C
Hot spring flow rate	3 l/s
Working fluid flow rate	15 kg/s
Cooling water flow rate	340 kg/s
Cooling water inlet temperature	15 ^{0}C
Cooling water outlet temperature	25 ^{0}C

3.2.5. Designing the System

Designing the system shows the sketch on the system and also how the system work. Calculation can be made by using all the collected data and by using appropriate formula. All the calculation includes the temperature and pressure inlet and outlet in all equipments (evaporator, turbine, and condenser) will be carried out. Then, power of turbine can be determined. The function of equipment and the system operated also being explained.

CHAPTER 4

RESULT AND DISCUSSION

4.1. System Layout

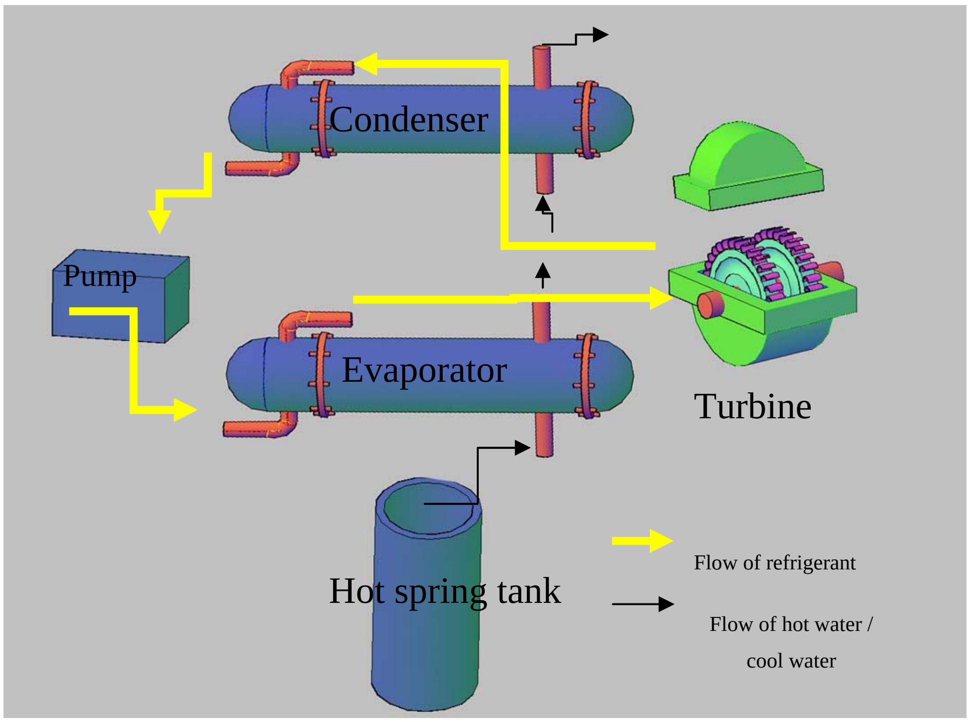


Figure 8: Overall layout for this system

This system consists of four major equipment which are heat exchanger (evaporator and condenser), turbine and pump. Hot spring water is collected in a tank and it is pumped to evaporator. Here, heat transfer occur and make R123 evaporate and enter the turbine. Increasing in pressure and velocity of this refrigerant makes turbine to rotate and give power output. However, the temperature of hot spring is 95 ^{0}C which is very low and the temperature difference is very small. Because of that, there are problem regarding heat exchanger sizing.

As a solution, solar panel is added to increase the temperature of hot spring. The panels collect energy from the rays of the sun. This energy is stored in the heat transfer fluid, which brings the heat from the collection point to the hot spring. Depending on the climate, solar water heaters can provide as much as 85% of the energy necessary for hot water.

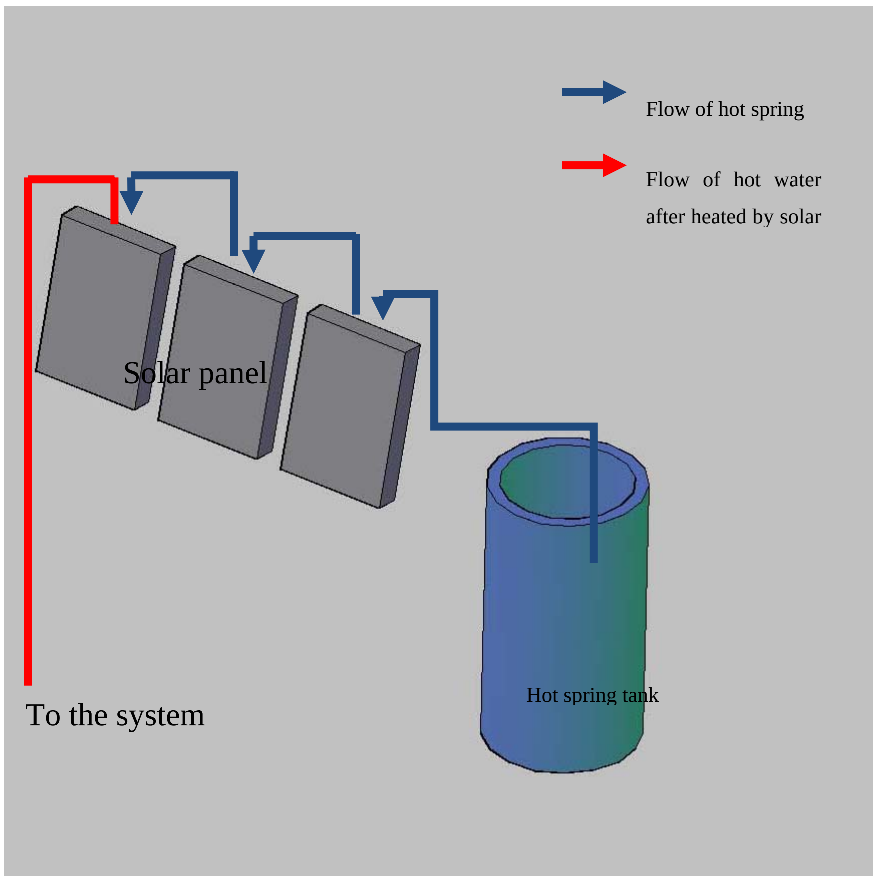


Figure 9: Layout of hot spring tank with solar panel

4.2. Experimental Set-up for Solar Water Heater

4.2.1. Objective

To determine the efficiencies of a solar collector at different water flow rate

4.2.2. Theory of water heater

The efficiency (η) of a collector is defined as the ratio between the power absorbed by the thermal carrier ($\boldsymbol{P_u}$) and that absorbed by the collector exposed to radiating energy ($\boldsymbol{P_i}$); this is expressed by the formula:

$$\eta = \boldsymbol{P_u / P_i}$$

$\boldsymbol{P_u}$ [W] can be calculated using the formula:

$$P_u = \frac{Q(t_{fu} - t_{fi}) r_o c}{3600[\sec/hr]}$$

Where;

Q = water flow rate as indicated by the flow meter [*liters/hour*]

t_{fu} = temperature of the same fluid at the output of the collector indicated on the appropriate thermometer [C^o]

t_{fi} = fluid temperature in the input [C^o]

r_o = mass, assumed constant, of the thermal carrier; as a first approximation for water we can consider $r_o = 1$ [*kg/liter*]

C = specific heat, assumed constant; as a first approximation for water we can consider c = 4 180 [*J/kg°C*].

Using these approximations the formula becomes:

$$P_u = 1{,}161\ Q\,(t_{fu} - t_{fi})$$

P_i[W] can be calculated using the formula:

$$P_i = P_s \cdot A$$

Where;

P_s = specific flow of radiating energy and can be measured using a solarimeter [W/m^2]

A = area of the collector and either the useful area (the actual collecting area) or the otal area (surface area of the panel); obviously the results change according to the values used, so it is advisable to indicated which one had been chosen [m^2].

4.2.3. Test Procedure

1. Valve 4 is closed and valve 7 and 8 is opened.
2. Flow meter is adjusted by using valve 10.
3. Switch is turned on then water inside the tube will flow through the solar heater.
4. Let the equipment running for about 15 minutes.
5. After 15 minutes, temperature inlet and outlet is taken.
6. Irradiation from sun is measured using solarimeter.
7. Flow rate of water is taken from the flow meter.
8. All data is recorded in a table.
9. Procedure 4 to 7 is repeated for every 15 minutes.

4.2.4. Equipment Detail

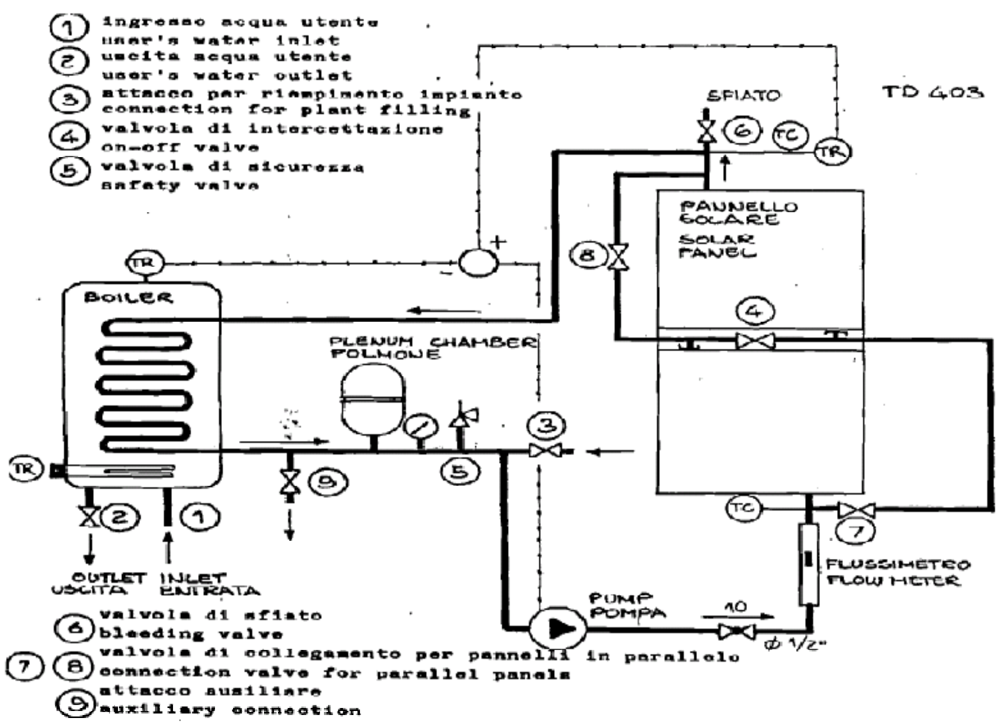


Figure 10: Drawing of solar water heater

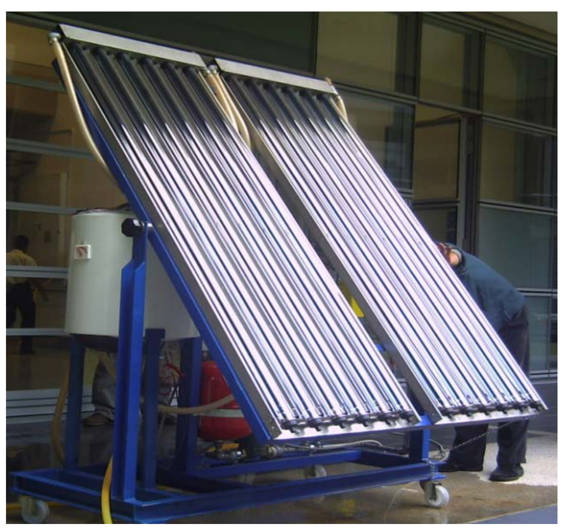


Figure 11: Solar water heater circulation unit assembly

4.2.5. Result and Calculation

Table 4: Data collection from the experiment

Time	Q (l/h)	I (W/m^2)	T input (^{0}C)	T output (^{0}C)	Pu (W)	Pi (W)	n (%)
1000	94	615	38	44	654.804	2460	0.26618
1015	94	628	45	55	1091.34	2512	0.434451
1030	92	623	51	65	1495.368	2492	0.600067
1045	92	625	60	68	854.496	2500	0.341798
1100	90	633	62	69	731.43	2532	0.288874
1115	89	620	63	70	723.303	2480	0.291654
1130	88	601	64	68	408.672	2404	0.169997
1145	88	584	62	68	613.008	2336	0.262418
1200	88	553	62	66	408.672	2212	0.184752
1215	88	560	61	65	408.672	2240	0.182443
1230	88	557	60	65	510.84	2228	0.229282

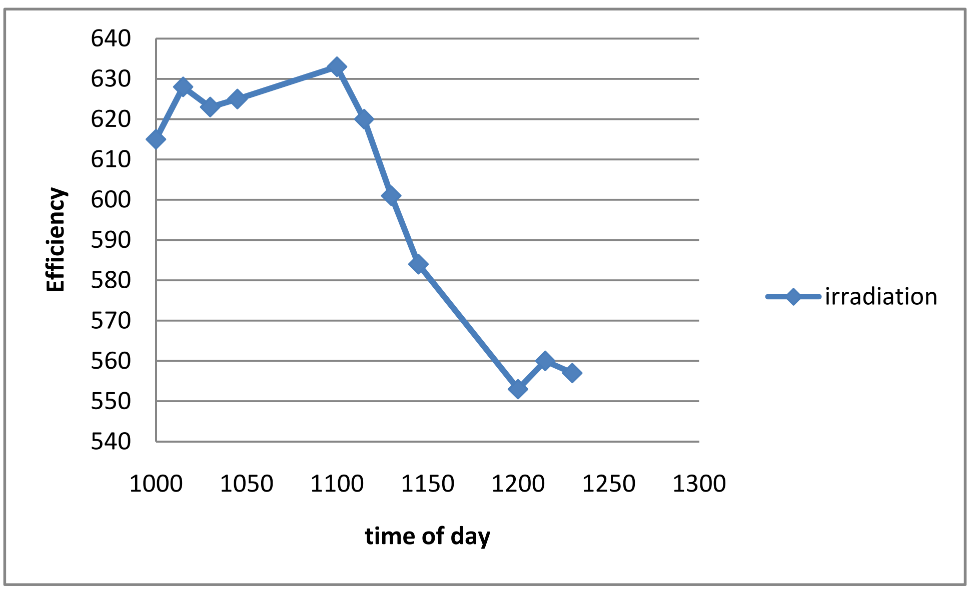


Figure 12: Graph shows the irradiation versus time

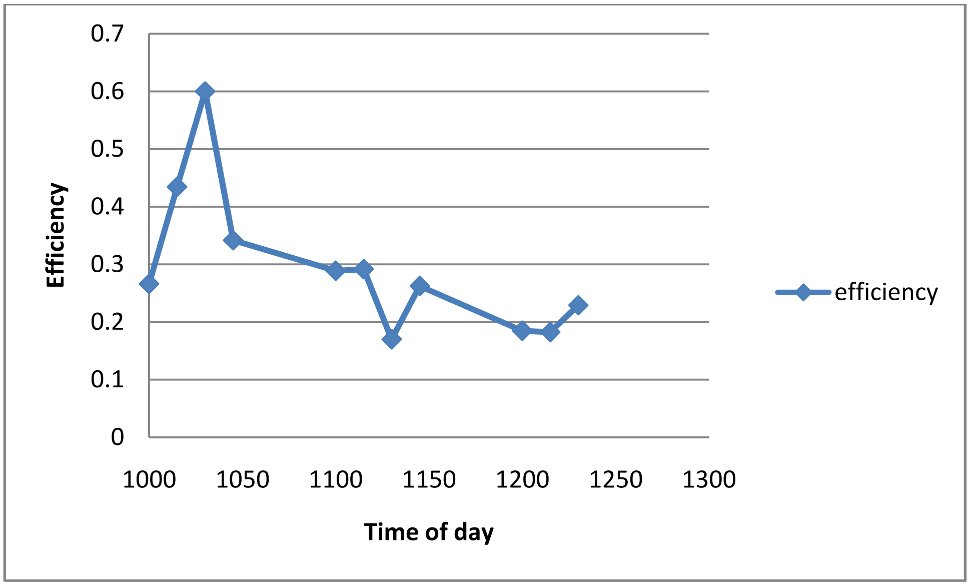


Figure 13: Graph show the efficiency of solar water heater versus time

$$\eta = \frac{\sum_1^n \eta_n}{n}$$

$$= 0.3\%$$

Irradiation is high around 10am to 11am. It is because the solar panel is facing east which is at the sun rise direction. Due to this reason, the efficiency is also high around 10 am. The efficiency of this solar water heater is about 0.3% which is slightly low. To make it more accurate, it is suggested to make the experiment in difference places with least amount of shading effect. Unfortunately, this tube glasses are very fragile and difficult to move.

By using solar water heater, the temperature of hot spring can be increase. The combination of solar water heater with the Organic Rankine Cycle using currently available solar thermal collectors is potentially attractive for remote areas without or with very high cost access to the public electricity grid in concurrence with other renewable energy technologies.

4.3. Working Fluid Selection

A quick review of the literature about low temperature Rankine cycles gives an idea of the usual working fluids used in ORC systems. Table 6 and 7 give the main characteristics of those fluids, from an environmental and thermodynamic point of view.

Table 5: Environmental data for historical, current, and candidate chiller refrigerants [10]

Refrigerant	Atmospheric Lifetime	ASHRAE Level of Safety	ODP	Net GPW 100 Year (2102)	Phase Out Year
R11	45	A1	1	3660	1996
R22	12.0	A1	0.034	1710	2020
R113	85	A1	0.90	5330	1996
R123	1.3	B1	0.012	53	2030
R134a	14.0	A1	~0	1320	
R245fa	7.6	B1	~0	1020	
R717 (ammonia)		B2	~0	< 1	
R601 (*n*pentane)			~0	~20	
R601a (isopentane)			~0	~20	

Table 6: Thermodynamic properties of a few working fluids [10]

Working fluid	Slope of saturation vapor line	Critical point	Vaporization heat at 1 atm. [Kj/kg]	Boiling temperature at 1 atm.	Safety
Water	Wet	374°C – 220 bar	2258	100°C	Nonflammable
R11	Isentropic	198°C – 44.1 bar	180.4	23.5°C	Nonflammable
R22	Wet	96.1°C – 49.9 bar	232.7	41.1°C	Nonflammable
R113	Dry	214°C – 34.4 bar	143.9	47.8°C	Nonflammable
R123	Isentropic	184°C – 36.7 bar	171.5	27.7°C	Nonflammable
R134a	Wet	101°C – 40.6 bar	217.2	26.4°C	Nonflammable
R245fa	Isentropic	154°C – 36.4 bar	197.5	14.6°C	Nonflammable
R601 (*n*pentane)	Dry	196°C – 33.6 bar	358.7	35.5°C	Flammable
R601a (isopentane)	Dry	187°C – 33.7 bar	342.8	27.5°C	Flammable
C6H6 (benzene)	Dry	289°C – 49 bar	395.4	79.8°C	Flammable
C7H8 (Toluene)	Dry	319°C – 41 bar	362.5	110.4°C	Flammable
C8H10 (pxylene)	Dry	343°C – 35 bar	339.9	66.65°C	Flammable

A first selection can be achieved among those fluids given the working temperature range. The application envisaged in the present work have a heat source temperature ranging from 100 to 200 °C and an heat sink temperature ranging from 10 to 50 °C. It is obvious that R22 and R134a can be eliminated, their temperature range being too low (see table 7). In the same manner, water, benzene, toluene and pxylene have a too high temperature range and can be eliminated as well.

From an environmental point of view, R11 and R113 have a very high ozone depleting potential (ODP), and were phased out in 1996 by the Montreal protocol. Therefore, they won't be taken into account in this work.

The working fluids remaining from this first selection are R123, R245fa, n-pentane and isopentane. Each of them has its advantages and disadvantages. R123 and R245fa are nonflammable and isentropic, while n-pentane and isopentane have a higher vaporization heat, a lower GWP, and a much lower cost. R123 also has the no null ODP and will be forbidden in 2030.

4.4. Calculation in each equipment

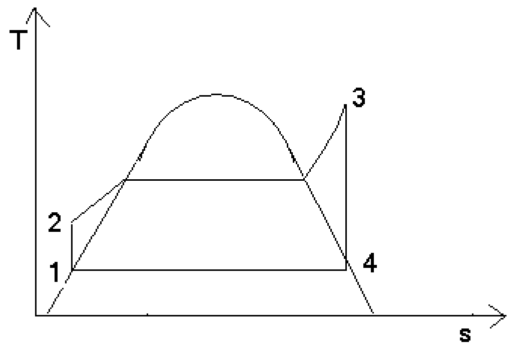


Figure 14: Temperature - entropy diagram for rankine cycle

1-2: compression in pump

2-3: heat addition in evaporator

3-4: expansion in turbine

4-1: heat rejection in condenser

Pump

From appendix 1,

V= $0.16451\ \frac{m^3}{kg}$

$p_1 = 94.8\ kpa$

$p_2 = 624.23\ kpa$

$h_1 = 226.16\frac{kJ}{kg}$

From appendix 2, h_2 is isentropic at P_2 = 624.23 kpa

$h_2 = 240\frac{kJ}{kg}$

$W_p = (h_2 - h_1)$

$= (240 - 226.16)$

$= 13.84 \frac{kJ}{kg}$

Evaporator

From appendix 2, h_3 is at superheated.

$h_3 = 439 \frac{kJ}{kg}$

$Q_H = h_3 - h_2$

$= 439 - 240$

$= 199 \frac{kJ}{kg}$

Turbine

From appendix 2,

$S_3 = S_4$

$x_4 = \frac{s_4 - s_f}{s_g - s_f}$

$= \frac{1.53 - 1.0913}{1.6628 - 1.0913}$

$= 0.76$

$h_4 = h_f + x_4(h_{gf})$

$= 226.26 + 0.76(397.12 - 226.16)$

$= 357.49 \frac{kJ}{kg}$

$w_t = h_3 - h_4$

$= 439 - 357.49$

$= 81.5 \frac{kJ}{kg}$

Condenser

$Q_L = h_4 - h_1$

$= 357.49 - 226.16$

$= 131.33 \frac{kJ}{kg}$

$W_{net} = W_t - W_p$

$= 81.5 - 13.84$

$= 67.66 \frac{kJ}{kg}$

Power produce $= m\ (W_{net})$

$= 15 \frac{kg}{s}\ (67.66 \frac{kj}{kg})$

$= \mathbf{1014.9\ W}$

4.5. Preliminary design for shell and tube heat exchanger

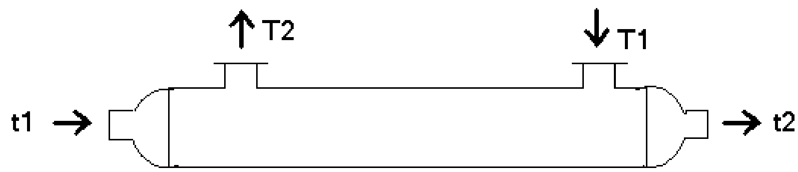


Figure 15: Temperature identification for countercurrent single phase flow in a shell and tube exchanger.

T1 = 40 ^{0}C

T2 = 90 ^{0}C

t1 = 106 ^{0}C

t2 = 70 ^{0}C

1) **Calculation of MTD**

$$LMTD = \frac{(t1 - T2) - (t2 - T1)}{\ln \frac{t1 - T1}{t2 - T1}}$$

$$= \frac{(106 - 90) - (70 - 40)}{ln \frac{106 - 90}{70 - 40}}$$

$$= 22.27$$

$$R = \frac{T1 - T2}{t2 - t1}$$

$$= \frac{106 - 70}{90 - 40}$$

$$= 0.72$$

$$P = \frac{t2 - t1}{T1 - t1}$$

$$= \frac{90 - 40}{106 - 40}$$

$$= 0.75$$

From appendix 3(two shells in series), with R=0.72 and P=0.75,

F = 0.84

$$MTD = 0.84 \times 22.27$$

$$\mathbf{= 18.71}$$

2) **Estimation of U, overall heat transfer estimation**

From appendix 4,

Water at tube and medium organic liquid at shell; estimate U to be **55 Btu/hr ft^2 F**

3) **Calculate the heat load,Q**

Hot water Flow rate = 81.7 kg/s

= 648423.6 lb/hr

106 C = 222.8 F

70 C = 158 F

$$Q = \left(648423.6 \frac{lb}{hr}\right)\left(\frac{0.241Btu}{lbF}\right)(222.8 - 158)F$$

$$\boldsymbol{= 10{,}126{,}301.68 \frac{Btu}{hr}}$$

4) **Total area, A_0**

$$A_0 = \frac{Q}{U(MTD)}$$

$$= \frac{10126301.68}{55(18.71)}$$

$$\boldsymbol{= 9840.43\ ft^2}$$

5) **Effective area, A_0'**

$A_0' = A_0 F_1 F_2 F_3 F_4$

Finding proper factors to put into equation.

F_1= 1.14. From appendix 5, assuming that a ¾ in outside diameter by 1 in triangular pitch.

F_2= 1.18. From appendix 6, assuming that the shell diameter will be in range of 13 ¼ in to 17 ¼ in and four tube passes will suffice.

F_3= 1.08. From appendix 7, U tube design and shell diameter in range of 13 ¼ in to 21 ¼ in.

F_4= 1.00. From appendix 8 The tubes are to be type S/T Trufin ¾ in. outside diameter with 19 fins/in.

$A_0' = 9840.43\ ft^2 \times 1.14 \times 1.18 \times 1.08 \times 1.00$

$= \mathbf{14296.33 ft^2}$

From appendix 9, it is find that this area can be accommodates by **17 ¼ in inside diameter shell, 12 ft tube length.**

The tubes are to be type S/T Trufin ¾ in outside diameter, 19 fins/in. A tube layout on a 1 in triangular pitch is specified.

CHAPTER 5

CONCLUSION

The methodologies are being done in order to achieve the main objective. This project starts with the selection of the appropriate system which is Organic Rankine Cycle. This system is being used in other countries but in Malaysia, we still study on it. Malaysia also has potential to build this geothermal power plan as we also have our own hot spring. The author has selected Hot Spring Sungai Klah as the research location.

This project basically can reduce the using of fossil fuel in order to produce energy. Greenhouse gas also will be decreased and can lead to improve our environment. Selection of the right refrigerant is very importance as we are very concern with our environment. Refrigerant must have low ozone depleting potential and low greenhouse warming potential. Based on the selection criteria, R 123 has been selected as working fluid. From the ASHRAE handbook 2001, R 123 or dichlorotrifluoreoethane is categorized under ethane series. The boiling point at 101.325 kPa is about 27.87^{0}C and freezing point is about -107.15^{0}C.

This project just focuses on thermodynamic part which was explained in this report and heat transfer part which is very importance in heat exchanger sizing. Based on calculation on Organic Rankine Cycle, 1014.9 W can be produced. All the figures are founded on properties table and p-h diagram for R 123.

For the heat exchanger, the author has to decide which stream goes into the tube and which into the shell. For this project, hot spring water has been selected to put in the tube because this fluid is highly corrosive and have severe fouling. It is easier to clean the tube side than the shell side by mechanical method. From the primary design calculation, the heat exchanger that is suitable for this project is the one with 17 ¼ in inside diameter shell, 12 ft tube length. The tubes are to be type S/T Trufin ¾ in outside diameter, 19 fins/in.

RECOMMENDATION

The requirements of this system have to study in detail to get the right specification for every equipment. This can help to increase the power produce by the system. To get the accurate parameters, it is suggested to make a modeling and simulation by using suitable software. Process simulator like Aspen Plus can generate inputs from other programmes in order to model the system.

Cost estimation is very importance as we want to evaluate whether this project capable or not to be develop. From the cost analysis, payback period and investment cost can be determined. Because of time constrain, the author just can focus more on thermodynamic analysis and heat transfer which is importance in order to achieve the objective.

CHAPTER 6

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APPENDICES

Appendix A: Gantt chart for FYP 2

No	Detail work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project work - Designing the system														
2	Submission of progress report 1														
3	Project work - Continues														
4	Submission of progress report 2														
5	Seminar														
6	Project work continues														
7	Poster Exhibition														
8	Submission of Dissertation Final Draft														
9	Oral presentation														
10	Submission of Dissertation (Hard														

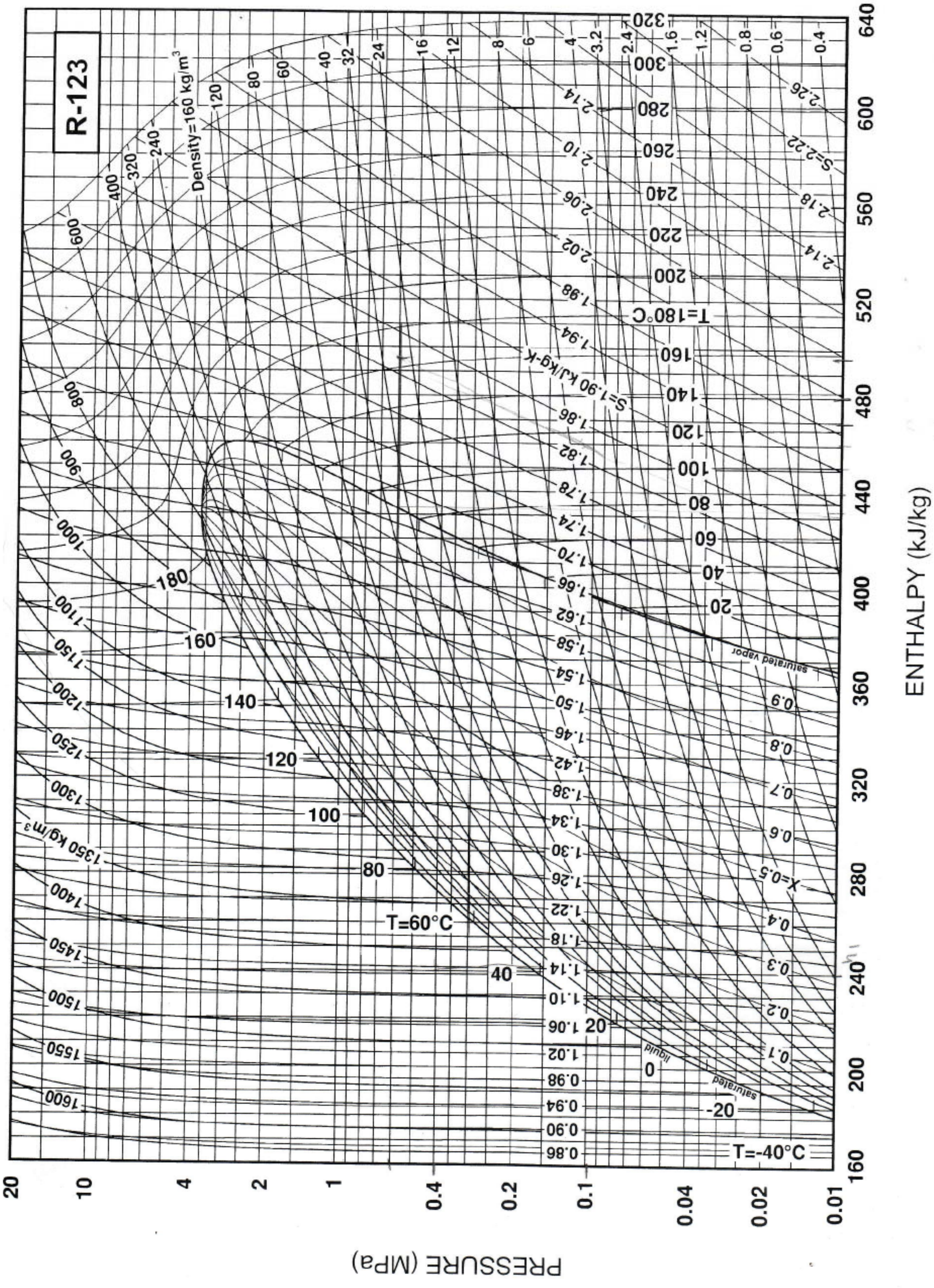
Appendix B: Thermodynamic properties of R123

Refrigerant 123 (2,2-Dichloro-1,1,1-trifluoroethane) Properties of Saturated Liquid and Saturated Vapor

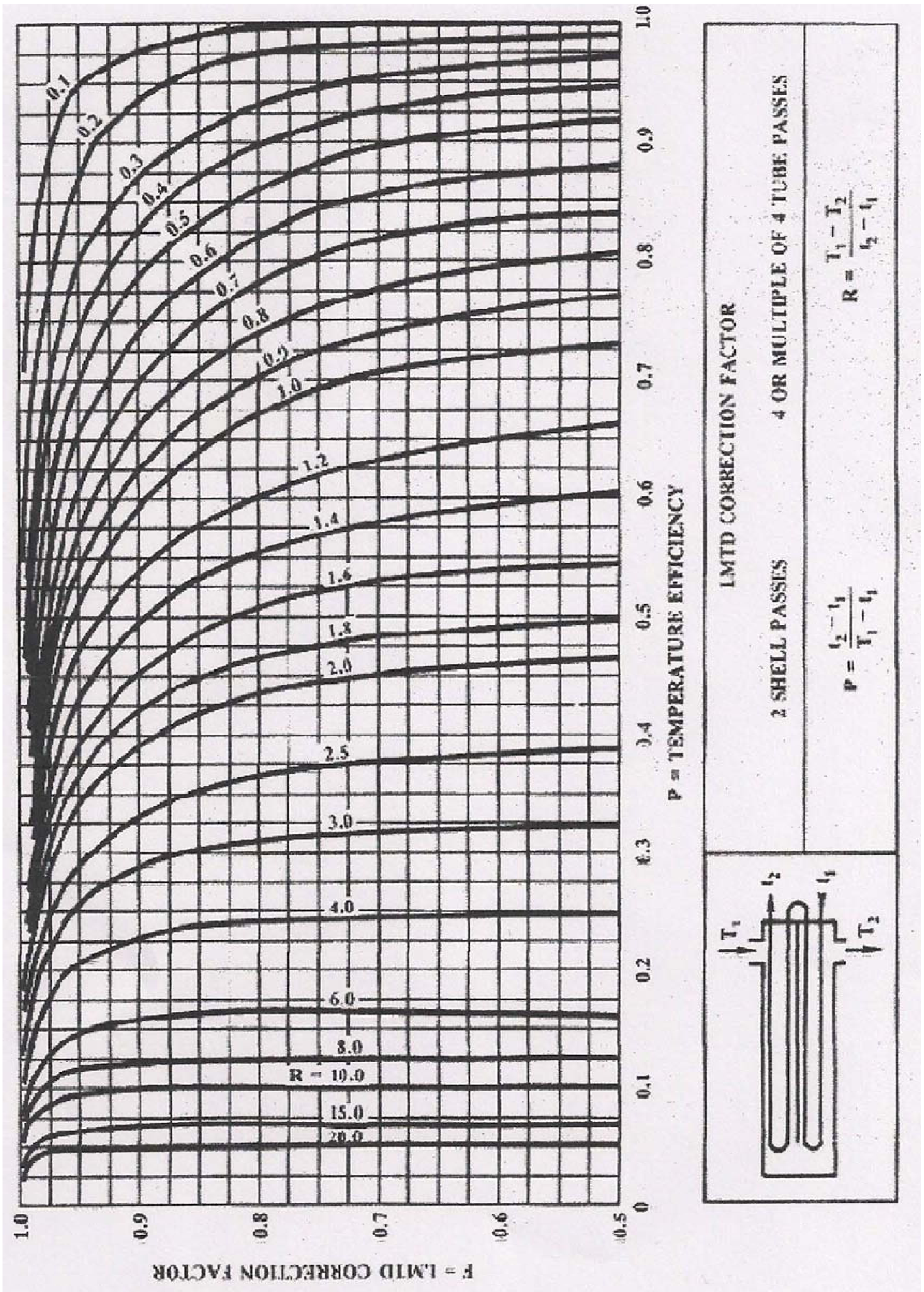
Temp.,* °C	Pressure, MPa	Density, kg/m³	Volume, m³/kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c_p, kJ/(kg·K)		c_p/c_v	Velocity of Sound, m/s		Viscosity, μPa·s		Thermal Cond., mW/(m·K)		Surface Tension, mN/m	Temp., °C
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
−80.00	0.00013	1709.6	83.667	123.92	335.98	0.6712	1.7691	0.924	0.520	1.117	1133.	108.3	2093.	6.68	107.4	3.22	28.42	−80.00
−70.00	0.00034	1687.4	32.812	133.17	341.25	0.7179	1.7422	0.927	0.537	1.113	1091.	110.8	1680.	7.09	104.8	3.79	27.09	−70.00
−60.00	0.00081	1665.1	14.333	142.46	346.66	0.7625	1.7206	0.932	0.553	1.110	1049.	113.3	1383.	7.50	102.0	4.35	25.78	−60.00
−50.00	0.00177	1642.6	6.8460	151.81	352.21	0.8054	1.7034	0.939	0.569	1.107	1006.	115.6	1160.	7.92	99.1	4.92	24.48	−50.00
−40.00	0.00358	1620.0	3.5319	161.25	357.88	0.8468	1.6901	0.948	0.585	1.105	964.	117.9	986.4	8.31	96.1	5.49	23.19	−40.00
−30.00	0.00675	1597.0	1.9470	170.78	363.65	0.8868	1.6800	0.958	0.601	1.103	923.	120.0	848.0	8.70	93.0	6.05	21.92	−30.00
−20.00	0.01200	1573.8	1.1364	180.41	369.52	0.9256	1.6726	0.968	0.617	1.102	881.	122.0	735.4	9.09	89.8	6.61	20.66	−20.00
−10.00	0.02025	1550.1	0.69690	190.15	375.45	0.9633	1.6675	0.979	0.634	1.102	841.	123.8	642.4	9.47	86.7	7.18	19.41	−10.00
0.00	0.03265	1526.1	0.44609	200.00	381.44	1.0000	1.6642	0.990	0.651	1.102	801.	125.4	564.6	9.84	83.7	7.74	18.18	0.00
2.00	0.03574	1521.3	0.40991	201.98	382.64	1.0072	1.6638	0.993	0.654	1.103	793.	125.7	550.6	9.92	83.1	7.86	17.94	2.00
4.00	0.03907	1516.4	0.37720	203.97	383.84	1.0144	1.6634	0.995	0.658	1.103	785.	126.0	537.0	9.99	82.5	7.97	17.70	4.00
6.00	0.04264	1511.5	0.34759	205.97	385.05	1.0216	1.6631	0.997	0.661	1.103	777.	126.3	523.8	10.06	81.9	8.08	17.45	6.00
8.00	0.04647	1506.6	0.32075	207.96	386.25	1.0287	1.6628	0.999	0.665	1.103	769.	126.6	511.1	10.13	81.3	8.20	17.21	8.00
10.00	0.05057	1501.6	0.29637	209.97	387.46	1.0358	1.6626	1.002	0.668	1.104	761.	126.8	498.8	10.20	80.7	8.31	16.97	10.00
12.00	0.05495	1496.7	0.27420	211.97	388.66	1.0428	1.6625	1.004	0.672	1.104	754.	127.1	486.8	10.28	80.1	8.43	16.73	12.00
14.00	0.05963	1491.7	0.25401	213.99	389.87	1.0499	1.6624	1.006	0.675	1.104	746.	127.3	475.3	10.35	79.5	8.54	16.49	14.00
16.00	0.06463	1486.7	0.23559	216.00	391.08	1.0569	1.6623	1.009	0.679	1.105	738.	127.6	464.0	10.42	79.0	8.66	16.25	16.00
18.00	0.06995	1481.7	0.21877	218.02	392.29	1.0638	1.6623	1.011	0.682	1.105	730.	127.8	453.2	10.49	78.4	8.77	16.01	18.00
20.00	0.07561	1476.6	0.20338	220.05	393.49	1.0707	1.6624	1.014	0.686	1.106	723.	128.0	442.6	10.56	77.8	8.89	15.77	20.00
22.00	0.08163	1471.5	0.18929	222.08	394.70	1.0776	1.6625	1.016	0.690	1.106	715.	128.2	432.4	10.63	77.3	9.01	15.53	22.00
24.00	0.08802	1466.4	0.17637	224.12	395.91	1.0845	1.6626	1.018	0.693	1.107	707.	128.4	422.4	10.70	76.7	9.12	15.30	24.00
26.00	0.09480	1461.3	0.16451	226.16	397.12	1.0913	1.6628	1.021	0.697	1.107	700.	128.6	412.8	10.77	76.1	9.24	15.06	26.00
27.82b	0.10133	1456.6	0.15453	228.03	398.22	1.0975	1.6630	1.023	0.701	1.108	693.	128.7	404.2	10.84	75.6	9.35	14.84	27.82
28.00	0.10198	1456.2	0.15360	228.21	398.32	1.0981	1.6630	1.023	0.701	1.108	692.	128.7	403.4	10.84	75.6	9.36	14.82	28.00
30.00	0.10958	1451.0	0.14356	230.26	399.53	1.1049	1.6633	1.026	0.705	1.109	684.	128.9	394.3	10.91	75.0	9.48	14.59	30.00
32.00	0.11762	1445.8	0.13431	232.31	400.73	1.1116	1.6635	1.028	0.709	1.109	677.	129.0	385.4	10.98	74.5	9.60	14.35	32.00
34.00	0.12611	1440.6	0.12577	234.38	401.93	1.1183	1.6639	1.031	0.712	1.110	669.	129.1	376.8	11.05	74.0	9.72	14.12	34.00
36.00	0.13507	1435.4	0.11789	236.44	403.14	1.1250	1.6642	1.033	0.716	1.111	662.	129.3	368.4	11.12	73.4	9.84	13.89	36.00
38.00	0.14452	1430.1	0.11060	238.51	404.34	1.1317	1.6646	1.036	0.720	1.112	654.	129.4	360.3	11.19	72.9	9.96	13.66	38.00
40.00	0.15447	1424.8	0.10385	240.59	405.54	1.1383	1.6651	1.038	0.724	1.113	647.	129.5	352.4	11.26	72.4	10.08	13.43	40.00
42.00	0.16495	1419.4	0.09759	242.67	406.73	1.1449	1.6655	1.041	0.728	1.114	639.	129.5	344.7	11.33	71.8	10.20	13.20	42.00
44.00	0.17597	1414.1	0.09179	244.76	407.93	1.1515	1.6660	1.044	0.732	1.115	632.	129.6	337.2	11.40	71.3	10.32	12.97	44.00
46.00	0.18755	1408.7	0.08641	246.86	409.12	1.1581	1.6665	1.046	0.736	1.116	624.	129.7	329.9	11.46	70.8	10.45	12.74	46.00
48.00	0.19971	1403.3	0.08140	248.95	410.31	1.1646	1.6670	1.049	0.741	1.117	617.	129.7	322.8	11.53	70.3	10.57	12.51	48.00
50.00	0.21246	1397.8	0.07674	251.06	411.50	1.1711	1.6676	1.052	0.745	1.119	610.	129.7	315.9	11.60	69.8	10.70	12.28	50.00
52.00	0.22584	1392.3	0.07240	253.17	412.69	1.1776	1.6682	1.055	0.749	1.120	602.	129.7	309.1	11.67	69.3	10.82	12.05	52.00
54.00	0.23985	1386.8	0.06836	255.28	413.87	1.1840	1.6688	1.058	0.753	1.121	595.	129.7	302.6	11.74	68.8	10.95	11.83	54.00
56.00	0.25451	1381.2	0.06458	257.41	415.05	1.1905	1.6694	1.060	0.758	1.123	588.	129.7	296.2	11.80	68.3	11.08	11.60	56.00
58.00	0.26985	1375.6	0.06106	259.53	416.23	1.1969	1.6701	1.063	0.762	1.124	580.	129.7	289.9	11.87	67.8	11.21	11.38	58.00
60.00	0.28589	1370.0	0.05777	261.67	417.40	1.2033	1.6707	1.066	0.767	1.126	573.	129.6	283.9	11.94	67.3	11.34	11.16	60.00
62.00	0.30264	1364.3	0.05469	263.81	418.57	1.2096	1.6714	1.069	0.771	1.127	566.	129.6	277.9	12.01	66.8	11.47	10.93	62.00
64.00	0.32013	1358.6	0.05180	265.95	419.73	1.2160	1.6721	1.072	0.776	1.129	558.	129.5	272.1	12.07	66.3	11.61	10.71	64.00
66.00	0.33838	1352.8	0.04910	268.10	420.89	1.2223	1.6728	1.076	0.781	1.131	551.	129.4	266.5	12.14	65.9	11.74	10.49	66.00
68.00	0.35740	1347.0	0.04656	270.26	422.05	1.2286	1.6735	1.079	0.785	1.133	544.	129.3	261.0	12.21	65.4	11.88	10.27	68.00
70.00	0.37722	1341.2	0.04418	272.42	423.20	1.2349	1.6743	1.082	0.790	1.135	536.	129.2	255.6	12.28	64.9	12.01	10.05	70.00
72.00	0.39787	1335.3	0.04195	274.60	424.35	1.2411	1.6750	1.085	0.795	1.137	529.	129.0	250.4	12.35	64.5	12.15	9.84	72.00
74.00	0.41936	1329.3	0.03985	276.77	425.50	1.2474	1.6758	1.089	0.800	1.139	522.	128.9	245.2	12.42	64.0	12.29	9.62	74.00
76.00	0.44171	1323.4	0.03787	278.96	426.63	1.2536	1.6766	1.092	0.806	1.142	515.	128.7	240.2	12.49	63.5	12.44	9.40	76.00
78.00	0.46494	1317.3	0.03601	281.15	427.77	1.2598	1.6774	1.096	0.811	1.144	507.	128.5	235.3	12.55	63.1	12.58	9.19	78.00
80.00	0.48909	1311.2	0.03426	283.35	428.89	1.2660	1.6781	1.100	0.816	1.147	500.	128.3	230.5	12.63	62.6	12.73	8.97	80.00
82.00	0.51416	1305.1	0.03261	285.55	430.01	1.2722	1.6789	1.103	0.822	1.150	493.	128.1	225.9	12.70	62.2	12.87	8.76	82.00
84.00	0.54019	1298.9	0.03105	287.77	431.13	1.2783	1.6797	1.107	0.827	1.152	486.	127.8	221.3	12.77	61.7	13.02	8.55	84.00
86.00	0.56720	1292.6	0.02958	289.99	432.23	1.2845	1.6806	1.111	0.833	1.156	478.	127.6	216.8	12.84	61.3	13.17	8.34	86.00
88.00	0.59520	1286.3	0.02819	292.22	433.33	1.2906	1.6814	1.115	0.839	1.159	471.	127.3	212.5	12.91	60.8	13.33	8.13	88.00
90.00	0.62423	1279.9	0.02687	294.45	434.43	1.2967	1.6822	1.120	0.845	1.162	464.	127.0	208.2	12.98	60.4	13.48	7.92	90.00
92.00	0.65430	1273.5	0.02563	296.70	435.51	1.3028	1.6830	1.124	0.851	1.166	457.	126.6	204.0	13.06	59.9	13.64	7.71	92.00
94.00	0.68544	1266.9	0.02445	298.95	436.59	1.3089	1.6838	1.129	0.858	1.169	449.	126.3	199.9	13.14	59.5	13.80	7.50	94.00
96.00	0.71768	1260.3	0.02334	301.21	437.66	1.3150	1.6846	1.133	0.864	1.173	442.	125.9	195.9	13.21	59.1	13.96	7.30	96.00
98.00	0.75103	1253.7	0.02228	303.49	438.72	1.3211	1.6854	1.138	0.871	1.177	435.	125.5	191.9	13.29	58.6	14.13	7.09	98.00
100.00	0.78553	1246.9	0.02128	305.77	439.77	1.3271	1.6862	1.143	0.878	1.182	427.	125.1	188.1	13.37	58.2	14.29	6.89	100.00
110.00	0.97603	1211.9	0.01697	317.32	444.88	1.3572	1.6902	1.172	0.917	1.208	391.	122.8	169.9	13.80	56.0	15.17	5.88	110.00
120.00	1.1990	1174.4	0.01361	329.15	449.67	1.3872	1.6938	1.207	0.964	1.243	354.	119.8	153.4	14.29	53.9	16.14	4.91	120.00
130.00	1.4578	1133.6	0.01094	341.32	454.07	1.4173	1.6969	1.254	1.026	1.294	317.	116.0	138.1	14.89	51.7	17.22	3.98	130.00
140.00	1.7563	1088.3	0.00879	353.92	457.94	1.4475	1.6992	1.318	1.111	1.369	279.	111.5	123.8	15.65	49.5	18.44	3.09	140.00
150.00	2.0987	1036.8	0.00703	367.10	461.05	1.4782	1.7003	1.415	1.240	1.493	239.	106.0	110.2	16.68	47.2	19.87	2.24	150.00
160.00	2.4901	975.7	0.00555	381.13	463.01	1.5101	1.6991	1.584	1.473	1.726	198.	99.3	96.8	18.19	44.8	21.63	1.45	160.00
170.00	2.9372	896.9	0.00425	396.61	462.89	1.5443	1.6939	1.979	2.033	2.309	154.	91.1	82.7	20.71	42.3	24.05	0.74	170.00
180.00	3.4506	765.9	0.00292	416.22	456.82	1.5867	1.6763	4.549	5.661	6.158	102.	80.6	64.3	26.59	39.7	28.82	0.15	180.00
183.68c	3.6618	550.0	0.00182	437.39	437.39	1.6325	1.6325	∞	∞	∞	0.	0.0	—	—	∞	∞	0.00	183.68

*Temperatures are on the ITS-90 scale b = normal boiling point c = critical point

Appendix C: Pressure-enthalpy diagram for R123



Appendix D: LMTD correction for two shells in series and four or multiple of four tube passes in series



Appendix E: Typical overall design coefficients for trufin tubed heat exchanger

TUBE-SIDE FLUID	SHELL-SIDE FLUID	TOTAL FOULING RESISTANCE IN hr ft^2°F/Btu	U_o Btu/hr ft^2°F
Water	Gas, about 10 psig	0.002	15-20
Water	Gas, about 100 psig	0.002	25-35
Water	Gas, about 1000 psig	0.002	50-75
Water	Light organic liquids	0.0025	70-120
Water	Medium organic liquids	0.003	50-80
Water	Heavy organic liquids	0.0035	30-65
Water	Very heavy organic liquids (cooling)	0.005	5-30
Condensing Steam	Gas, about 10 psig	0.0005	15-20
Condensing Steam	Gas, about 100 psig	0.0005	25-40
Condensing Steam	Gas, about 1000 psig	0.0005	60-85
Condensing Steam	Light organic liquids	0.001	100-150
Condensing Steam	Medium organic liquids	0.0015	75-130
Condensing Steam	Heavy organic liquids	0.002	50-85
Condensing Steam	Very heavy organic liquids	0.0035	10-40
Light organic liquids	Light organic liquids	0.0017	60-90
Light organic liquids	Medium organic liquids	0.0022	40-70
Light organic liquids	Heavy organic liquids	0.0027	25-55
Light organic liquids	Very heavy organic liquids	0.0042	5-25
Medium organic liquids	Heavy organic liquids	0.0037	20-40
Medium organic liquids	Very heavy organic liquids	0.0055	5-25

Appendix F: F_1 for various unit cells

Tube Outside Diameter, In.	Tube Pitch, In.	Layout	F_1
5/8	13/16	→ ◁	0.90
5/8	13/16	→ ◇, □	1.04
3/4	15/16	→ ◁	1.00
3/4	15/16	→ ◇, □	1.16
3/4	1	→ ◁	1.14
3/4	1	→ ◇, □	1.31
1	1 1/4	→ ◁	1.34
1	1 1/4	→ ◇, □	1.54

Appendix G: F_2 for various number of tube-side passes

INSIDE SHELL DIAMETER, IN.	F_2 NUMBER OF TUBE-SIDE PASSES			
	2	4	6	8
Up to 12**	1.20	1.40	1.80	--
13 ¼ to 17 ¼**	1.06	1.18	1.25	1.50
19 ¼ to 23 ¼	1.04	1.14	1.19	1.35
25 to 33	1.03	1.12	1.16	1.20
35 to 45	1.02	1.08	1.12	1.16
48 to 60	1.02	1.05	1.08	1.12
Above 60	1.01	1.03	1.04	1.06

Appendix H: F_3 for various tube bundle constructions

TYPE OF TUBE BUNDLE CONSTRUCTION	F_3 INSIDE SHELL DIAMETER IN.				
	UP TO 12	13 ¼ - 21 ¼	23 ¼ - 35	37 - 48	ABOVE 48
Split Backing Ring (TEMA S)	1.30	1.15	1.09	1.06	1.04
Outside Packed Floating Head (TEMA P)	1.30	1.15	1.09	1.06	1.04
U – Tube* (TEMS U)	1.12	1.08	1.03	1.01	1.01
Pull-Through Floating Head (TEMA T)	—	1.40	1.25	1.18	1.15

Appendix I: F_4 for various tube area enhancements

TUBE DESCRIPTION	F_4	TUBE DESCRIPTION	F_4
Plain (unfinned) tube, any outside diameter*	2.56	S/T Trufin, 26 fins/in.:	
		5/8 in. O.D.	0.76
		3/4 in. O.D.	0.79
		1 in. O.D.	0.75
S/T Trufin, 11 fins/in.:		S/T Trufin, 28 fins/in.:	
3/4 in. O.D.	0.87	3/4 in. O.D.	0.97
7/8 in. O.D.	0.83	7/8 in. O.D.	0.96
1 in. O.D.	0.81	1 in. O.D.	0.96
S/T Trufin, 16 fins/in.:		S/T Trufin, 32 fins/in.:	
1/2 in. O.D.	1.29	5/8 in. O.D.	1.01
5/8 in. O.D.	1.23	3/4 in. O.D.	1.00
3/4 in. O.D.	1.20	7/8 in. O.D.	0.99
7/8 in. O.D.	1.17	1 in. O.D.	0.99
1 in. O.D.	1.16		
S/T Trufin, 19 fins/in.:		S/T Trufin, 40 fins/in.:	
3/8 in. O.D.	1.12	3/4 in. O.D.	0.78
1/2 in. O.D.	1.05	3/4 in. O.D.	0.54
5/8 in. O.D.	1.02		
3/4 in. O.D.	1.00		
7/8 in. O.D.	0.99		
1 in. O.D.	0.97		

Appendix J: Area as a function of shell inside diameter and effective tube length for ¾ in OD. S/T Trufin 19 in. Fins/in on 15/16. Equilateral triangular tube layout fixed tube sheet. One tubeside pass, fully tubed shell.