U7

THERMODYNAMIC ANALYSIS OF A THREE-FLUID ABSORPTION REFRIGERATION MACHINE

By

Andrew Zulu

Submitted to the University of Cape Town in partial fulfilment of the requirements for the degree of Master of Science in Engineering

September 2000

ACKNOWLEDGEMENTS

I express with sincerity my deep gratitude to my supervisor Dr G. Vicatos for his incredible practical and technical assistance throughout each stage of the project. He tirelessly offered a lot of useful suggestions, encouragement and guidance, which have shaped a large part of this work.

I also thank my sponsors in the Netherlands for their financial support and more specifically Project Co-ordinators Dr L.Robben and Ms. L.Van Kollenburg for their availability throughout the period.

I also wish to thank Mechanical Engineering Workshop staff Mr L. Watkins and Mr H. Tomlinson for the their technical assistance with the modifications to the rig; Mr J. Mayer for his assistance with regard to the test instrumentation.

SYNOPSIS

The design of systems that operate on low-grade energy is receiving increased attention. This is motivated by global rapid energy consumption, its increasing cost and depletion of energy resources such as petroleum fuels [10]. Since its development in the middle of the twentieth century, there has been growing amount of research into optimising its energy utilisation.

This thesis investigates the three-fluid absorption refrigeration system operating on low-grade (heat) energy. In particular the temperature-time response of the various components of a domestic size absorption unit were investigated with respect to the pressure of hydrogen in the system under varying power input. Design modifications of the boiler, lift tube, vapour-liquid separator and heat exchanger were made while maintaining the same principle of operation.

Data collected in the form of temperatures, hydrogen pressure and power input revealed that the time-temperature response of the unit improved from six hours (according to manufacturer's recommendations) to just over one hour. This data was recorded for a range of hydrogen pressures between 7.5 bar and 27.5 bar and for power supplies of 261W, 315W and 370W.

Despite the much faster time response, the performance of the unit was poor. The refrigeration capacity was measured to be 11W at lowest evaporator temperature, which was obtained at 12.5 bar hydrogen pressure. With a generator power input of 370W the Coefficient of Performance (COP) was insignificant. Since the load on the evaporator could not be measured the COP and various component loads could not be determined.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLANTURE

SYMBOL	DESCRIPTION	UNITS
A_i	coefficients for equations for pure components	[-]
B_i	coefficients for equations for pure components	[-]
C_i	coefficients for equations for pure components	[-]
COP	coefficient of performance	[-]
C_p	specific heat capacity at constant pressure	kJ/kg.K
D_i	coefficients for equations for pure components	[-]
E_i	coefficients for Gibbs excess free energy	[-]
F	number of degrees of freedom	[-]
G	Gibbs free energy	kJ
g	Gibbs specific free energy	kJ/kg
H	Henry's law constant	kPa
h	specific enthalpy	kJ/kg
I	irreversibility factor	[-]
m	mass flow rate	g/s
n	ratio of condenser to absorber heat rate	[-]
P	pressure; number of phases	bar; [-]
Q	heat rate	W
R	molar gas constant	kJ/kmol.K
S	entropy	kJ
s	specific entropy	kJ/kg
T	absolute temperature	K
t	temperature	°C
v	specific volume	m^3/kg
W	work	W

x	liquid-phase concentration	[-]
y	gas-phase concentration	[-]

GREEK SYMBOL	DESCRIPTION	UNITS
α	relative volatility	[-]
Δ	change	[-]
$\mathcal{E}$	effectiveness	[-]
η	efficiency	[-]
μ	chemical potential	kJ

INDEX	DESCRIPTION
a	absorber; ammonia
b	boiler; reduction reference value
c	condenser
CF	cooling fluid
e	evaporator; excess energy (Gibbs) function
ehp	high pressure evaporator
elp	low pressure evaporator
g	gas phase; vapour; generator (boiler)
H	high(est)
hex	solution heat exchanger
l/L	liquid phase
m	mixture
o	reference state; ambient
pch	high pressure pre-cooler
pcl	low pressure pre-cooler
R	rectifier; refrigerated
r	reduced state
s	sink
w	water

CHAPTER 1

INTRODUCTION

1.1 HISTORICAL NOTE

The principle of refrigeration has been known since the ancient civilisations. The earliest recorded patent for a gas compression refrigeration machine was in Britain in 1790 by Thomas Harris and John Long.

While vapour compression refrigeration advanced by various inventions, to become commercialised by the turn of the century, the principle of absorption refrigeration was discovered by Michael Faraday in 1824 while working for the Royal Institute of London. He succeeded in condensing ammonia gas to a liquid, which until then was believed only to exist as a vapour (in fact classified by chemists as a "fixed" gas). Faraday's experiment pioneered absorption refrigeration of the intermittent type [1].

The first continuous type absorption machine was inverted by a French researcher, Ferdinand Carre' in 1859 [10]. This machine used sulphuric acid to absorb water[1] and a later machine used water to absorb ammonia (Carre'), Figure 1.1.

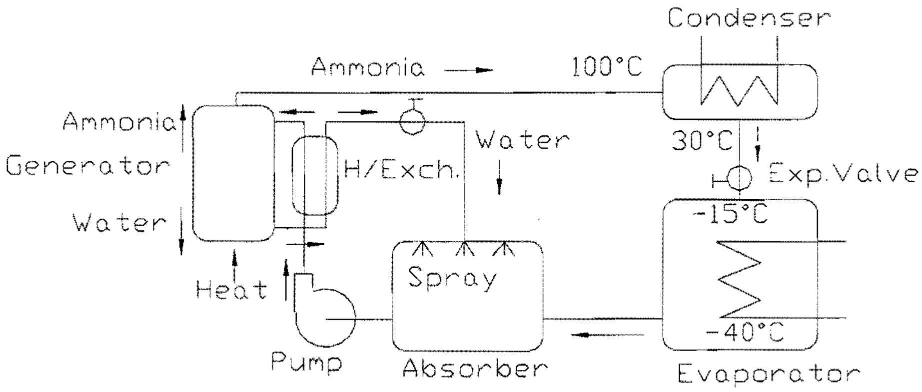


Figure 1.1 Schematic diagram of the simple two-fluid absorption machine

---

[1] Carre, Leslie and Winchausen (1878)

By the turn of the 19^{th} century absorption machines were discarded because of their low coefficient of performance and bulky design. Vapour compression machines took up the market share. However in the 1930's continuous absorption machines were revived by the development of two Swedish researchers, Balzer Von Platen and Carl Munters, at the Royal Institute of Technology. The three-fluid absorption refrigerator was developed with ammonia as refrigerant, water as absorbent and hydrogen as pressure equaliser to compensate for the pressure difference between the absorber/evaporator and the generator/condenser. Therefore the use of a liquid pump, necessary for the two-fluid systems, was avoided.

1.2 WHY AQUA-AMMONIA ABSORPTION REFRIGERATION?

The most important advantage of the three-fluid absorption refrigeration machine is that it does not require "high grade" energy to operate. Energy, which could otherwise be put to waste such as hot combustion gases and low-pressure steam, can be used. This means that the machine can be used in areas where there is no electricity. Since there are no moving parts the machine is also silent. For this reason it regained popularity as a domestic refrigerator during the time of the Second World War. Maintenance costs are also reduced as a result of the lack of moving parts [16].

Absorption machines also have the advantage of high reliability, long service life, easy capacity control and meeting the variable load easily and efficiently as given by Ibrahim and Sadik [8].

They however, suffer from the disadvantage of having low coefficient of performance compared to vapour compression machines and are usually bulky, hence high production cost. Tyagi and Shankar [20] however, argue that this comparison with vapour compression machines is not fair on the basis of COP. This is because the energy input to the absorption machines is in form of low-grade heat in contrast to mechanical or electrical energy input for vapour compression machines.

Large absorption plants are restricted to industrial applications for both refrigeration and air conditioning purposes where low-grade energy is readily available. These plants are of the two-fluid type and because they require a solution pump, electricity must be available. Depending on the availability of heat, plants with capacities of

25 MW have been built. Domestic units, which are limited at present to small capacities, are of the three-fluid systems, also known as the diffusion type absorption machines.

1.3 OBJECTIVES OF THIS WORK

Vapour compression machines are designed on the basis of refrigeration effect and required evaporator temperature. But, for absorption machines the methodology is not that straight forward. A literature survey shows that there are not many methods for the analysis. Vicatos' [21] graphical method and computer simulation is accurate for the design, optimisation and sizing of a two-fluid absorption plant. However, it contains empirical polynomial equations produced by curve-fitting experimental data and Fourier equations to curve-fit data obtained by tracing the enthalpy-concentration (h-x) diagram, published by Ziegler and Trepp [24].

Because of the availability of low-grade heat, the performance of absorption units was not an important issue for an engineering design. Hence many units exist in the market not only having a low COP but also hardly meeting refrigeration demands. Some units are also problematic, without the manufacturers being able to rectify them.

The design of absorption refrigeration machines requires knowledge of chemical thermodynamics and property of mixtures. This fact alone not only complicates the proper design and optimisation of the machines, but in case of malfunction, there are not that many responsible companies that can restore them into a working order.

This thesis investigates some of the design parameters with regard to the working pressure, temperature, and the level of charge, for a fixed concentration according to the manufacturer's advice. An existing unit that had "no ice" conditions is used. Hence the objectives of the thesis are to:

- make design modifications to the unit in order to make it work
- collect sufficient data for an individual component and overall refrigerator's performance

- to produce a computerised model based on the thermodynamic equations by Ziegler and Trepp [24] and to implement it as a subroutine in the overall simulation by Vicatos [21].

CHAPTER 2

THE THREE-FLUID ABSORPTION REFRIGERATION MACHINE – LITERATURE REVIEW

2.1 PRINCIPLE OF OPERATION

The principal components of the system are the generator, condenser, evaporator and absorber and the heat exchanger. There are three working circuits; namely the ammonia circuit, solution circuit and hydrogen circuit. This is shown in Figure 2.1.

The cycle operates on the principle of Dalton's law of partial pressures, which states that the total pressure of any mixture of gases and vapours is the sum of the partial pressures exerted by each of the gases and vapours in the mixture.

The total pressure exerted everywhere in the system is the same. With reference to Figures 2.1, heat supplied to the boiler causes the ammonia to boil off the solution. The vapour is a gaseous mixture of ammonia and water vapours. The bubbles formed due to boiling, carry slugs of liquid (weak solution) up the lift-tube to the vapour-liquid separator. The hot-weak solution will flow by gravity down the tube (8), will enter the heat exchanger and then to the absorber (9). The vapour will follow the inverted "U" tube (11), and then it will be forced through a liquid path to the analyser (12). Because the analyser contains hot liquid, the ammonia vapour will not be absorbed, but any traces of water vapour will condense into the bulk of the solution. This "stripping off" the less volatile water vapour from the vapour mixture, liberates almost pure ammonia vapour, which then ascends through the rectifier tube to the condenser (1). After condensation (2), the liquid ammonia cools further in a tube exposed to the environment (2 to 3) and even further in the pre-coolers. Then it enters

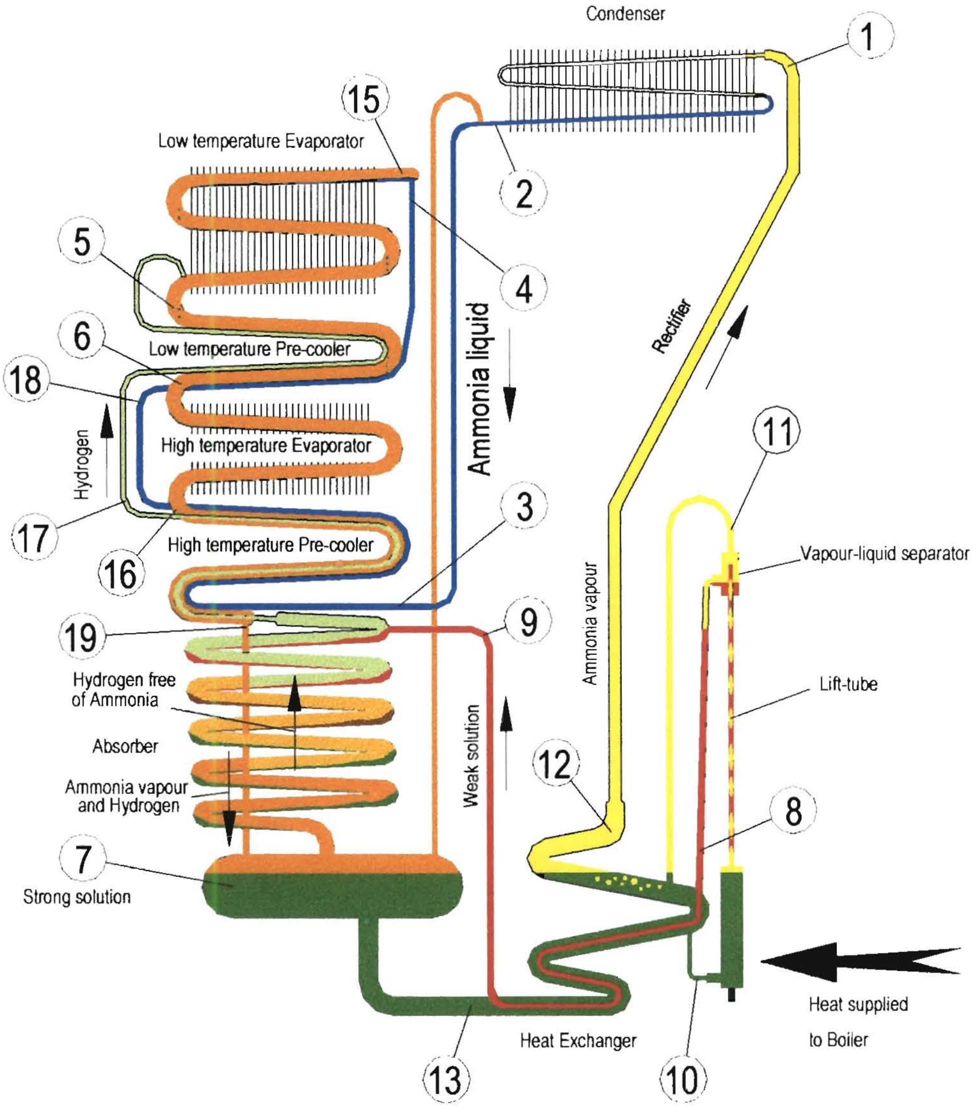


Figure 2.1 Principle of operation of the Three-fluid experimental unit [23]

the low temperature evaporator (15). Evaporation takes place in the tube from (15), through (5 and 6), to (16) in an environment full of high-pressure hydrogen. The mixture of ammonia and hydrogen descends through the tube (19) and enters the absorber's reservoir, where it flows over the surface of the strong solution and enters the absorber's ascending coiled tube. There the mixture of ammonia and hydrogen comes into contact with the descending weak solution and absorption takes place within the absorber's coils, thus entrapping the ammonia vapour and liberating the hydrogen which is free to return to the evaporator coils through the tube (17).

The strong solution formed is collected in the absorber's reservoir (7) from where it flows through the heat exchanger (13) to enter the boiler (10).

2.2 THE WORKING FLUIDS

2.2.1 Ammonia-water

Ammonia offers an advantage as a refrigerant in that it has a very high latent heat of vaporisation (1313.3 kJ/kg at –15 °C: this figure is nine times greater than that of R-12 or R-22) as given by ASHRAE [2]. It does not react with ozone (O_3) hence does not deplete the ozone layer in contrast to most chloro-fluorocarbons (CFCs). Vast quantities of ammonia can easily be dissolved in water and both fluids are inexpensive. In addition, a detailed data bank exists for thermodynamic properties of ammonia, water and their mixtures making it easy to predict the performance for refrigeration applications [17].

Ammonia is however toxic. At a concentration of 150,000 parts per million it is inflammable under room temperature conditions; at high temperatures (170 degrees centigrade and above) it produces inert gases, which have to be removed from the system according to Yaron *et al* [23]. Ammonia is corrosive in presence of water to non-ferrous metals in particular copper and its alloys, this means that mild steel has to be used for construction.

The ammonia-water pair has the disadvantage that the volatility differential between the refrigerant and absorbent is not sufficient to avoid the need for rectification of the refrigerant vapour [11].

2.2.2 Hydrogen

To maintain circulation between the evaporator and absorber of the refrigeration machine it is important that the inert gas used is as light as possible. This is because the refrigeration capacity is dependent upon the rate of diffusion. It has been proved by various researchers that the diffusion coefficient is indirectly proportional to the molar mass of the diffusing gas [4]. The weight of a gas is proportional to its molar mass, and since the molar masses of ammonia and hydrogen are 17 and 2 respectively, this difference is sufficient to initiate and maintain circulation between the evaporator and absorber. It is also preferred because it has low specific heat; it is non-corrosive and insoluble in water.

2.3 THEORETICAL ANALYSIS OF AN IDEAL CYCLE

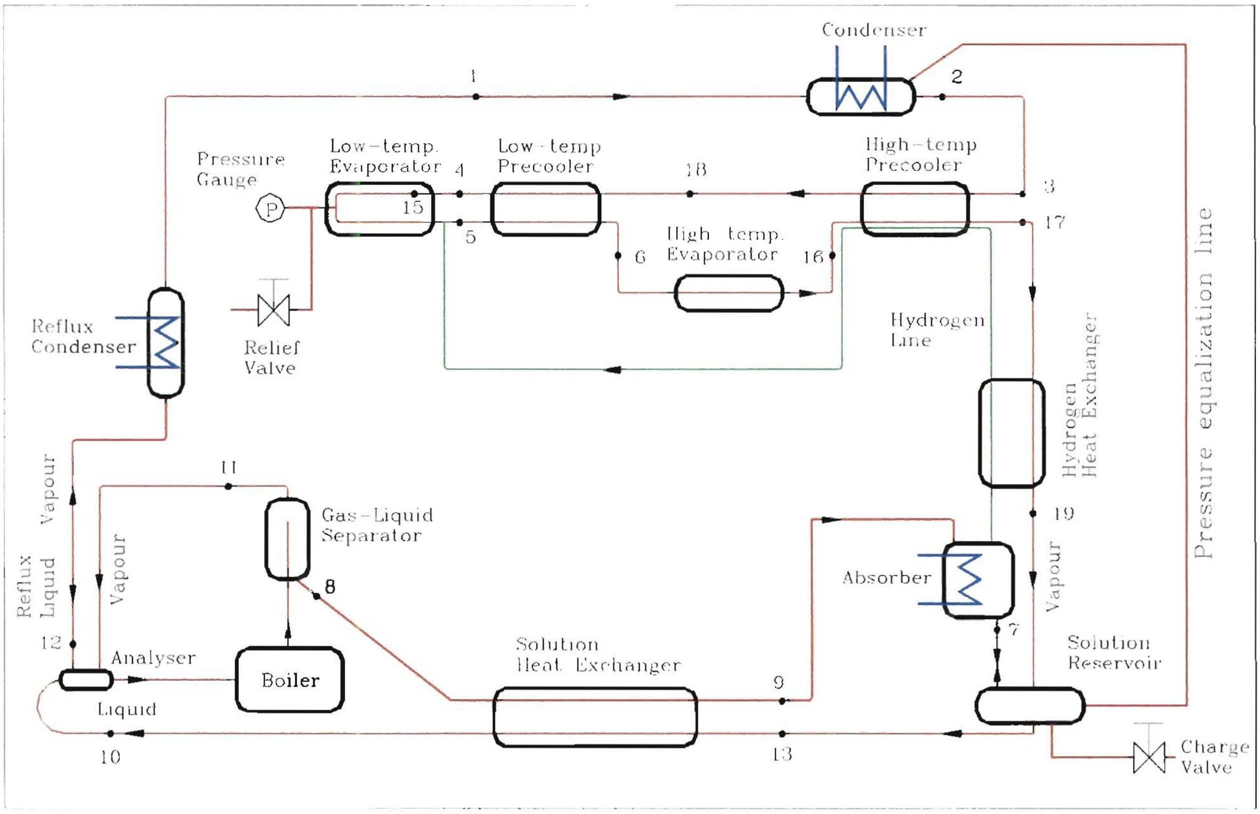


Figure 2.2 Schematic line diagram of the experimental three-fluid absorption machine

2.3.1 First Law analysis

The state points refer to Figure 2.2

First Law analysis entails analysing the system with regards to mass and energy balances and equilibrium relationships. Under steady-state conditions, the rate equation from the First Law for the whole system, assuming no heat losses or gains, is given by:

$$Q_a + Q_c = Q_g + Q_e \qquad \ldots (2.1)$$

where Q = heat rate and subscripts *a, c, g* and *e* represent the absorber, condenser, generator and evaporator respectively

A number of basic assumptions are needed in order to study the thermodynamic performance of the cycle. The major assumptions [11] are:

(i) The high pressure in the system is the equilibrium pressure corresponding to the temperature and concentration in the condenser. The pressures in the generator and rectifier are equal to the condenser pressure.

(ii) The low pressure in the system is the equilibrium pressure corresponding to the evaporator temperature and concentration entering the evaporator. It is also equal to the pressure in the absorber.

(iii) The hydrogen equalises the two pressures in (i) and (ii) above.

(iv) The purge liquid leaving the evaporator is at a constant pressure and has a temperature higher than the evaporator temperature. This is in accordance with the theory of binary mixtures and the "glide" in temperatures when the mixture is not at its azeotropic concentration[1] [21].

(v) The mass flow and concentration of the refrigerant in the vapour prior to the condenser are assumed constant.

The following basic system equations are obtained:

For m_1 = mass flow rate of refrigerant

y_1 = concentration of ammonia in vapour

<u>Mass balance</u>

Generator: $m_{10} = m_8 + m_{11}$

Reflux condenser: $m_{11} = m_{12} + m_1$

Condenser: $m_2 = m_1$

L.T Pre-cooler: $m_4 = m_{18};\ m_6 = m_5$

H.T Pre-cooler: $m_{18} = m_3;\ m_{17} = m_{16}$

L.T Evaporator: $m_5 = m_4$

H.T Evaporator: $m_{16} = m_6$

Absorber: $m_7 = m_9 + m_{19}$

Solution H/Exchanger: $m_{10} = m_{13};\ m_9 = m_8$ ... (2.2)

Ammonia balance

Generator: $m_{10}x_{10} = m_8x_8 + m_{11}x_{11}$

Reflux condenser: $m_{11}x_{11} = m_1y_1 + m_{12}x_{12}$

Condenser: $m_2x_2 = m_1y_1$

L.T Pre-cooler: $m_4\, x_4 = m_{18}x_{18};\ m_6x_6 = m_5x_5$

H.T Pre-cooler: $m_{18}x_{18} = m_3x_3;\ m_{17}x_{17} = m_{16}x_{16}$

L.T Evaporator: $m_5x_5 = m_4x_4$

H.T Evaporator: $m_{16}x_{16} = m_6x_6$

Absorber: $m_7x_7 = m_9x_9 + m_{19}x_{19}$

Solution H/Exchanger: $m_{13}x_{13} = m_{10}x_{10}$ ... (2.3)

Other

Condenser, Refrigerant concentration: $x_2 = y_1$

L.T Pre-cooler, heat exchange: $Q_{PCL} = m_4(h_{18} - h_4) = m_4(h_5 - h_6)$

Effectiveness: $\mathscr{E}_{PCL} = \dfrac{h_{18} - h_4}{h_6 - h_4}$ ... (2.4)

H.T Pre-cooler, heat exchange: $Q_{PCH} = m_3(h_3 - h_{18}) = m_{16}(h_{16} - h_{17})$

Effectiveness: $\mathscr{E}_{PCH} = \dfrac{h_{16} - h_{17}}{h_{18} - h_{17}}$ ... (2.5)

Solution H/Exchanger, Heat Exchange: $Q_{HEX} = m_{13}(h_{10} - h_{13}) = m_8(h_8 - h_9)$

Effectiveness: $\mathscr{E}_{HEX} = \dfrac{h_{13} - h_{10}}{h_9 - h_{10}}$ ... (2.6)

Also,

$$COP = \frac{Q_E}{Q_G} \quad \text{... (2.7)}$$

2.3.2 Second Law analysis

Energy balance

Generator: $m_{10}h_{10} + Q_G = m_8h_8 + m_{11}h_{11}$

Reflux condenser: $m_{12}h_{12} = m_1h_1 + Q_R$

Condenser: $m_1h_1 = m_2h_2 + Q_C$

L.T Pre-cooler: $m_{18}h_{18} + m_4h_4 = m_5h_5 + m_6h_6$

H.T Pre-cooler: $m_3h_3 + m_{18}h_{18} = m_{16}h_{16} + m_{17}h_{17}$

L.T Evaporator: $m_5h_5 = m_4h_4 + Q_{ELP}$

H.T Evaporator: $m_{16}h_{16} = m6h6 + Q_{EHP}$

Absorber: $m_7h_7 = m_9h_9 + Q_A$

Solution H/Exchanger: $m_{10}h_{10} - m_{13}h_{13} = m_8h_8 - m_9h_9$ … (2.8)

The state of the working fluid throughout the system is determined by the equations of heat balance, conservation of mass as governed by the First Law outlined in section 2.2.1. However, it is argued by Dalichaouch [7] that this conventional First Law method of evaluating losses and efficiency is not a true representation of the effectiveness i.e. it gives a poor indication of how well the system utilises a given energy.

The Second Law of Thermodynamics provides a means of assigning a quality index to energy. Real processes are irreversible, and the transfer of heat and work from one form to another always results in some loss of available work. Each time the working fluid in the system goes through a process, some of the initially available work in the fluid is lost. For efficient conservation of energy, the Second Law gives a right measure of the losses in the system processes, through an evaluation of the lost available work, the entropy production or the irreversibility.

The entropy generation of the overall cycle is the sum of the entropy generated by all of the cycle's components. If the source of entropy generation in an individual component is studied, insight may be gained on how to reconfigure that component to reduce the generated entropy as argued by Kaushik and Bhardwaj [11].

For a closed system performing a thermodynamic cycle and in thermal contact with *n* heat reservoirs reference [7] gives (assuming steady state operation):

By the First Law: $W = \sum_{i=1}^{n} Q_i$ … (2.9)

By the Second Law: $\Delta S_{\text{system}} + \Delta S_{\text{heat reservoirs}} \geq 0$

Where W = work; S = entropy

The Second Law efficiency is defined as the ratio of the required minimum energy input for an ideal system to the actual input of a real system. A general definition has been formulated as:

$$\eta = \frac{-Q_E(1-T_O/T_R)}{Q_G(1-T_O/T_H)+Q_C(1-T_O/T_{CF1})+Q_A(1-T_O/T_{CF2})} \qquad \ldots (2.10)$$

where η = efficiency

T_R = temperature of refrigerated fluid

T_{CF} = temperature of cooling fluid

T_H = highest temperature in cycle

If the temperatures T_{CF1}, T_{CF2} of the cooling media are equal to the ambient temperature T_0, the efficiency expression reduces to:

$$\eta = \frac{-Q_E(1-T_0/T_R)}{Q_G(1-T_0/T_H)} \qquad \ldots (2.11)$$

2.3.3 Vapour-Liquid Equilibrium

The equilibrium in vapour-liquid systems is restricted by the phase rule:

$$F = C - P + 2 \qquad \ldots (2.12)$$

where P is the number of phases at equilibrium, C is the total number of components and F is the number of degrees of freedom of the system [5]. Hence, for the ammonia-water-hydrogen system, F=3-2+2 = 3.

There are 3 degrees of freedom. This implies that if the total temperature and pressure are set, only one other variable can be arbitrarily set. If the mole fraction composition, x_A, of ammonia in the liquid phase is set, the mole fraction composition, y_A, or pressure p_A in the gas phase is automatically determined. Three variants are needed to define the state point of a three degrees-of-freedom system.

The absorption of gas or vapour is governed by Raoult's law, which states that at a given temperature the ratio of partial pressure of a volatile component in a solution to the vapour pressure of the pure component is equal to its mole fraction in the solution [5].

$$p_A = x_A P_A \qquad \dots (2.13)$$

where p_A = partial pressure of component of component A in the vapour

P_A = vapour pressure of pure component A

x_A = mole fraction of A in the liquid

Raoults law holds only for ideal solutions. Many systems that are real such as the ammonia-water system follow Henry's law in dilute solutions.

$$p_A = Hx_A \qquad \dots (2.14)$$

where H = Henry's law constant (atmospheres per mole fraction)

The conditions for phase equilibrium for liquid and gaseous phases have been quantified by Schulz [18]:

$$\begin{aligned} T^l &= T^g \\ P^l &= P^g \\ \mu^l_1 &= \mu^g_1 \\ \mu^l_2 &= \mu^g_2 \end{aligned} \qquad \dots (2.15)$$

where T, P and μ represent temperature, pressure and chemical potential respectively

superscripts *l* and *g* represent the liquid and gaseous phases

subscripts 1 and 2 represent the number of components

These functions give these expressions for the phases:

Liquid phase:

$$g^l = (1-x)g^l{}_w + x^l{}_a + RT[(1-x)\ln(1-x) + x\ln x] + g_e \qquad \ldots (2.16)$$

where *g*, *R*, *T* and *x* represent Gibbs free energy, gas constant, temperature and ammonia concentration in liquid phase respectively

subscripts *w*, *a* and *e* represent water, ammonia and excess (Gibbs) energy

Similarly for the gas phase:

$$g^g = (1-y)g^g{}_w + x^g{}_a + RT[(1-y)\ln(1-y) + y\ln y] \qquad \ldots (2.17)$$

The Gibbs free energy of a phase is the sum of the contributions of the pure components, the ideal free energy of mixing and the free excess energy. It is noted that the excess energy (g_e) term falls away for the gaseous phase since it is assumed an ideal mixture of real components.

Using the equations (2.15), (2.16) and (2.17), Schulz has derived expressions for the molar volume, molar enthalpy, molar entropy and chemical potential.

2.3.4 Cycle Optimisation

The COP of a reversible absorption refrigeration machine operating between four temperature levels is given by Jincan Chen [6]:

$$COP = \frac{[(1/T_a) - (1/T_g)] + n[(1/T_c) - (1/T_g)]}{[(1/T_e) - (1/T_a)] + n[(1/T_e) - (1/T_e)]} \qquad \ldots (2.18)$$

where T_a, T_g, T_c, T_e are temperatures of the absorber, generator, condenser and evaporator respectively; and

$$n = \frac{Qc}{Qa}$$

Q_c and Q_a are, respectively, the rates of heat transfer from the absorber and condenser to two heat reservoirs at temperatures T_a and T_c

When $T_a = T_c = T_s$ (sink temperature), equation (2.18) may be written as:

$$COP = \frac{(T_g - T_s)}{T_g} \frac{T_e}{(T_s - T_e)} \qquad \text{... (2.19)}$$

Equation (2.19) is independent of n and is mostly quoted in literature as the Carnot COP of a reversible absorption refrigerator operating between three temperature limits T_g, T_s and T_e.

The reversible COP is important in theory, but it is an impractical measure of the COP of a real absorption refrigerator. Real absorption refrigerators usually suffer from a series of irreversibilities. For example, there exist not only the irreversibility of the finite rate heat transfer, but also the internal irreversibilities resulting from friction, eddies, mixing, distillation, absorption and disorption.

It is shown in references [6] and [12] that the irreversibility factor is represented by the equation:

$$I = \frac{(Q_a / T_a) + (Q_c / T_c)}{(Q_g / T_g) + (Q_e / T_e)} \geq 1 \qquad \text{... (2.20)}$$

When the cycle of the working substance is internally reversible I = 1, when internally irreversible I > 1.

Hence the COP of an internally irreversible four-temperature level absorption refrigeration machine is obtained as:

$$COP = \frac{|(1/IT_a) - (1/T_g)| + n|(1/IT_c) - (1/T_g)|}{[(1/T_e) - (1/IT_a)] + n[(1/T_e) - (1/IT_c)]} \qquad \text{... (2.21)}$$

Thus the COP is thus maximised when the irreversibility factor I = 1.

CHAPTER 3

THE ENTHALPY-CONCENTRATION DIAGRAM

3.1 THEORY AND DERIVATION

Many researchers have published the relations between the thermodynamic properties of binary mixtures. The relation between pressure, temperature and concentration of the refrigerant (P-T-x) plays a key role in the determination of equilibrium properties. This relation has been derived by some researchers for the ammonia-water mixture [21], [9], [3] and [4]. In this work a more accurate equation for the relation has been derived from the data published by Scatchard *et al* [17]. This has in turn been used to evaluate the Gibbs free energy and hence the enthalpy in both the liquid and gaseous mixture phases as determined from the equations given by Ziegler and Trepp [24]. The integration was evaluated in Mathsoft's Mathcad (version 6.0) and then implemented in Microsoft Excel for finding the x, y coordinates which were introduced into AutoCAD for the final plot.

(i) Determination of pressure P at constant temperature with varying concentration[1]:

$$\log P = \left(\frac{1000 * U}{T} + V \right) / 14.696 \qquad \dots (3.1)$$

where,

$$U = \sum_{i=0}^{6} u_i x^i$$

$$V = \sum_{i=0}^{6} v_i x^i$$

P = pressure (bar); T = temperature (K); x = mass concentration of liquid ammonia in solution; Coefficients u_i and v_i are given in Table 3.1

---

[1] Equation 3.1 originally derived by Bulgan [4], has been modified by the author to predict the pressure/temperature/concentration relationship of the ammonia-water mixtures. The predicted temperatures diviate from those published by Scatchard *et al* [17] by 0.86%

(ii) Determination of Gibbs free energy G for pure components:

$$G = h_o - Ts_o + \int_{T_o}^{T} Cp.dT - T \int_{T_o}^{T} (Cp/T).dT + \int_{P_o}^{P} v.dP \qquad \ldots (3.2)$$

where h_o, s_o, T_o and P_o are the specific enthalpy, specific entropy, temperature and pressure, respectively of the reference state (subscript *o* represents reference state); C_p is the specific heat capacity at constant pressure.

The 'reduced' form of equation (3.2) is given by:

$$G_r = h_{ro} - T_r s_{ro} + \int_{T_{ro}}^{T_r} Cp_r.dT_r - T_r \int_{T_{ro}}^{T_r} (Cp_r/T_r).dT_r + \int_{P_{ro}}^{P_r} v_r.dP_r \qquad \ldots (3.2b)$$

where r represents the reduced property as given by:

$T_r = T/T_b$; $P_r = P/P_b$; $G_r = G/RT_b$; $S_r = S/R$; $T_b = 100$ [K]; $P_b = 10$[bar]

$C_{pr} = C_p/R$; $v_r = v/R$; $R = 8.314$ [kJ/kmol.K]

Liquid phase: $v_r = A_1 + A_2.p + A_3.T + A_4.T^2$ $\qquad \ldots (3.3)$

$$C_{pr} = B_1 + B_2.T + B_3.T^2$$

Gas phase: $v_r = RT/p + C_1 + C_2/T^3 + C_3/T^{11} + C_4.p^2/T^{11}$ $\qquad \ldots (3.4)$

$$C_{pr} = D_1 + D_2.T + D_3.T^2$$

(Constants A_i, B_i, C_i, *and* D_i for the reduced state are given in Table 3.2)

Evaluating the integral in equation 3.2b gives:

Liquid phase:

$$G_r^L = h_{ro}^L - T_r s_{ro}^L + B_1.(T_r - T_{ro}) + (B_2/2).(T_r^2 - T_{ro}^2) + (B_3/3).(T_r^3 - T_{ro}^3)$$

$$- B_1 T_r.\ln(T_r/T_{ro}) - B_2 T_r.(T_r - T_{ro}) - (B_3/2).T_r.(T_r^2 - T_{ro}^2)$$

$$+ (A_1 + A_3 T_r + A_4 T_r^4).(P_r - P_{ro}) + (A_2/2).(P_r^2 - P_{ro}^2) \qquad \ldots (3.5)$$

Gas phase:

$$G_r^g = h_{ro}^g - T_r s_{ro}^g + D_1.(T_r - T_{ro}) + (D_2/2).(T_r^2 - T_{ro}^2) + (D_3/3).(T_r^3 - T_{ro}^3)$$
$$- D_1 T_r.\ln(T_r/T_{ro}) - D_2 T_r.(T_r - T_{ro}) - (D_3/2).T_r.(T_r^2 - T_{ro}^2)$$
$$+ T_r.\ln(P_r/P_{ro}) + C_1(P_r - P_{ro}) + C_2(P_r/T_r^3 - 4P_{ro}/T_{ro}^3 + 3P_{ro}T_r/T_{ro}^4)$$
$$+ C_3(P_r/T_r^{11} - 12P_{ro}/T_{ro}^{11} + 11P_{ro}T_r/T_{ro}^{12}) + (C_4/3)(P_r^3/T_r^{11}$$
$$-12P_{ro}^3/T_{ro}^{11} + 11P_{ro}^3 T_r/T_{ro}^{12}) \qquad \ldots (3.6)$$

The Gibbs excess free energy is given as:

$$G_{re} = [E_1 + E_2P_r(E_3 + E_4P_r)T_r + E_5/T_r + E_6/T_r^2 + [E_7 + E_8P_r + (E_9$$
$$+ E_{10}P_r)T_r + E_{11}/T_r + E_{12}/T_r^2](2x-1) + (E_{13} + E_{14}P_r + E_{15}/T_r$$
$$+ E_{16}/T_r^2)(2x-1)^2]x(1-x) \qquad \ldots (3.7)$$

Constants $E_1 \ldots E_{16}$ are given in Table 3.3.

(iii) Determination of the molar enthalpies h for pure components:

The molar specific enthalpy as function of the Gibbs free energy is given as:

$$h = -RT_bT_r^2\left[\frac{\partial}{\partial T_r}\left(\frac{G_r}{T_r}\right)\right]_P \qquad \ldots (3.8)$$

Substituting equations (3.5), (3.6) and (3.7) into equation (3.8) gives for each phase the following expressions for molar enthalpies:

Liquid phase:

$$h_r^{\ell} = h_{ro}^{\ell} - B_1T_{ro} - (B_2/2)(T_r^2 + T_{ro}^2) - (B_3/3)(2T_r^3 + T_{ro}^3) + B_1T_r$$
$$+ B_2T_r^2 + B_3T_r^3 + (A_1 - A_4T_r^2)(P_r - P_{ro}) + (A_2/2)(P_r^2 - P_{ro}^2) \qquad \ldots (3.9)$$

Gas phase:

$$h_r{}^g = h_{ro}{}^g - D_1T_{ro} - (D_2/2)(T_r{}^2 + T_{ro}{}^2) - (D_3/3)(2T_r{}^3 + T_{ro}{}^3) + D_1T_r$$
$$+ D_2T_r{}^2 + D_3T_r{}^3 + C_1(P_r - P_{ro}) + C_2(P_r/T_r{}^3 - 4P_{ro}/T_{ro}{}^3) + C_3(P_r/T_r{}^{11}$$
$$-12P_{ro}/T_{ro}{}^{11}) + (C_4/3)(P_r{}^3/T_r{}^{11} - 12P_{ro}{}^3/T_{ro}{}^{11}) \qquad \ldots (3.10)$$

Excess enthalpy (liquid phase):

$$h_{re} = [E_1 + 2E_5/T_r + 3E_6/T_r{}^2 + (E_7 + E_8P_r + 2E_{11}/T_r + 3E_{12}/T_r{}^2)(2x-1)$$
$$+ (E_{13} + E_{14}P_r + 2E_{15}/T_r + 3E_{16}/T_r{}^2)(2x-1)^2]x(1-x) \qquad \ldots (3.11)$$

(iv) Mixture enthalpies:

$$hr_m^L = (1-x)hr_w^L + xhr_a^L + hre$$

$$h_m^L = RTb.hr_m^L/[17x + 18(1-x)] \qquad \ldots (3.12)$$

$$hr_m^g = (1-y)hr_w^g + yhr_a^g$$

$$h_m^g = RTb.hr_m^g/[17y + 18(1-y)] \qquad \ldots (3.13)$$

where subscripts *m, w* and *a* represent *mixture, water* and *ammonia* respectively

r = reduced property

y = weight fraction of ammonia in the gaseous phase (as given in (v))

17, 18 = the relative molecular masses of ammonia and water respectively.

(v) Determination of weight fraction y of ammonia in the gas phase:

The condition for phase equilibrium in terms of the chemical potential μ is given by Ziegler [24] as:

$$\mu^L{}_{,water} = \mu^g{}_{,water}$$

$$\mu^L{}_{,ammonia} = \mu^g{}_{,ammonia} \qquad \ldots (3.14)$$

The chemical potential for water is related to Gibbs free energy by:

$$\mu^L = G^L - x[\frac{\partial}{\partial x}(G^L)]$$

$$\mu^g = G^g - y[\frac{\partial}{\partial y}(G^g)] \qquad \text{... (3.15)}$$

Equating the right hand side of these two equations and solving for y yields:

$$y = 1 - \exp[(G_r{}^L - G_r{}^g + T_r.\ln(1-x) + [E_1 + E_2 P_r (E_3 + E_4 P_r) T_r + E_5 / T_r$$
$$+ E_6 / T_r{}^2]x^2 + [E_7 + E_8 P_r + (E_9 + E_{10} P_r) T_r + E_{11} / T_r + E_{12} / T_r{}^2 (-3x^2$$
$$+ 4x^3) + (E_{13} + E_{14} P_r + E_{15} / T_r + E_{16} / T_r{}^2)(12x^4 - 16x^3 + 5x^2)) / T_r] \qquad \text{... (3.16)}$$

(<u>Note</u>: $G_r{}^L$ and $G_r{}^g$ in this equation are for <u>water</u>, the values of which are calculated by equations 3.5 and 3.6)

Alternatively y is expressed in terms of the volatility factor α as [17] and [15]:

$$y = \frac{\alpha x}{1 + (\alpha - 1)x} \qquad \text{... (3.17)}$$

(<u>Note</u>: equations 3.14 and 3.15 give identical y for given x and corresponding α)

The volatility factor is determined from empirical relations as follows:

$$\log(\alpha) = Pt^2 + Qt + R$$

where t = temperature [°C]

$$P = \sum_{i=0}^{6} p_i x^i$$

$$Q = \sum_{i=0}^{6} q_i x^i$$

$$R = \sum_{i=0}^{6} r_i x^i$$

Coefficients p_i, q_i and r_i are given in Table 3.1

Table 3.1 Coefficients for polynomial equations (3.1) and (3.17)

	$i=0$	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$	$i=6$
u_i	-2.9128	5.5525	-23.122	59.828	-81.736	54.662	-14.212
v_i	7.0262	-9.0153	42.752	-102.09	122.54	-69.896	14.937
p_i	8x10^{-6}	10^{-4}	0.002	-0.0082	0.0167	-0.0161	0.0058
q_i	-5.5x10^{-3}	4.5x10^{-3}	-0.221	0.739	-1.3412	1.22	-0.4248
r_i	1.6172	1.2249	4.2909	1.82	-12.005	6.5404	0.0907

Table 3.2 Coefficients for the equations for pure components [24]

Coefficient	Ammonia	Water
A1	3.971423x10^{-2}	2.748796x10^{-2}
A2	-1.790557x10^{-5}	-1.016665x10^{-5}
A3	-1.308905x10^{-2}	-4.452025x10^{-3}
A4	3.752836x10^{-3}	8.389246x10^{-4}
B1	16.34519	12.14557
B2	-6.508119	-1.898065
B3	1.448937	0.2911966
C1	-1.049377x10^{-2}	2.136131x10^{-2}
C2	-8.288224	-31.69291
C3	-664.7257	-46346.11
C4	-3045.352	0
D1	3.673647	4.019170
D2	9.989629x10^{-2}	-5.17555x10^{-2}
D3	3.167622x10^{-2}	1.959939x10^{-2}
hor^L	4.878573	21.821141
hor^g	26.468879	60.965058
sor^L	1.644773	5.733498
sor^g	8.339026	13.453430
Tor	3.2252	5.0705
Por	2.0000	3.0000

Table 3.3 Coefficients for the Gibbs excess free energy function [24]

E1	-46.26129	*E9*	-1.475383
E2	2.060225×10^{-2}	*E10*	-5.038107×10^{-3}
E3	7.292369	*E11*	-96.40398
E4	-1.032613×10^{-2}	*E12*	122.6973
E5	80.74824	*E13*	-7.582637
E6	-84.61214	*E14*	6.012445×10^{-4}
E7	24.52882	*E15*	54.87018
E8	9.598767×10^{-3}	*E16*	-76.67596

3.2 GRAPHICAL MODEL

The above equations were plotted to formulate the enthalpy-concentration (h-x), plotted in figure 3.1. These equations were used to create a computer program that gives the properties of ammonia, water and their mixture in both liquid and vapour states. This program was then converted into subroutines to serve as a more precise calculation tool of the properties of the mixture, in the simulation program of absorption refrigeration machines by Vicatos [21].

The enthalpy-concentration diagram produced in this work, figure 3.1, agrees entirely with that of the publication of Ziegler and Trepp [24] shown in appendix 5. But in addition to this, for the first time known to the author, a computer program that evaluates these properties has been made public.

The reference state for the plot is zero enthalpy at zero degrees centigrade for both pure ammonia and pure water.

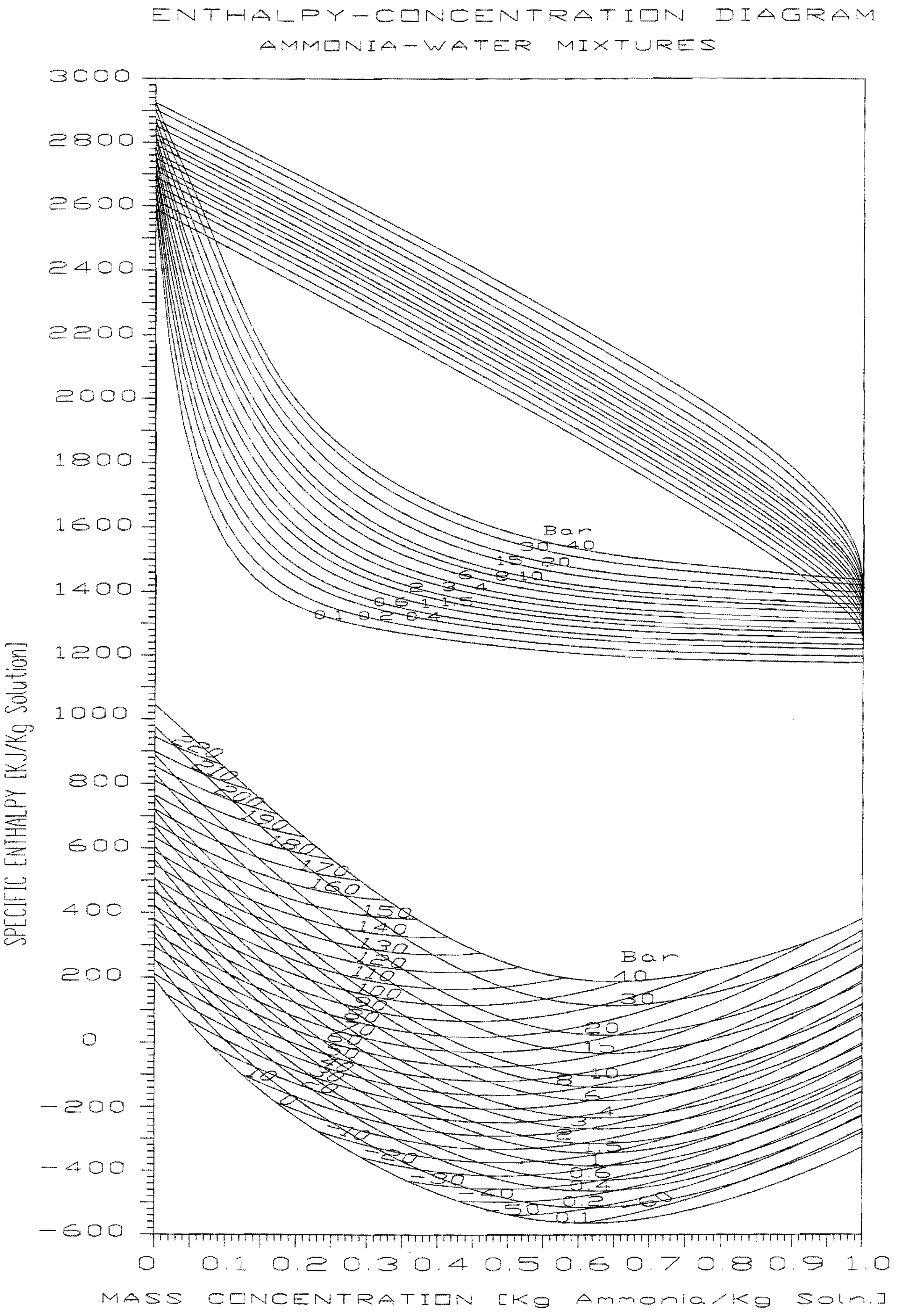


Figure 3.1 Enthalpy-concentration diagram for ammonia-water mixtures

3.3 FLOWCHART

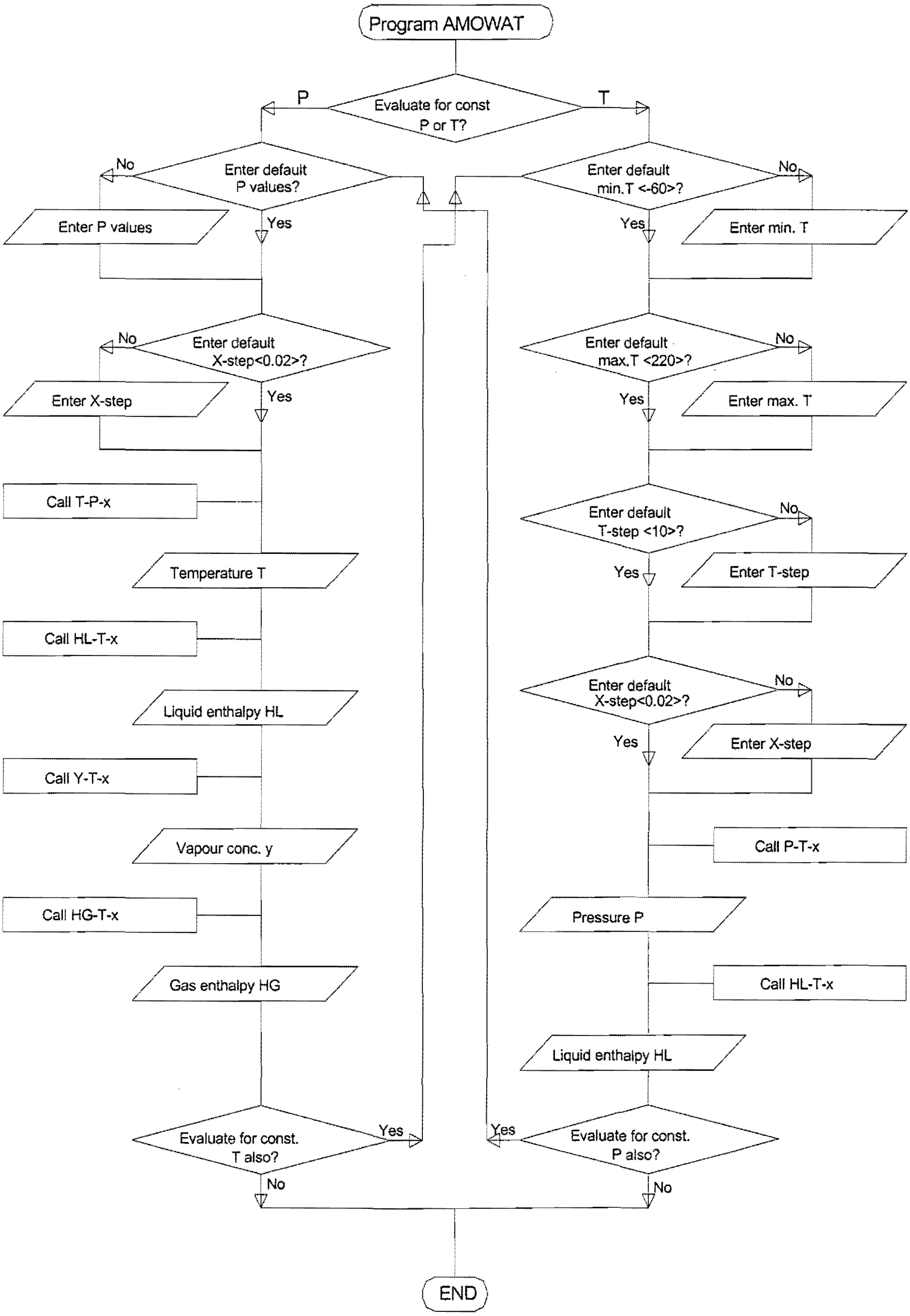


Figure 3.2 Flowchart for h-x program (program listed in appendix 3)

CHAPTER 4

DESIGN MODIFICATIONS AND EXPERIMENTAL METHOD

4.1 DESIGN MODIFICATIONS

4.1.1 Lift tube and Boiler pump

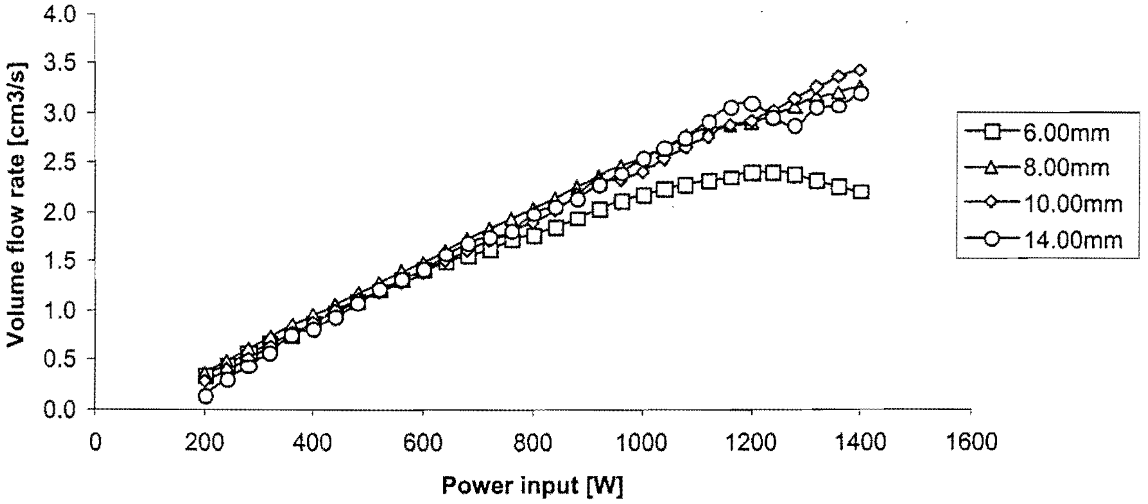


Figure 4.1 Lift tube performance for various internal tube diameters (2-phase flow)

The lift-tube has received attention from a number of researchers, the most recent being the publication by M.v.B. Smith [19]. However, its importance has been overestimated as far as the choice of its diameter is concerned.

G.D.S. Lister [13] investigated the performance of the lift-tube by using water at its boiling state, Figure 4.1. Volume rates were recorded using tubes of internal diameters 6mm, 8mm, 10mm and 14mm for varying power inputs.

It was observed that power input and flow rate had a linear relationship. It was further found that, with the exception of the 6mm tube and only for powers above 800W, the performance of the lift-tube pump has a small dependency on tube diameter. This work is in agreement with that of Nicklin [14] who experimented with airlift pumps.

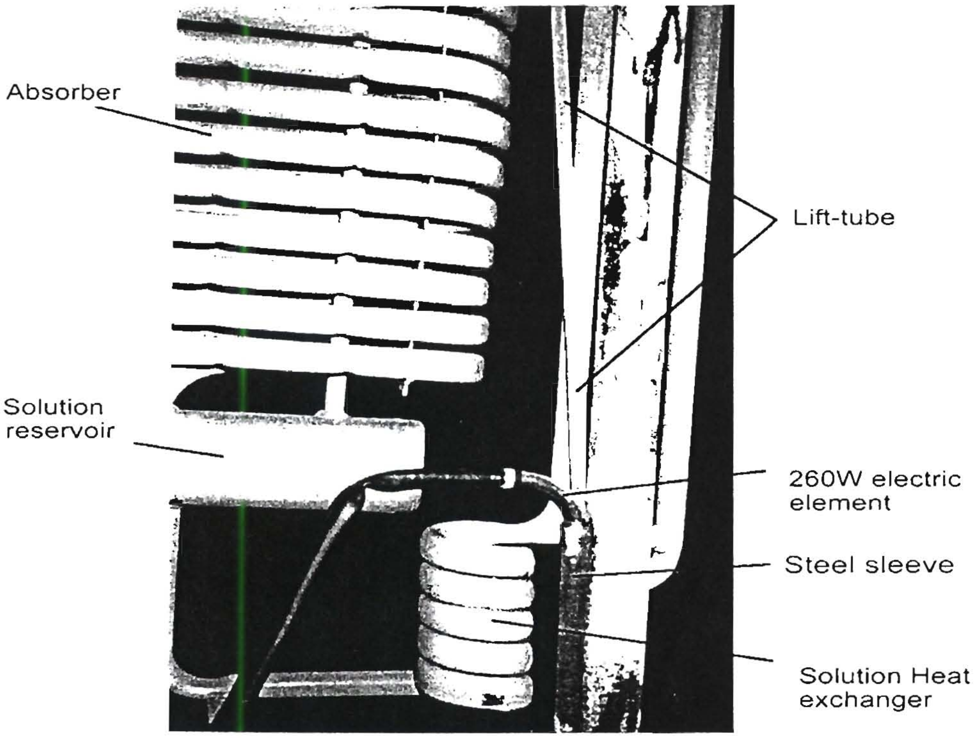


Figure 4.2 The original lift-tube and solution heat exchanger arrangement

The percolator pump could be powered using gas or an electric element. Figure 4.2 shows the original lift-tube-pump. Heat is transferred from a steel sleeve heated by a 260W electric element, to the lower section of the lift-tube, through three 1cm long butt welds. The heat transfer was minimal in this arrangement, as most of the heat was lost to the surroundings. Figures 2.1 and 4.3 show the new arrangement of the boiler and a 8mm lift-tube where heat was supplied from an electric element directly to the solution in the boiler.

The heights of the lift-tube and the position of the liquid-vapour separator was designed to allow fluid flow to the absorber by gravity.

4.1.2 Liquid-vapour separator

The liquid-vapour was designed form of a t-piece as shown in Figure 4.4. The hot ammonia vapour is released into the vertical tube (towards the bend) whereas the weak solution is released into the horizontal tube.

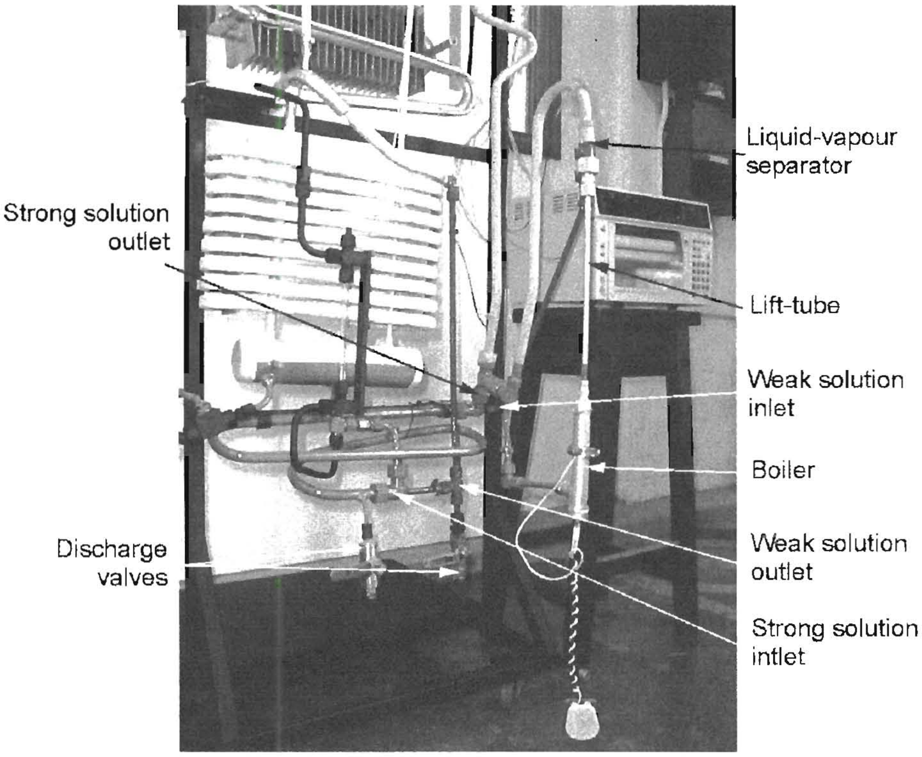


Figure 4.3 The modified lift-tube/boiler, incorporating the immersed heating element, and the heat exchanger [22].

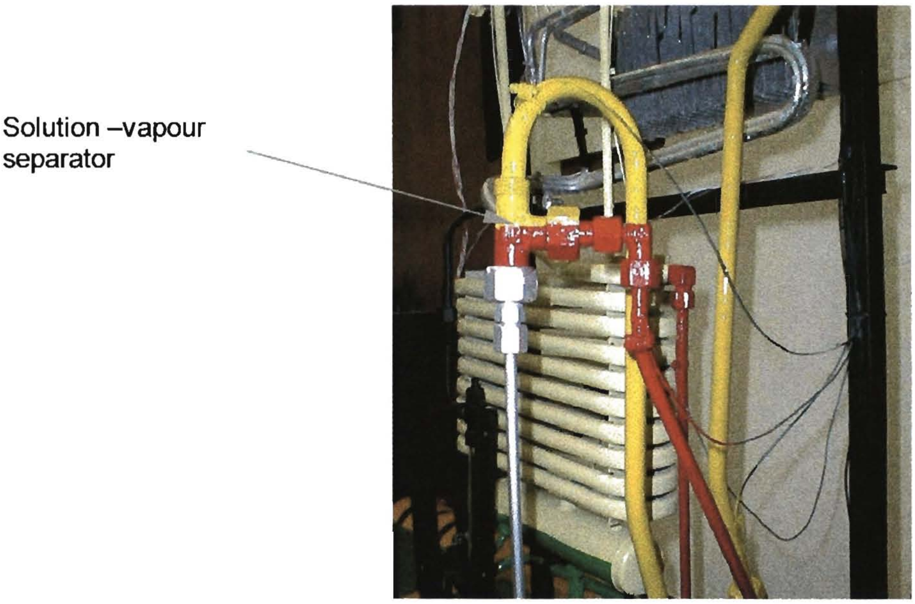


Figure 4.4 The modified liquid-vapour separator

4.1.3 Charge Level Indicator (Sight glass)

The correct amount of charge is also important in performance, though there is no correlation between the amount of charge and refrigeration effect. This charge depends mainly on the volume capacity of the machine. The charge level in the solution reservoir is critical since a small or large amount will lead to either heater element burnout or cut-off in hydrogen gas ascension respectively. A by-pass line was installed between inlet to absorber and exit from reservoir to monitor the solution level (Figure 4.5).

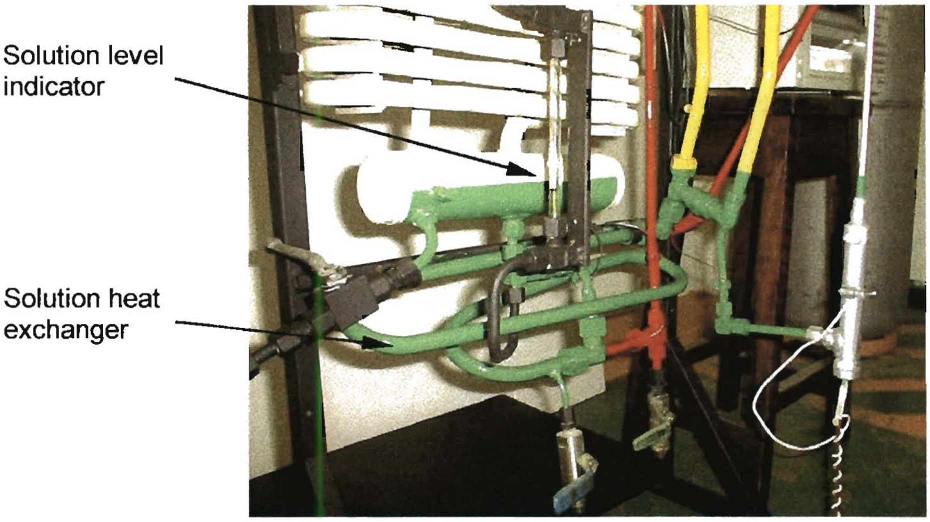


Figure 4.5 The solution level indicator

4.1.4 Solution Heat Exchanger

The original solution heat exchanger is shown in Figure 4.2 where the cold solution flows through the inner tube and the hot weak solution flows through the annular space. The modified and installed heat exchanger is shown in Figure 4.3 and 4.5 where the flows have been reversed i.e. the hot stream in the inside tube. This new design has increased the effectiveness of the heat exchanger, as it will be indicated with the results in paragraph 5.5.

4.2 EXPERIMENTAL METHOD

4.2.1 Charging

4.2.1.1 Introduction

Charging refers to the filling of the refrigeration machine with refrigerant-absorbent solution and applying inert gas pressure to the system. Charging requires three important parameters: Concentration of ammonia-water solution, quantity of ammonia-water solution and the overall pressure of the system. The influence of these parameters on the system is discussed below:

I. The Concentration of ammonia-water solution (measured in kg of ammonia per kg of solution): The right solution concentration is required as a low concentration leads to a low flow rate of ammonia to the evaporator and hence low refrigeration effect. A high solution concentration leads to a high partial pressure of ammonia, which will affect the boiling temperature in the evaporator. Typical charge concentrations range from 28% for a deep freezer to 35% for a domestic refrigerator[1]. The tests in this work were done with a manufacturer's recommended concentration of 34%.

II. The Quantity of ammonia-water solution: Too little solution may cause the element to burnout since the element is designed to work under full immersion (Figure 4.5). It is also clear that too much solution may seal the outlet tube of the absorber hence cutting off the flow of hydrogen to the evaporator. For a domestic size refrigerator, the charge capacity ranges from 0.45 to 2.25 litres of solution. Due to the component modifications the quantity of charge in this work was 0.998 litres, which was established by trial and error.

III. The overall Pressure of the system: This is made up of two partial pressures, the pressure exerted by ammonia-water mixture and pressure exerted by the hydrogen gas. Since the pressure is the same throughout the system, a too low

---

[1] Reference: Privately owned notes from various South African manufacturers

overall pressure, means a relatively high ammonia saturation pressure in the evaporator and hence a reduced cooling effect. A too high overall pressure on the other hand, necessitates a high boiler temperature to release the ammonia vapour. This means that the absorber receives a relatively large amount of heat from the boiler beyond its design capability. This will reflect to a high ammonia partial pressure and temperature in the evaporator, which will reduce both refrigeration capacity and coefficient of performance. The charged hydrogen pressure typically varies between 14 and 25 bar. In this work several tests were done with hydrogen pressures ranging from 7.5 to 27.5 bar.

4.2.1.2 Charging Procedure

The set-up for the charging procedure is shown in Figure 4.6.

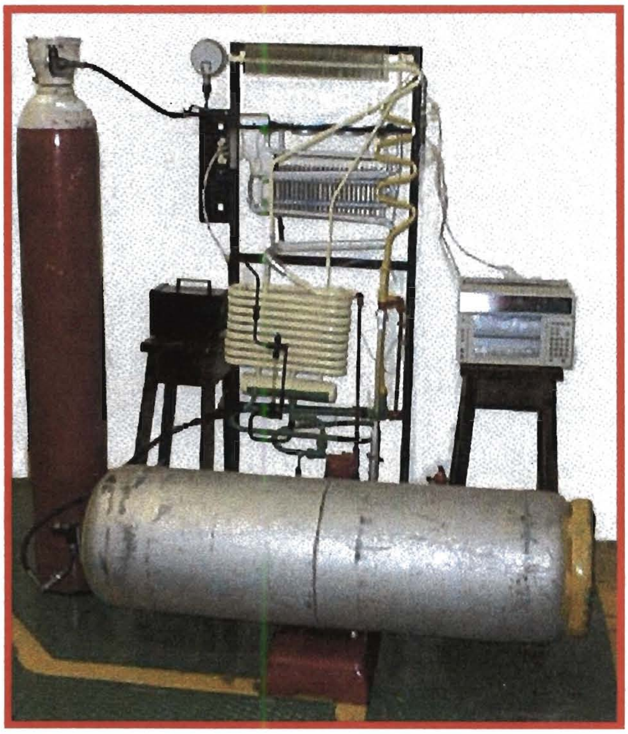


Figure 4.6 Charging of ammonia and hydrogen

A pre-determined amount of sodium dichromate ($Na_2Cr_2O_7.2H_2O$) crystals (about 1.5% the weight of water) were dissolved in water. Sodium dichromate acts as rust inhibitor but because it is acidic it is neutralised by sodium hydroxide (NaOH), which is alkaline. The amount of the sodium hydroxide pellets was about half the mass of the sodium dichromate crystals.

The rig was evacuated and the solution (distilled water, sodium dichromate and sodium hydroxide) was charged into the rig.

The ammonia was charged into the rig until the desired amount by mass as determined by the difference in mass of the cylinder before and after the charge.

The actual amounts charged were:

- 698cc of boiling distilled water
- 360g of anhydrous ammonia (from ammonia cylinder)
- 10.4g of sodium dichromate
- 3.5g of sodium hydroxide

4.2.2 Temperature Measurement

The temperatures were measured by copper-constantan (type "T") thermocouples that were silver-soldered onto the tubes. The voltage signal produced at the junction was converted into a temperature reading by two analogue-to-digital instruments. The time-temperature data were recorded on a printout.

4.2.3 Test Procedure and Data Collection

The boiler was switched on and the solution was allowed to circulate for about an hour before any tests were done[1]. Then the boiler was turned off and the unit was allowed to cool to the ambient temperature of approximately 20°C. The pressure gauge indication of 0.0 bar confirmed the saturation pressure of 0.34 solution concentration at 20°C. To this basic pressure, hydrogen was added in steps of 2.5 bar starting from 7.5 bar. The experimental set-up with the instruments for capturing data is shown in Figure 4.7.

---

[1] This was necessary in order to make the solution in the boiler and the absorber of uniform concentration.

Data were collected as temperature-time variations taken from the components of the unit. These readings were grouped in sets of power input (i.e. 260W, 315W and 370W) within each hydrogen pressure setting, starting from 7.5 bar up to 27.5 bar. There were nine hydrogen pressure settings, thus producing altogether 27 power input-hydrogen pressure sets each of which contained temperature-time data for every component of the unit (Appendix 1).

The tests involved applying a pressure of hydrogen, setting the power input and letting the rig run for an average of 4.5 - 6 hours to allow for steady-state conditions. Between experiments the unit was allowed to cool to ambient temperature for about 5 hours. The recording intervals varied during experimentation. At the beginning of each experiment where the response of the unit was rapid, the readings were taken every 3 - 5 minute intervals; thereafter data were obtained at intervals of 10 minutes.

The line diagrams of Figures 2.1 and 2.2 show the measuring positions for the thermocouple joints. Table 4.1 below correlates these positions to the components.

Table 4.1 Thermocouple measuring points

COMPONENT	THERMOCOUPLE POINTS
Boiler	T_8, T_{10}, T_{11}, T_{12}
Condenser	T_1, T_2, T_3
Reflux condenser	T_{12}, T_1
Low-temp pre-cooler	T_{18}, T_4, T_5, T_6
High-temp pre-cooler	T_3, $T1_8$, T_{16}, T_{19}
Low-temp evaporator	T_4, T_{15}, T_5
High-temp evaporator	T_6, T_{16}
Absorber	T_7, T_9, T_{19}
Solution heat exchanger	T_{13}, T_{10}, T_8, T_9
Hydrogen heat exchanger	T_{17}, T_{16}, T_{19}

Figure 4.7 Front and back views of the experimental unit, with temperature recording instruments [22]

CHAPTER 5

RESULTS AND DISCUSSION

5.0 TEMPERATURE PROFILES

All the recorded temperatures are tabulated in Appendix 1 in groups of power input and hydrogen pressure.

5.1 BOILER

The temperature of the strong solution in the boiler rises sharply for the first 15 to 20 minutes. It then reaches steady state conditions (figures 5.1-5.5). From figures 5.4 and 5.5 it can be seen that there is an increase in the time to attain steady state conditions. These steady state temperatures increase with the increase in power input and also with the increase of hydrogen pressure, figures 5.1 to 5.5.

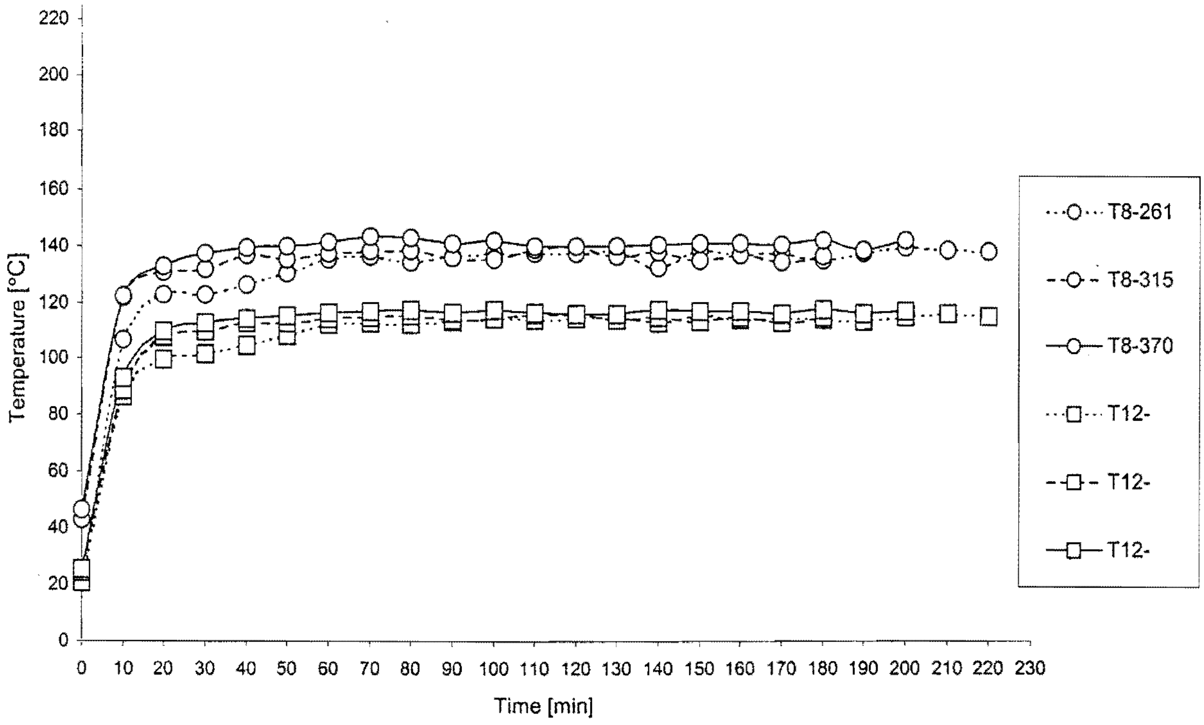


Figure 5.1 Boiler's time response at 7.5 bar hydrogen

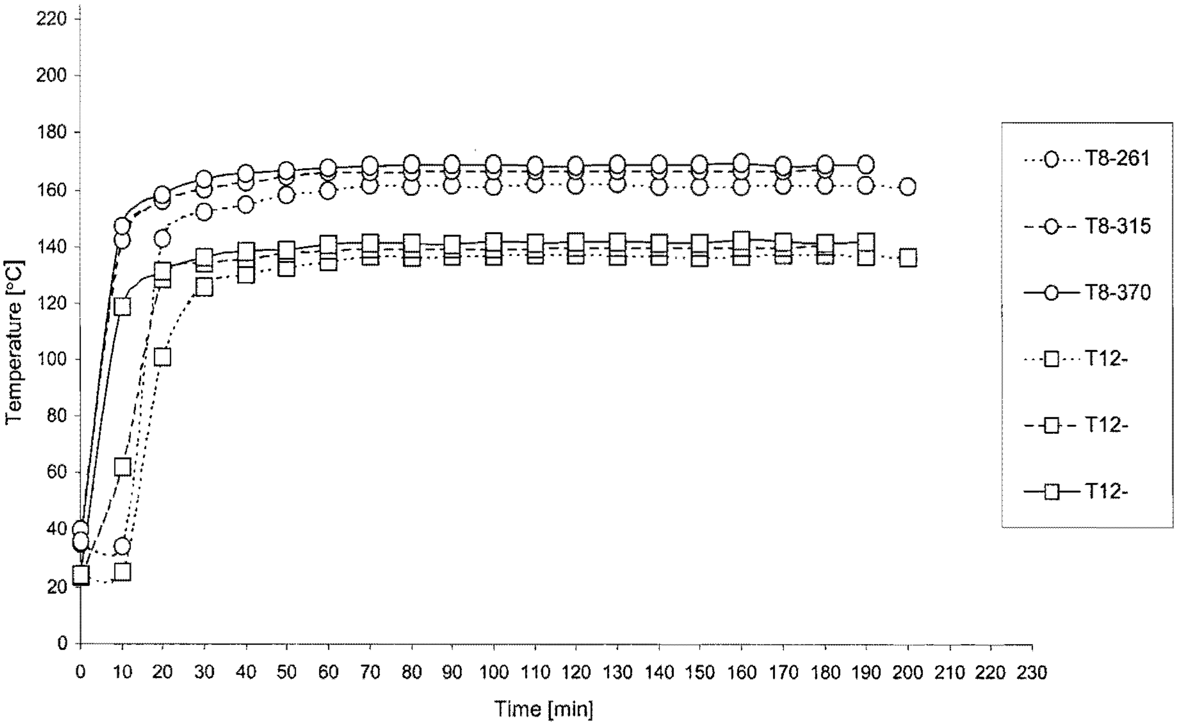


Figure 5.2 Boiler's time response at 12.5 bar hydrogen

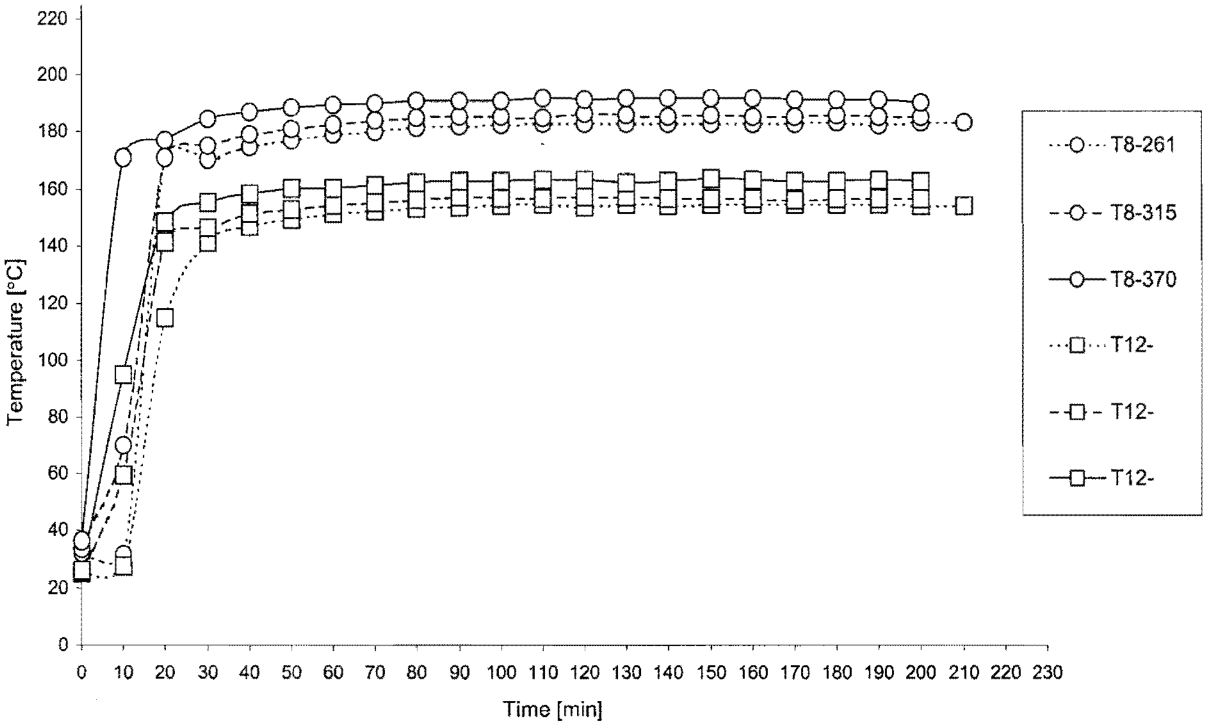


Figure 5.3 Boiler's time response at 17.5 bar hydrogen

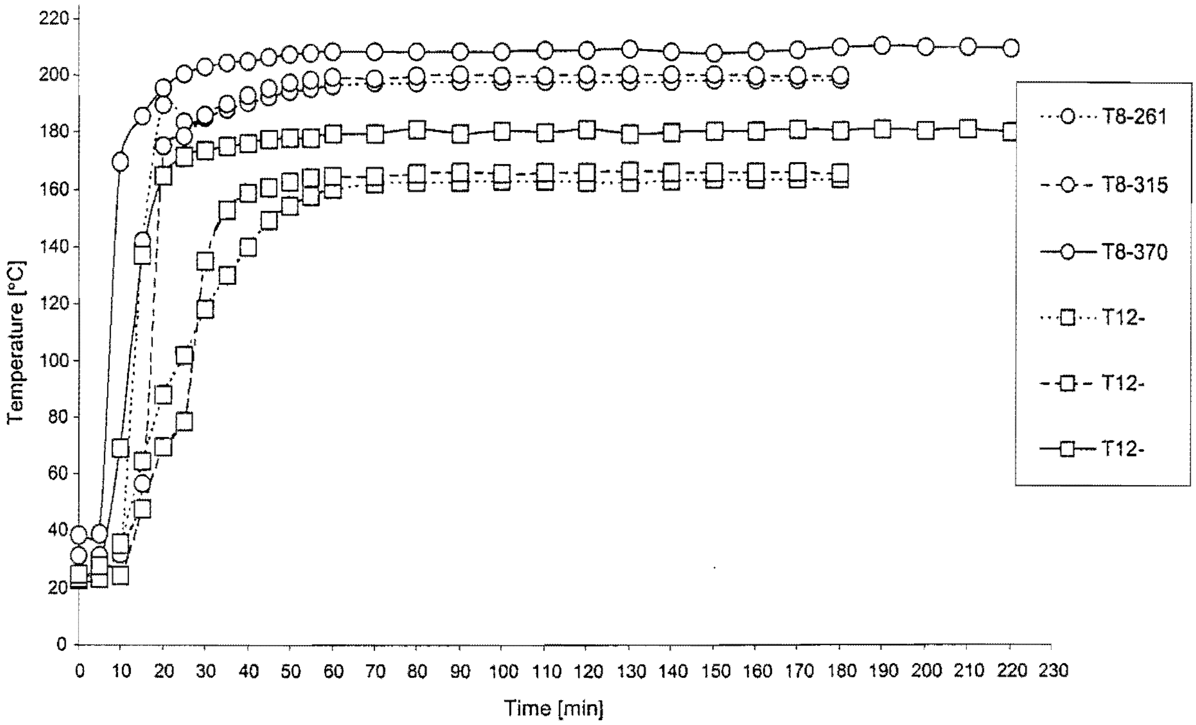


Figure 5.4 Boiler's time response at 22.5 bar hydrogen

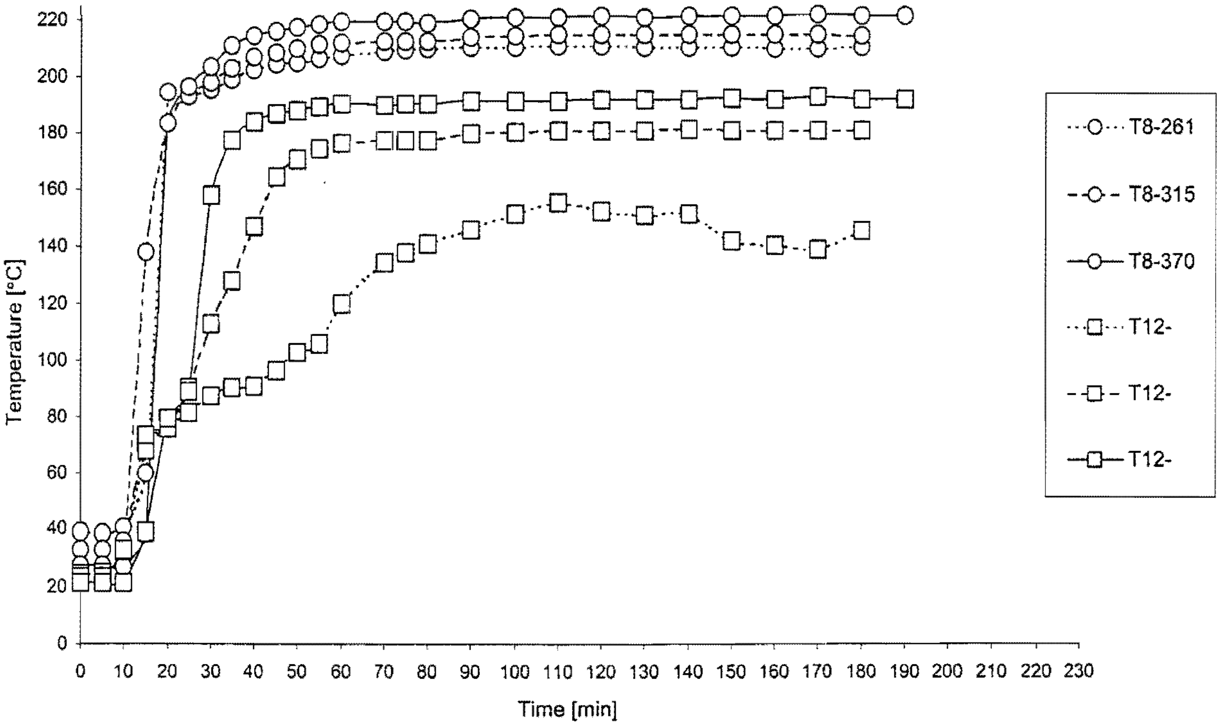


Figure 5.5 Boiler's time response at 27.5 bar hydrogen

5.2 CONDENSER

The condenser's time response is shown in figures 5.6 to 5.10. It is observed that the condenser reaches steady state conditions in 40 to 45 minutes. In all experiments it is observed that the higher the power input the higher the condenser temperature. For the higher hydrogen pressures the curves produce two temperature "regimes" as shown in figures 5.8 to 5.10. These are the inlet temperature T_1 and the outlet temperatures T_2 and T_3. It is quite clear that the higher the hydrogen pressure the larger the separation of these temperatures. In addition the condensate temperature T_2 is almost constant regardless of the experimental condition. This behaviour can be explained as follows:

In the condenser there is a phase change of the ammonia-water vapour mixture from gas to liquid and because there is no hydrogen in the condenser, the total pressure is equal to the ammonia-water vapour partial pressure.

Since there is no distillation column, it can be assumed that the ammonia-water vapour has a concentration of 0.9. Referring to figure 5.11, this vapour at 22 bar pressure condenses at 60°C. From figure 5.9, which shows a similar working pressure of 22.5bar, it is evident that the incoming vapour is slightly superheated (67°C) and hence it reaches saturation within a small distance from the inlet to condenser. The latent heat of condensation is given up at about 60°C and the remaining drop of temperature is due to the sub-cooling of the condensate to about 30°C, which is close to ambient temperature.

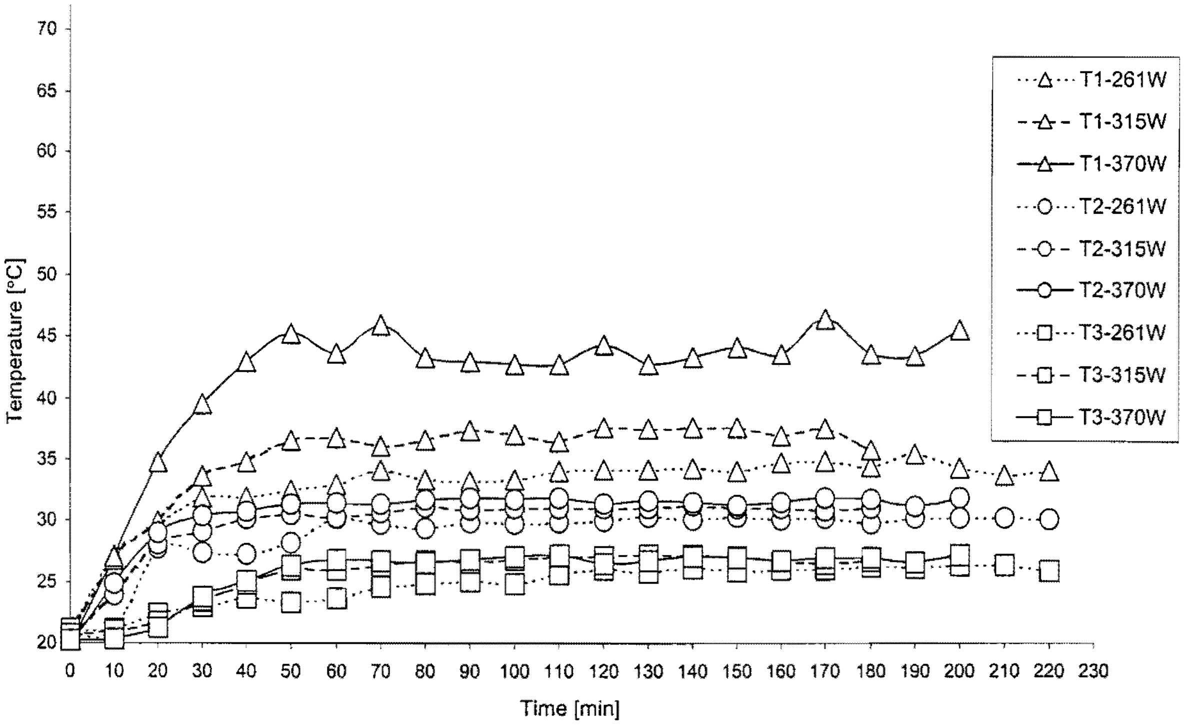


Figure 5.6 Condenser's time response at 7.5 bar hydrogen

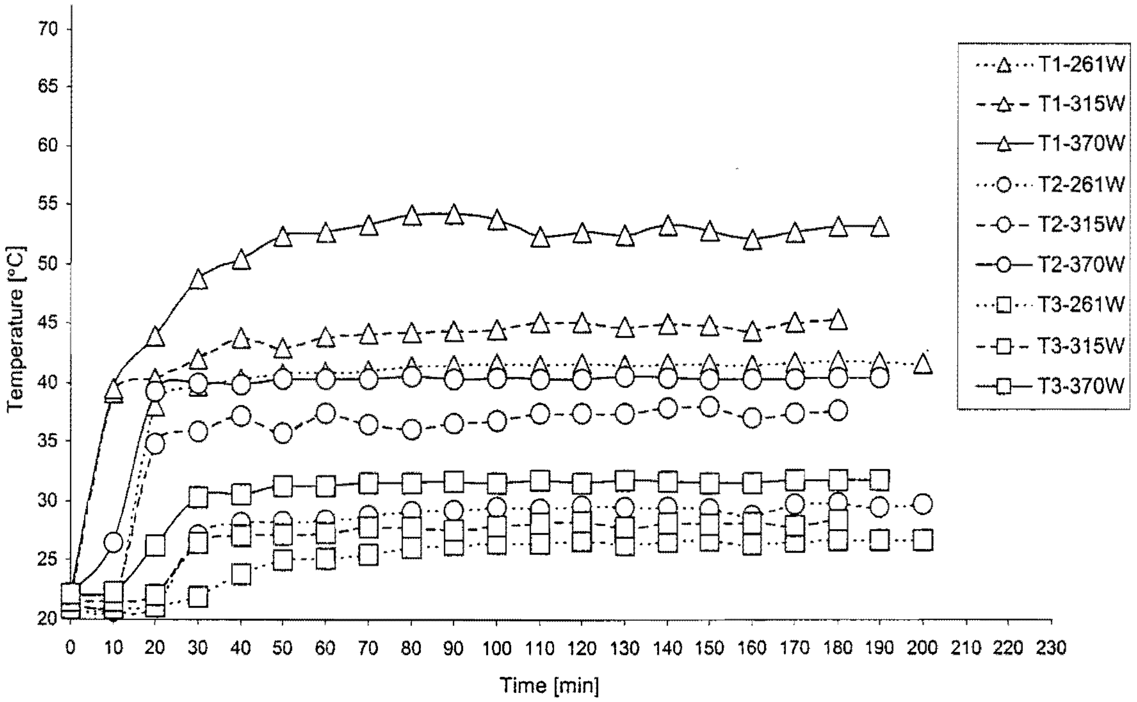


Figure 5.7 Condenser's time response at 12.5 bar hydrogen

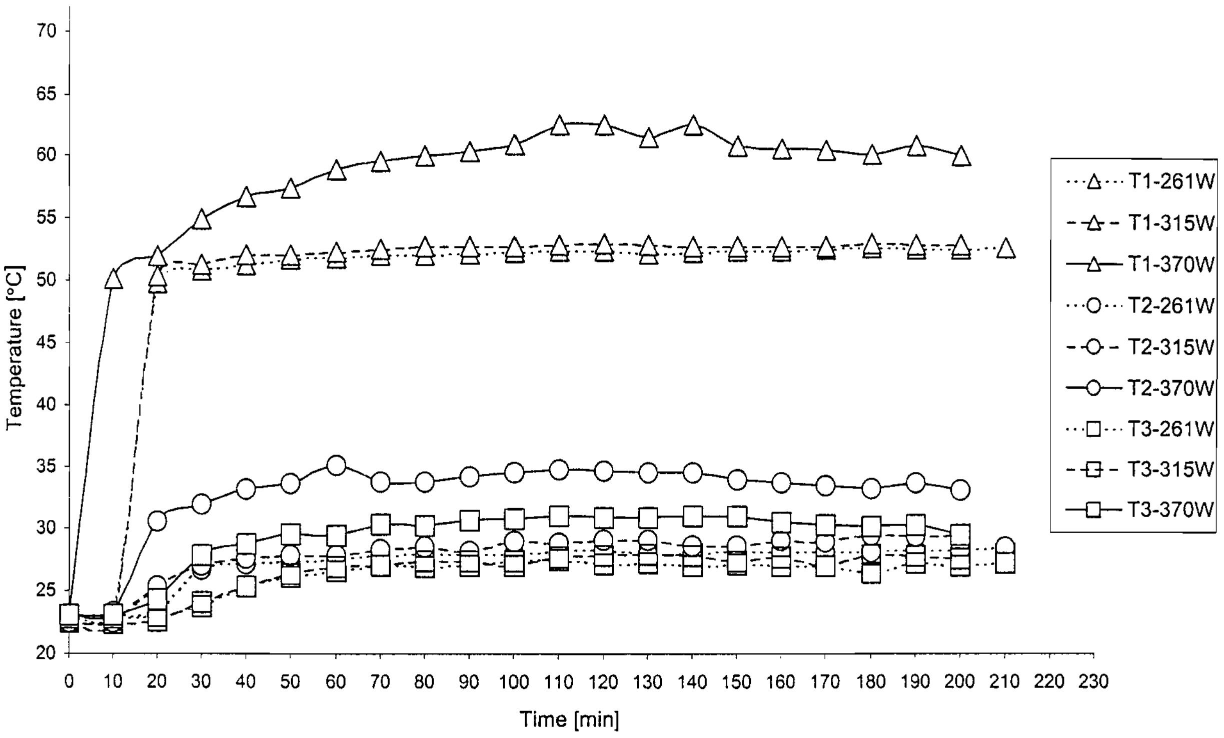


Figure 5.8 Condenser's time response at 17.5 bar hydrogen

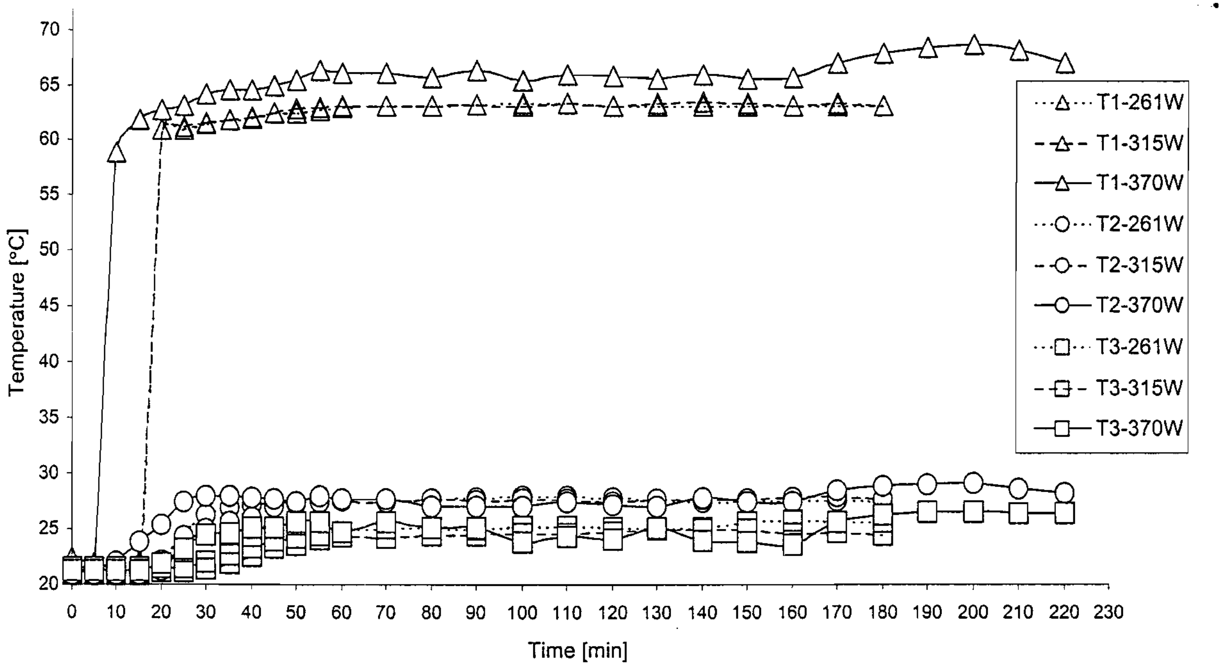


Figure 5.9 Condenser's time response at 22.5 bar hydrogen

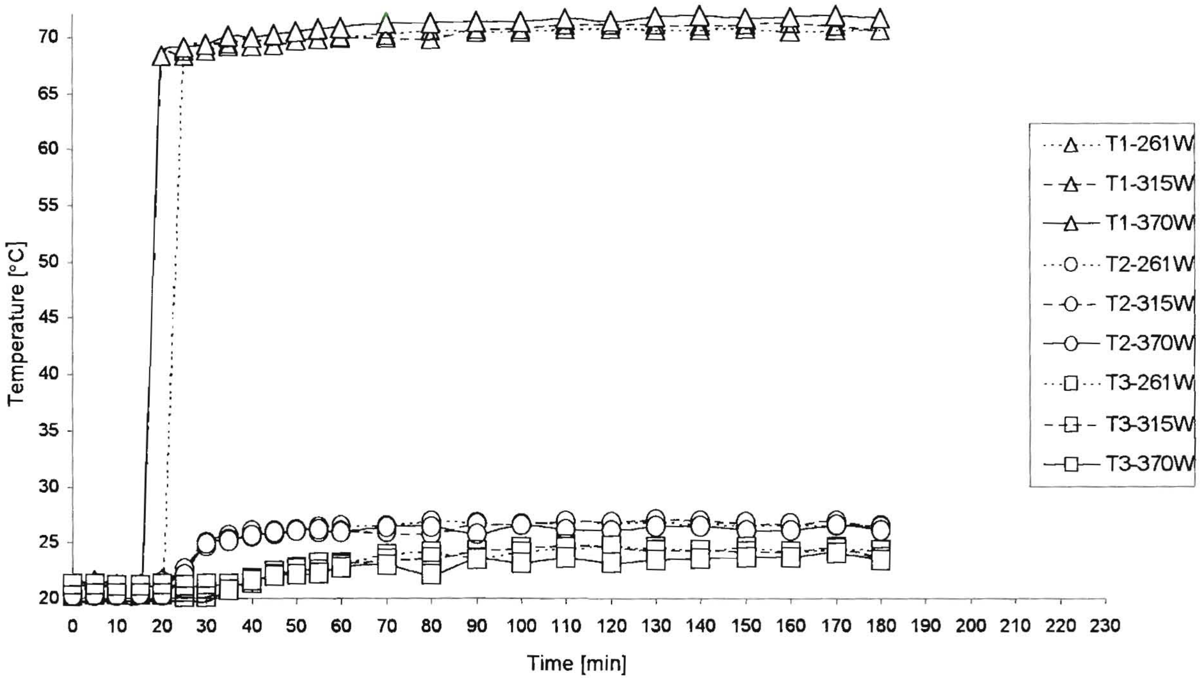


Figure 5.10 Condenser's time response at 25.0 bar hydrogen

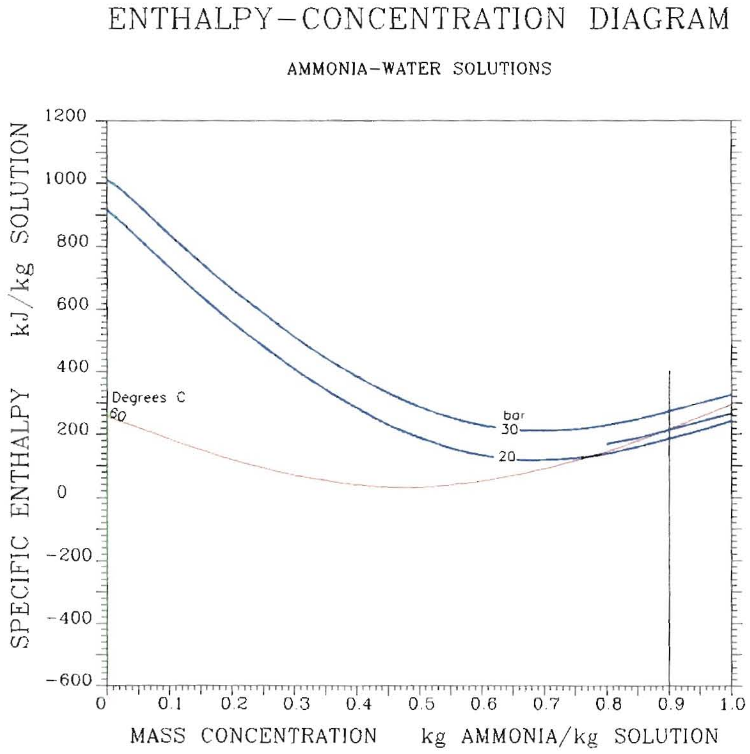


Figure 5.11 Saturation temperature in the condenser

5.3 EVAPORATORS

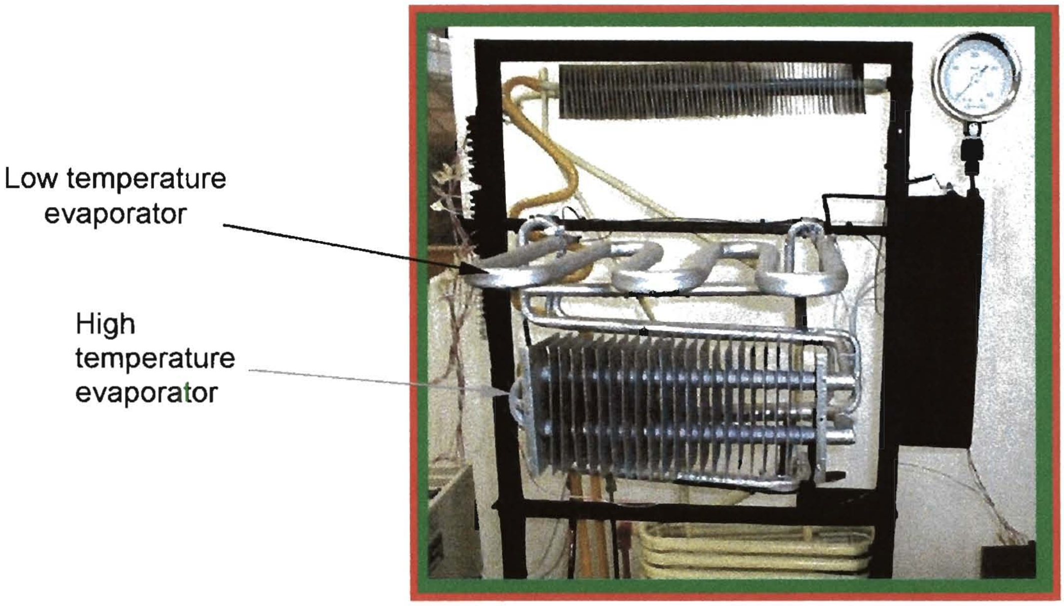


Figure 5.12 The two evaporators as they appear in the experimental rig [21].

The temperature-time response for the low and high temperature evaporators are shown in Figures 5.13-5.17 and Figures 5.18-5.22 respectively.

5.3.1 Low temperature evaporator

The general trend shows a sharp reduction in temperature within the first 40 to 45 minutes after which steady state conditions are attained. It can be noted that at 7.5 bar hydrogen pressure (Figure 5.13) the inlet temperature T_{15} is much lower than the outlet evaporator temperature T_5 that remains ambient. But the temperature T_5 is observed to reduce significantly as the hydrogen pressure is increased. This can be explained as follows:

When the pressure of hydrogen is increased, the contribution of the partial pressure of ammonia to the total pressure in the evaporator decreases. This increases the rate of ammonia boiling in the evaporator coil.

At 12.5 bar hydrogen, T_5 is at its lowest value for all power inputs and pressures. This is indicated in Figure 5.18, which summarises the steady-state temperature T_5.

At this stage it is appropriate to state that the lowest temperature attained i.e. –8.2°C at 12.5 bar of hydrogen contradicts the manufacturer's recommendation of 22 bar of hydrogen pressure. However it is felt that –8.2°C in the freezer space of the unit is insufficient. The reason for this behaviour will be explained together with the absorber's behaviour in paragraph 5.6 and in the comments that follow.

5.3.2 High temperature evaporator

Both inlet and exit of high temperature evaporator (Fig.5.19-5.23) also show a gradual decrease in temperature. These temperatures reach steady-state conditions after an hour. For the hydrogen pressure of 7.5 bar (Figure 5.19) the inlet and exit temperatures indicate no refrigeration. The explanation for this is similar to that of the low temperature evaporator. It can also be observed that the separation between inlet T_6 and outlet T_{16} temperatures is more evident as the pressure of hydrogen increases, with T_6 consistently lower than T_{16}.

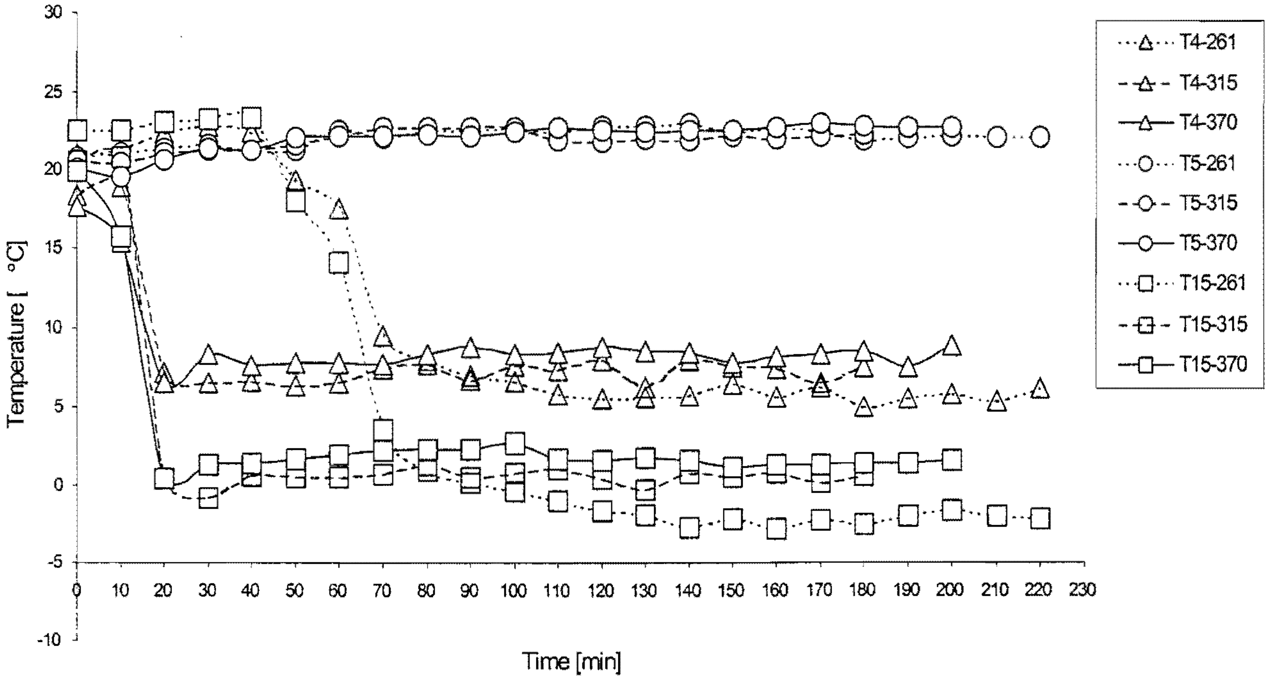


Figure 5.13 Low temperature evaporator's time response at 7.5 bar hydrogen

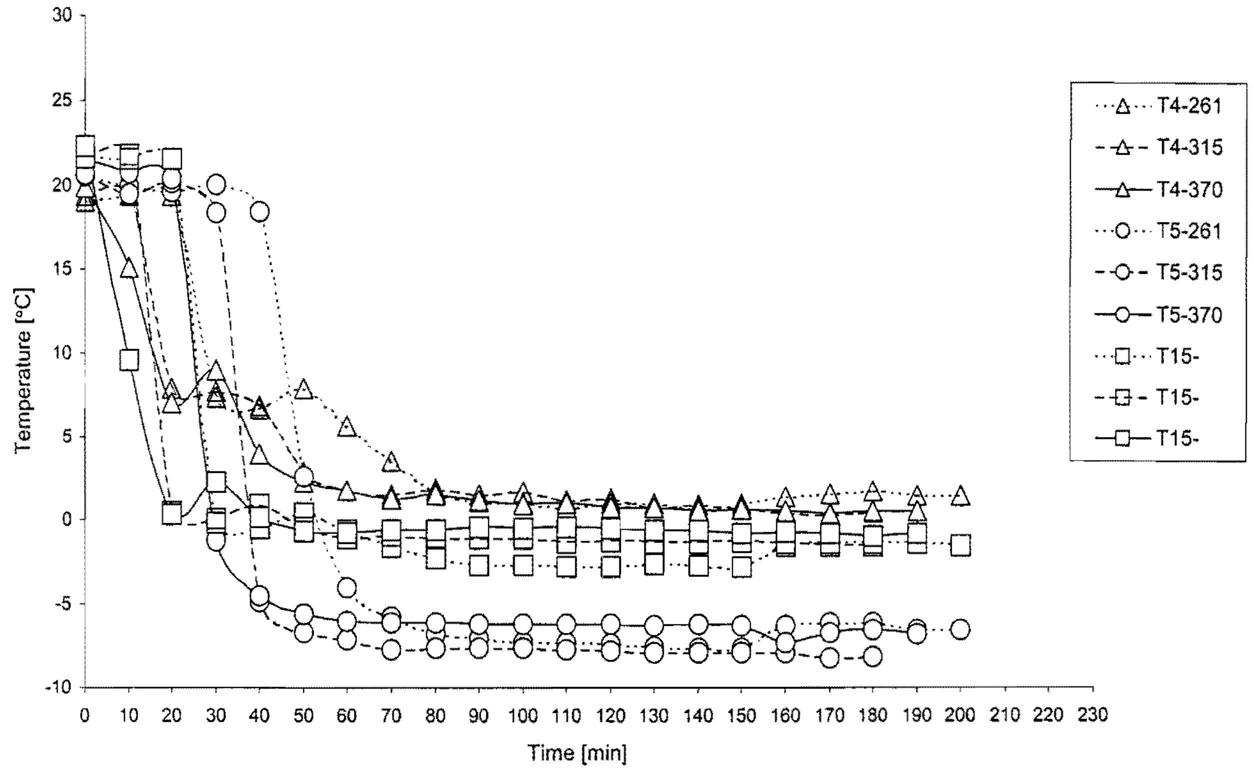


Figure 5.14 Low temp. evaporator's time response at 12.5 bar hydrogen

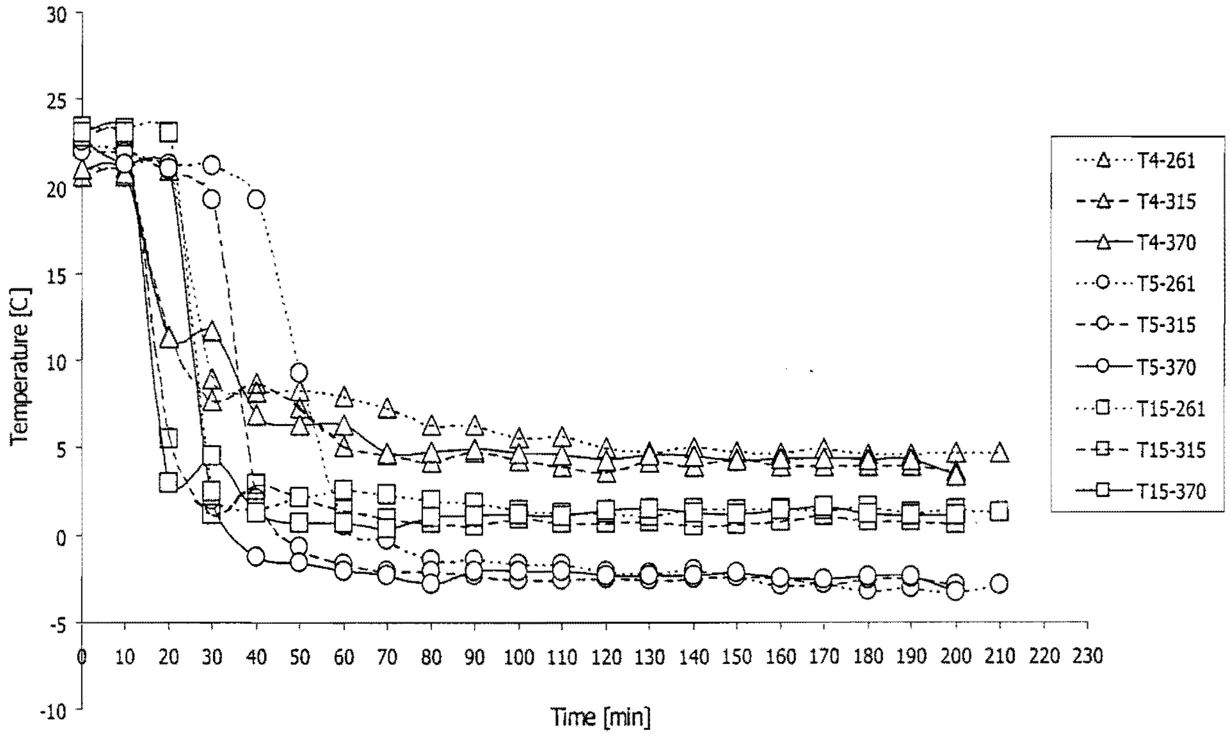


Figure 5.15 Low temp. evaporator's time response at 17.5 bar hydrogen

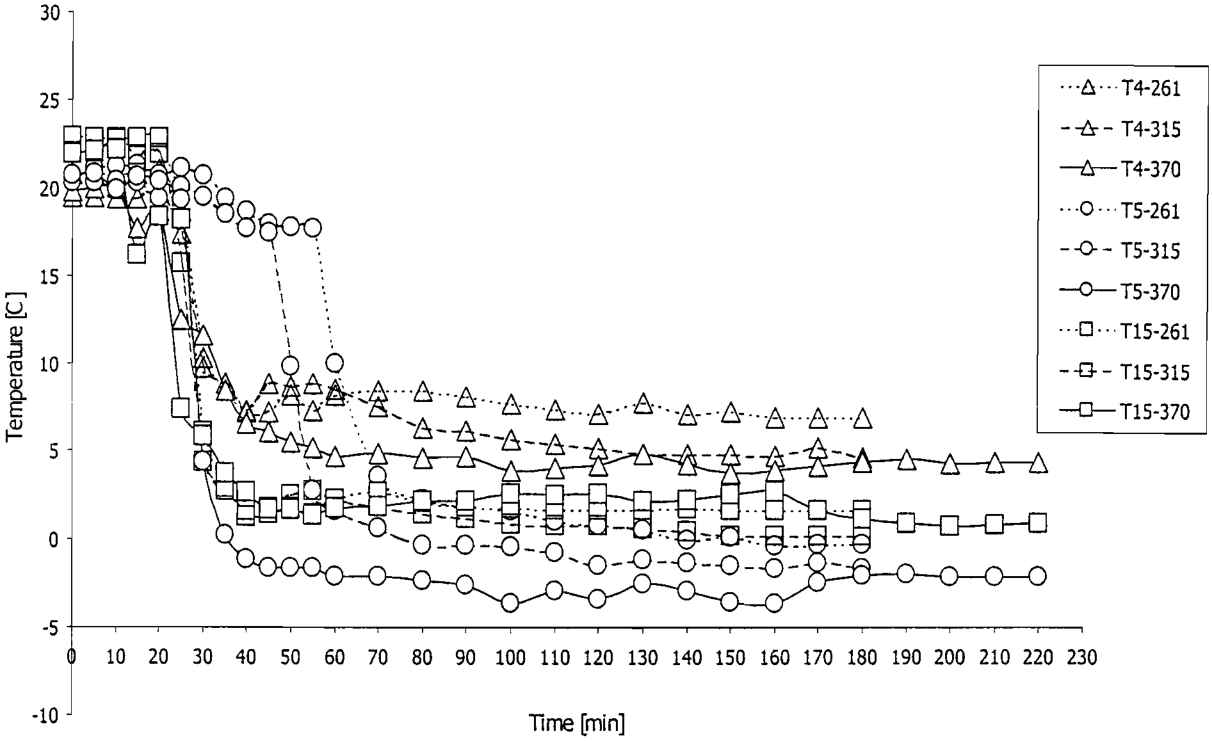


Figure 5.16 Low temp. evaporator's Time Response at 22.5 bars Hydrogen

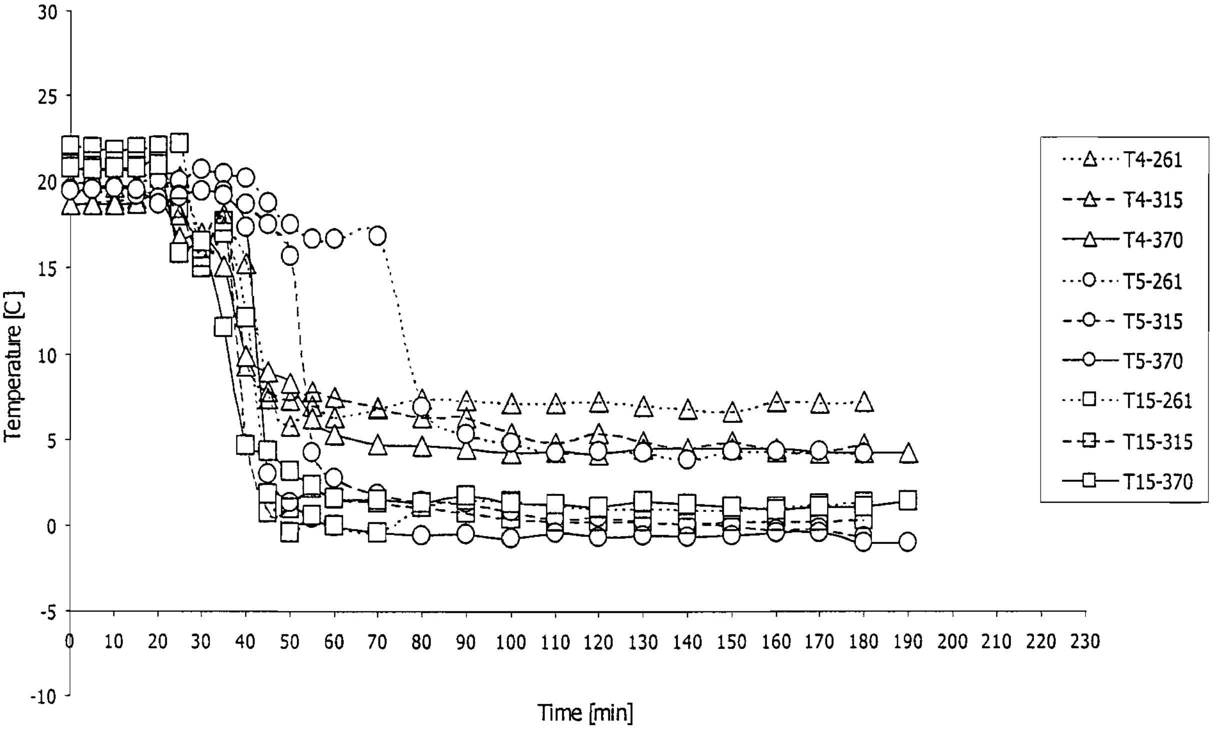


Figure 5.17 Low temp. evaporator's time response at 27.5 bar hydrogen

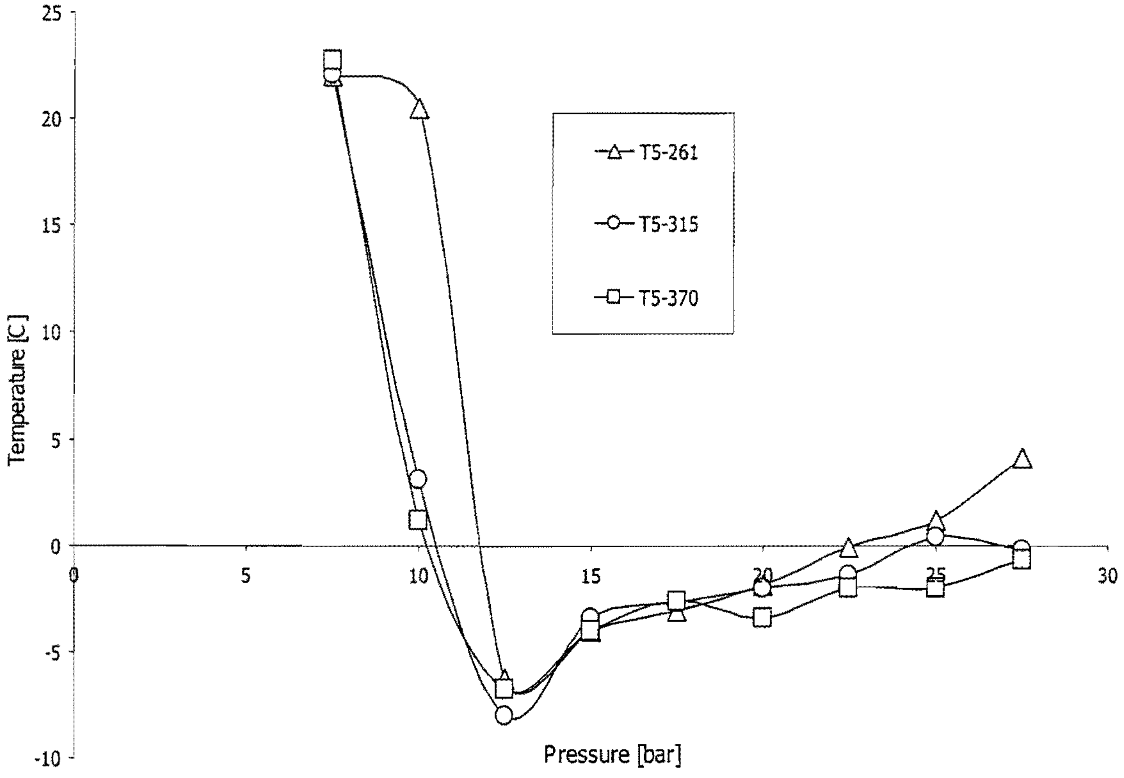


Figure 5.18 Evaporator temperature as a function of hydrogen pressure

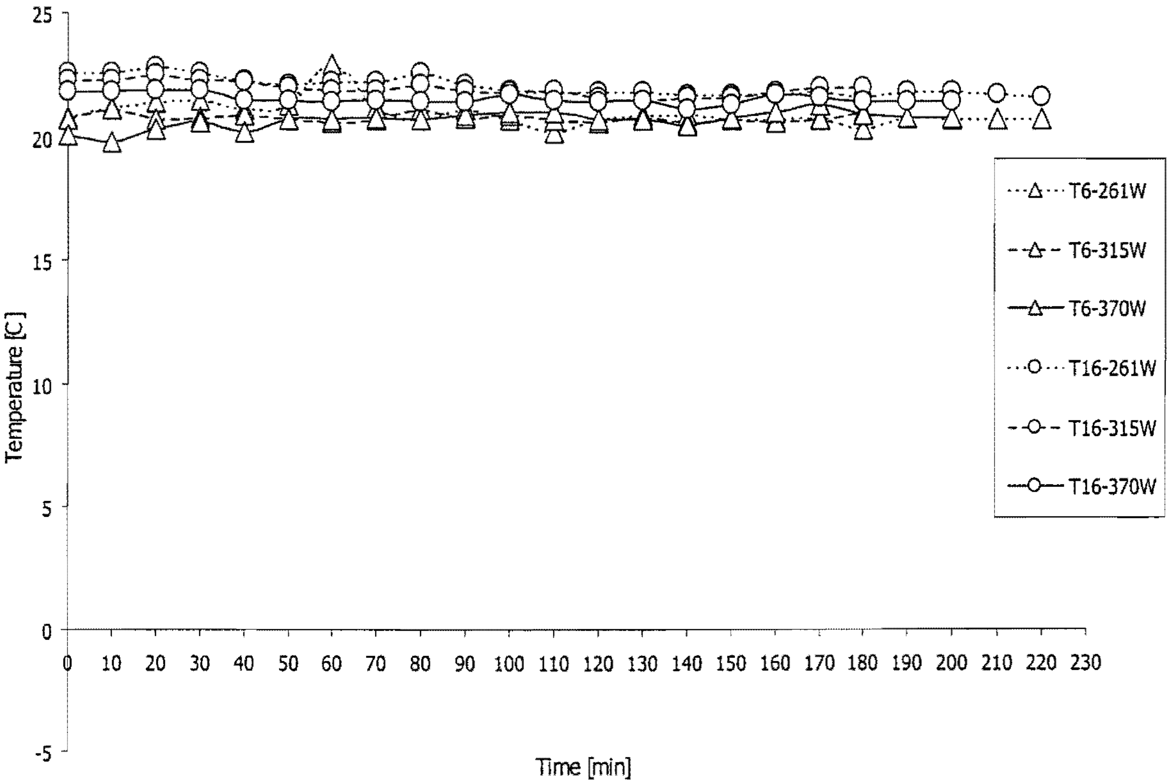


Figure 5.19 High temp. evaporator's time response at 7.5 bar hydrogen

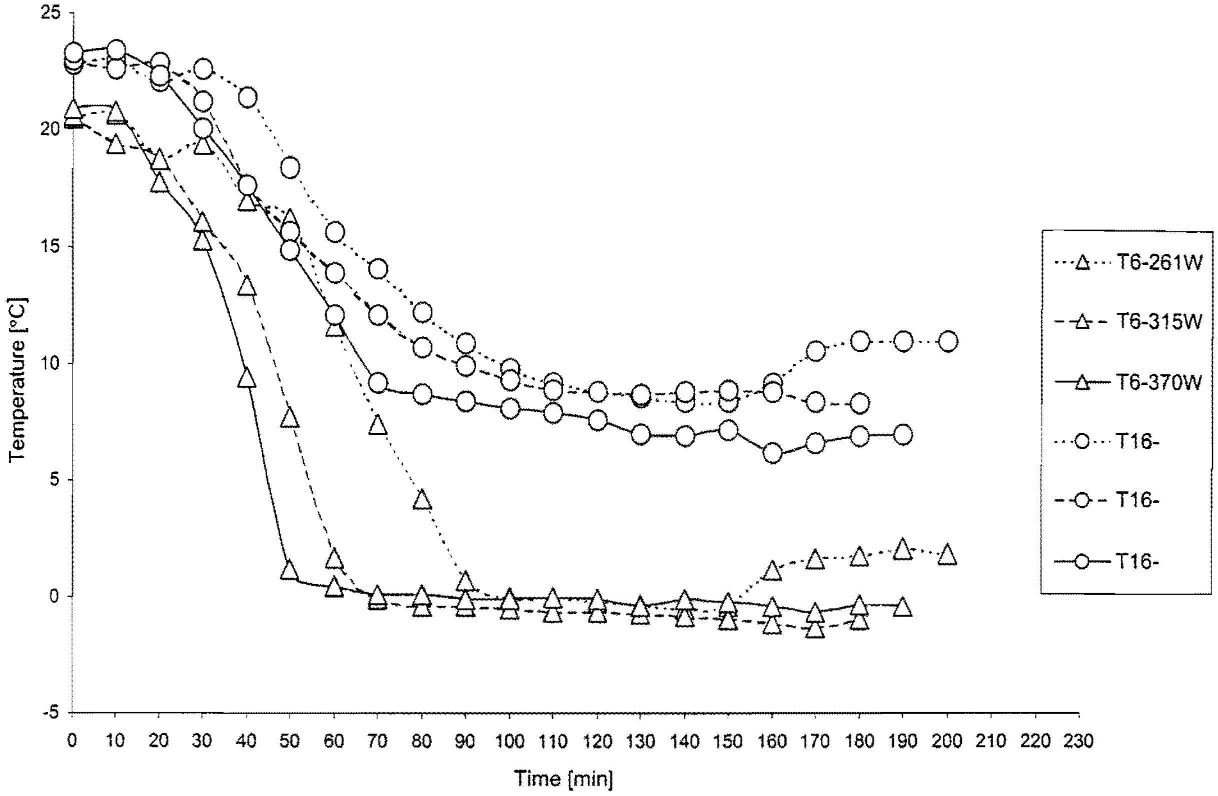


Figure 5.20 High temp. evaprator's time response at 12.5 bar hydrogen

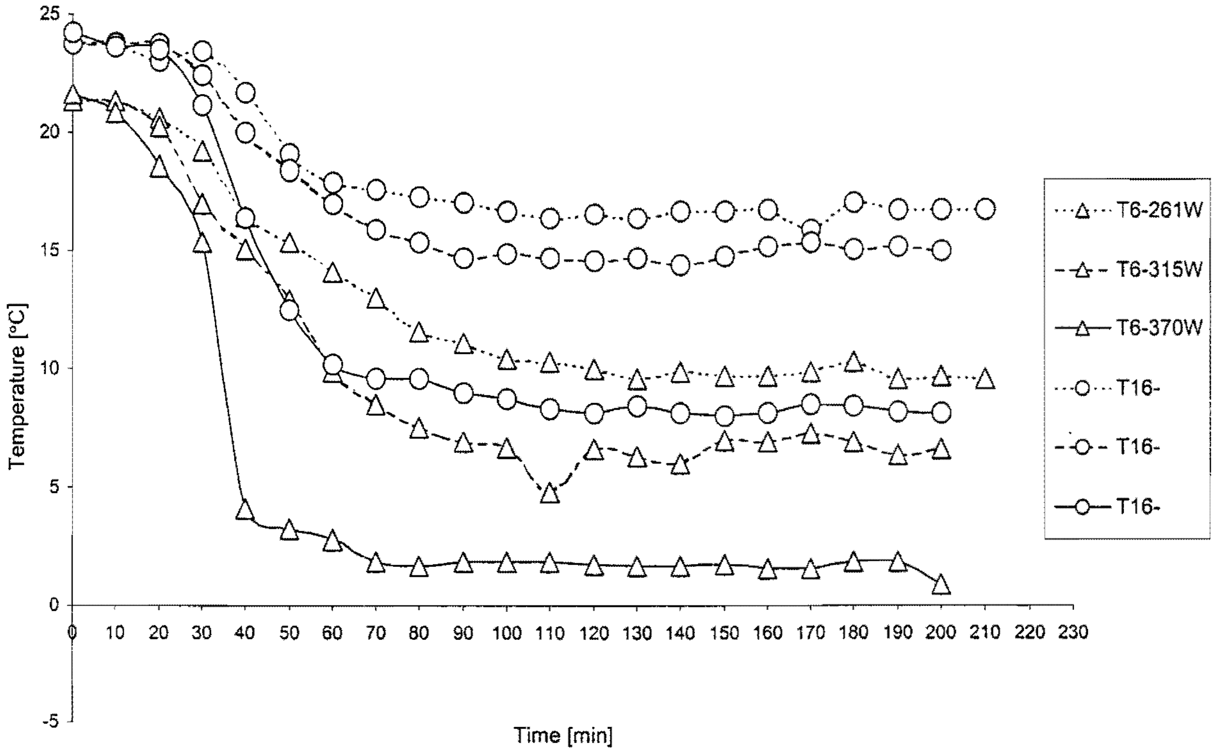


Figure 5.21 High temp. evaporator's time response at 17.5 bar hydrogen

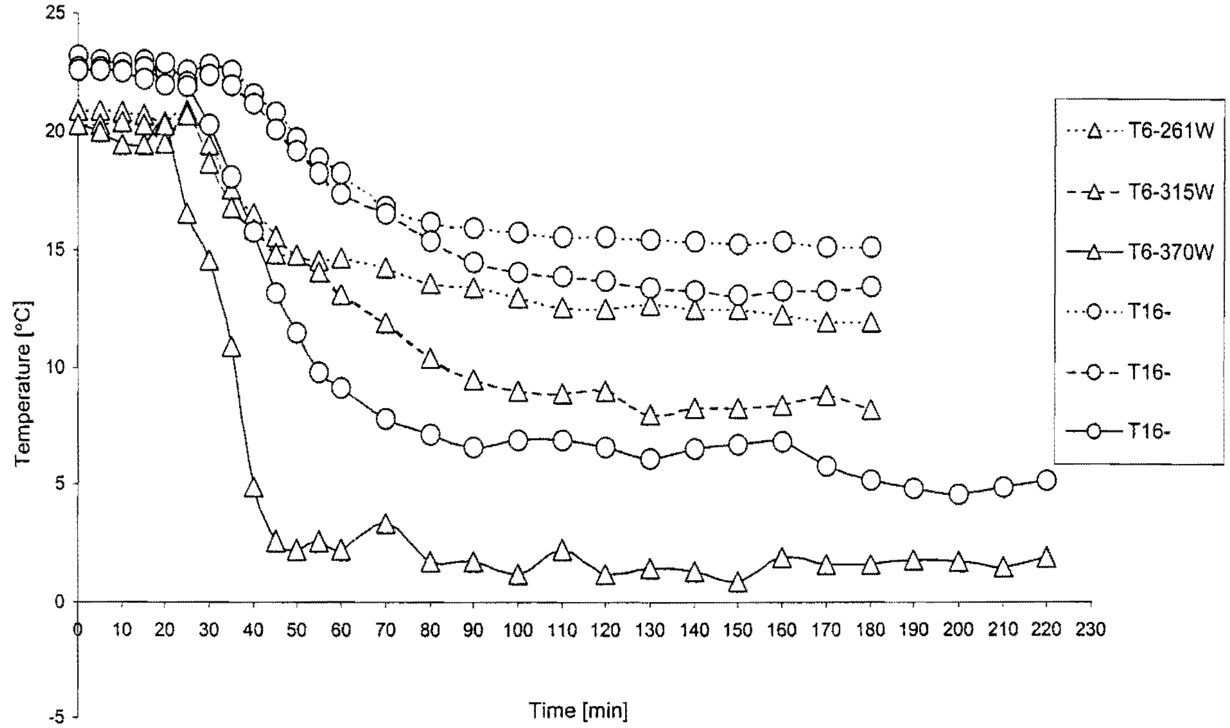


Figure 5.22 High temp. evaporator's time response at 22.5 bar hydrogen

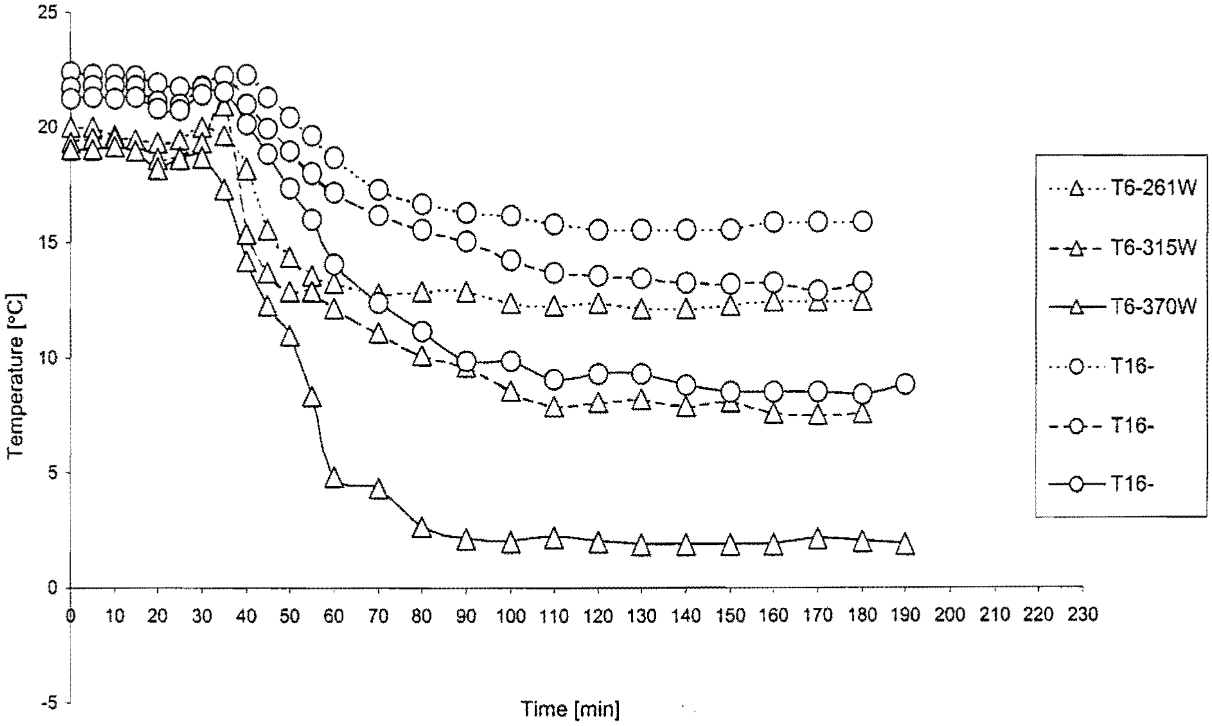


Figure 5.23 High temp. evaporator's time response at 27.5 bar hydrogen

5.4 PRE-COOLERS

The temperature-time response for the low and high temperature pre-coolers is shown in figures 5.24-5.28 and figures 5.29-5.33 respectively.

5.4.1 Low temperature pre-cooler

The cold stream temperatures T_5 and T_6 have been observed with the low and high temperature evaporators respectively and are hence not included in the Figures shown.

The Low temperature pre-cooler shows a decline of the hot stream temperatures T_{18} and T_4 with the increase in hydrogen pressure. At a hydrogen pressure of 7.5 bar, the temperature T_{18} is ambient. With reference to the line diagram of Figure 2.2, this is as expected because at low hydrogen pressures, T_{16} also be at ambient.

The response time to reach steady state is observed to increase with increase in hydrogen pressure.

5.4.2 High temperature pre-cooler

The temperatures T_3 and T_{18} have been observed with the condenser and low temperature pre-cooler respectively and are hence not included in the Figures shown.

The temperature profile of the high temperature pre-cooler shows a gradual decrease to steady state conditions. It can be observed that there is a time when both temperatures start changing. This response depends on the time response of the evaporators, and as expected it increases with the increase in hydrogen pressure.

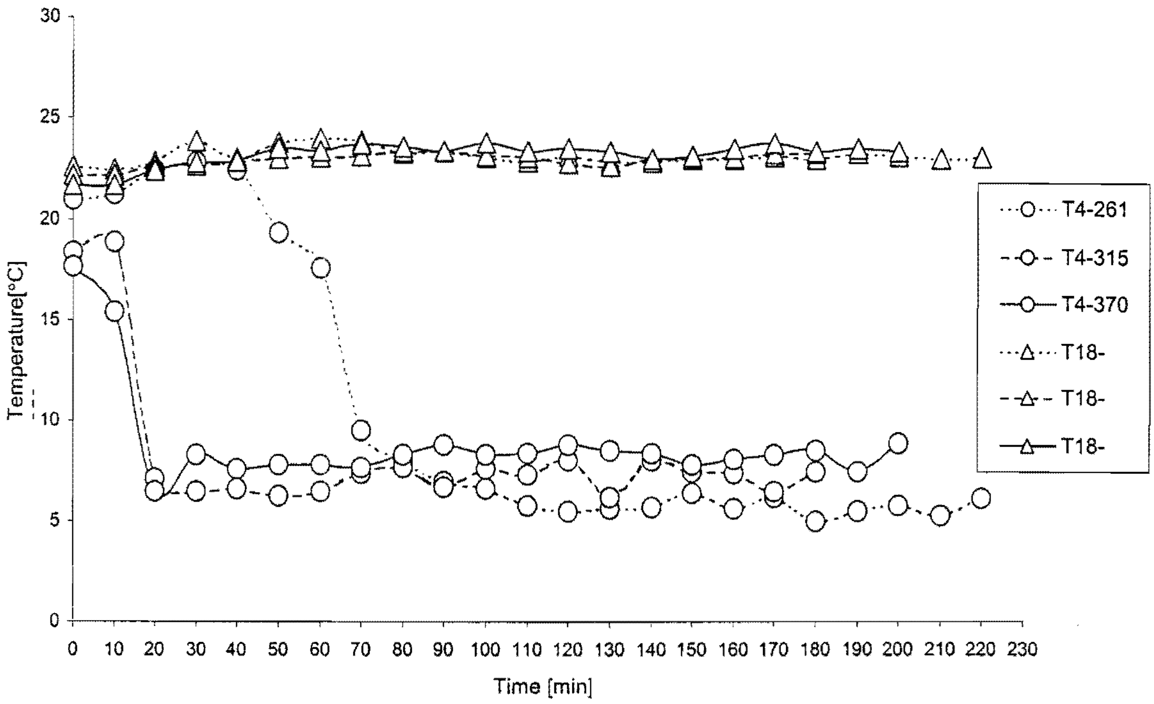


Figure 5.24 Low temp. pre-cooler's time response at 7.5 bar hydrogen

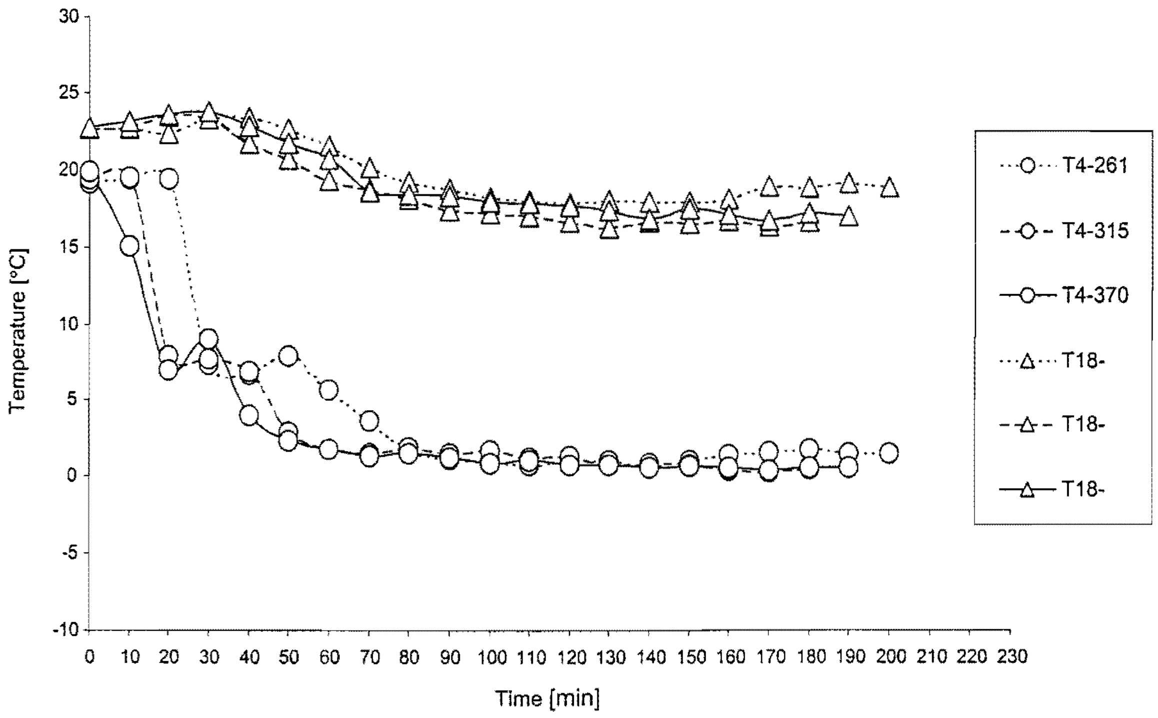


Figure 5.25 Low temp. pre-cooler's time response at 12.5 bar hydrogen

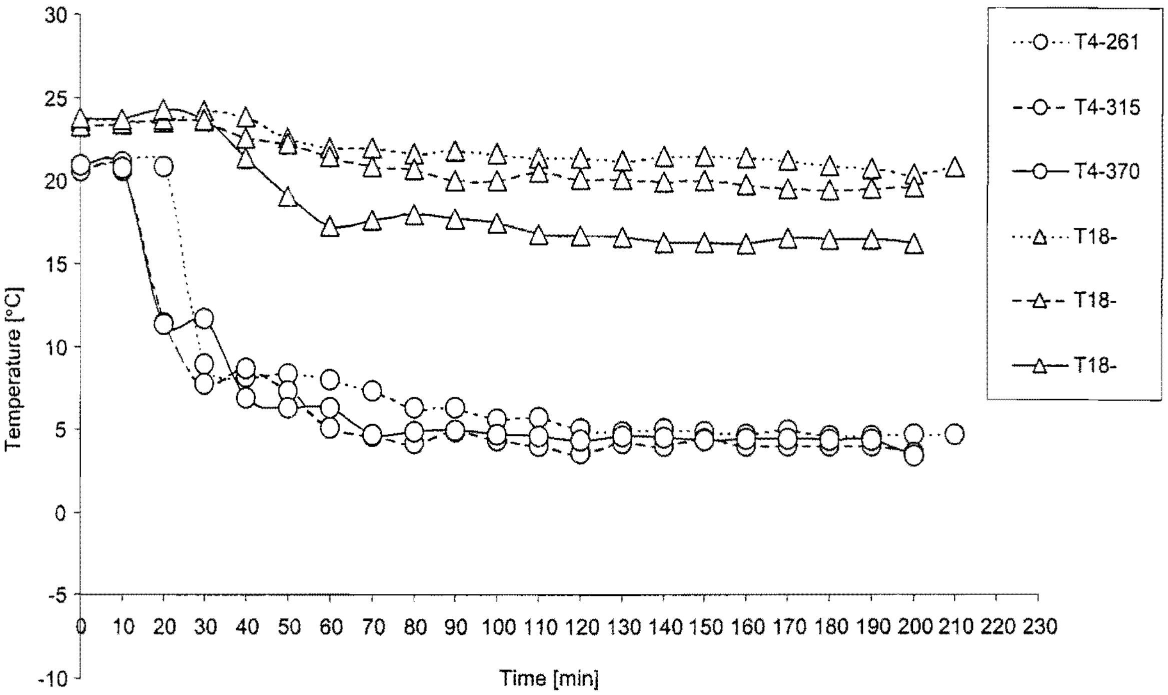


Figure 5.26 Low temp. pre-cooler's time response at 17.5 bar hydrogen

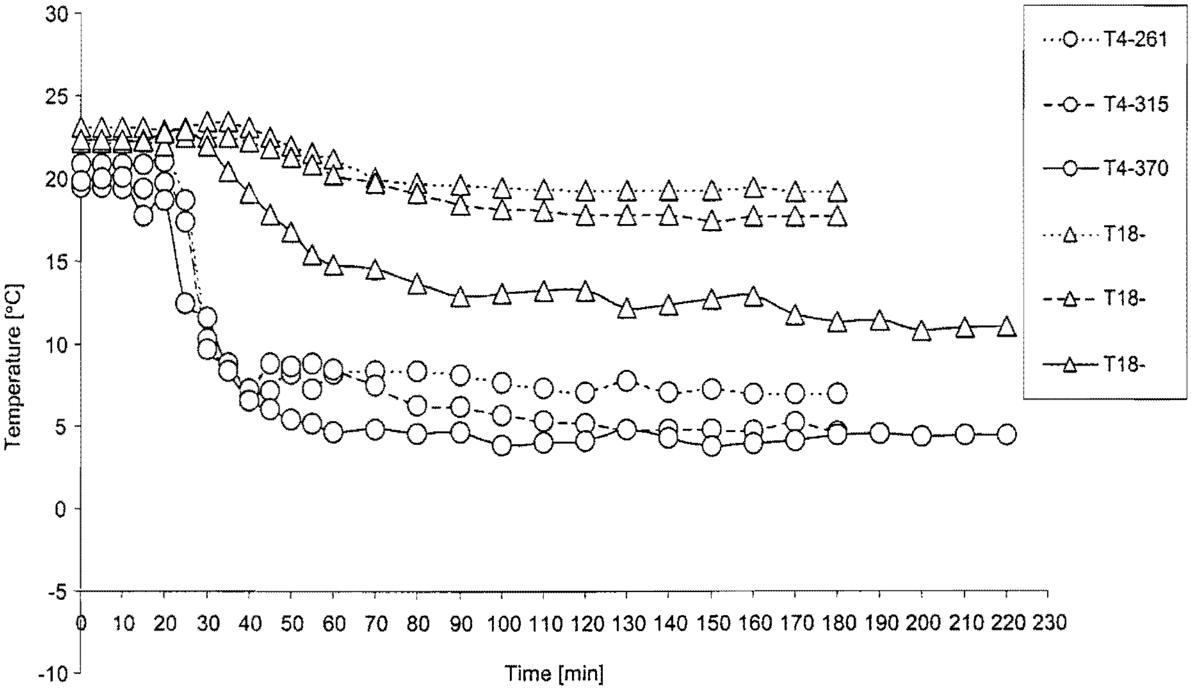


Figure 5.27 Low temp. pre-cooler's time response at 22.5 bar hydrogen

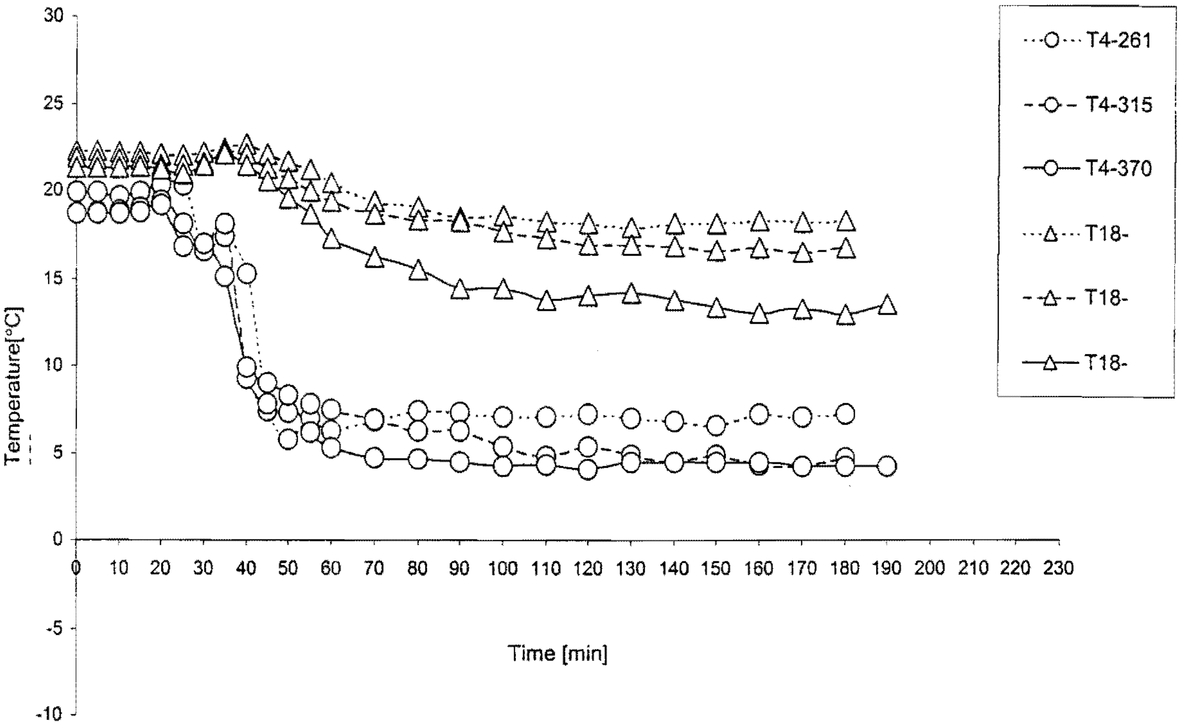


Figure 5.28 Low temp. pre-cooler's time response at 27.5 bar hydrogen

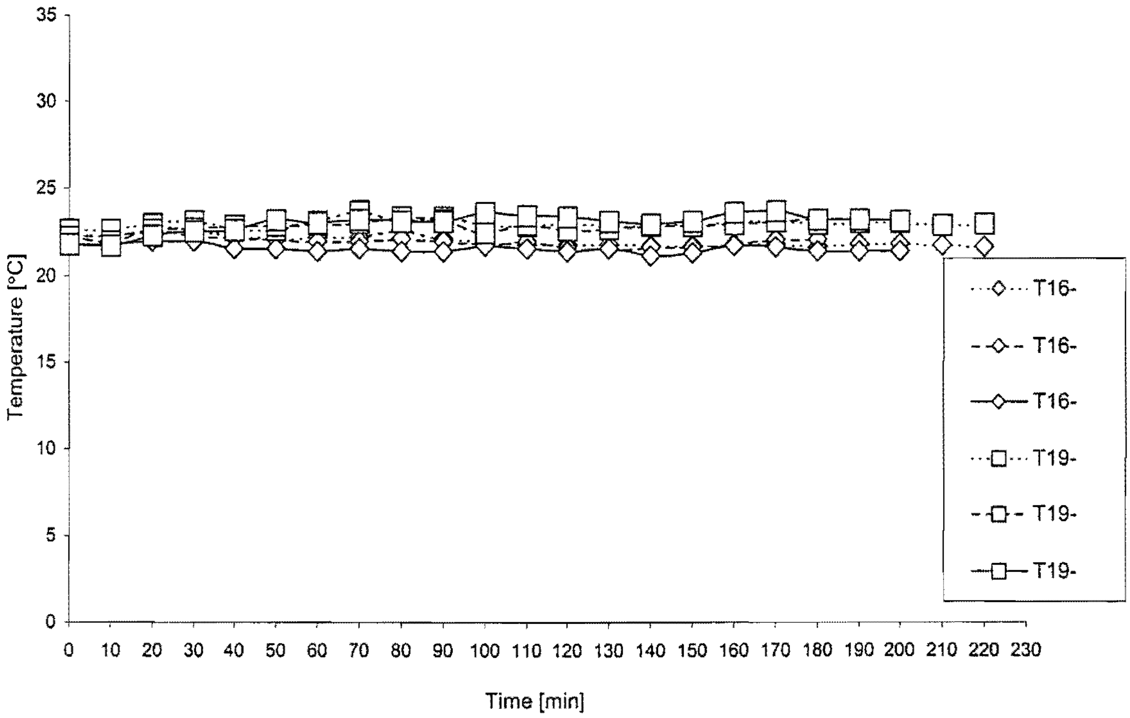


Figure 5.29 High temp. pre-cooler's time response at 7.5 bar hydrogen

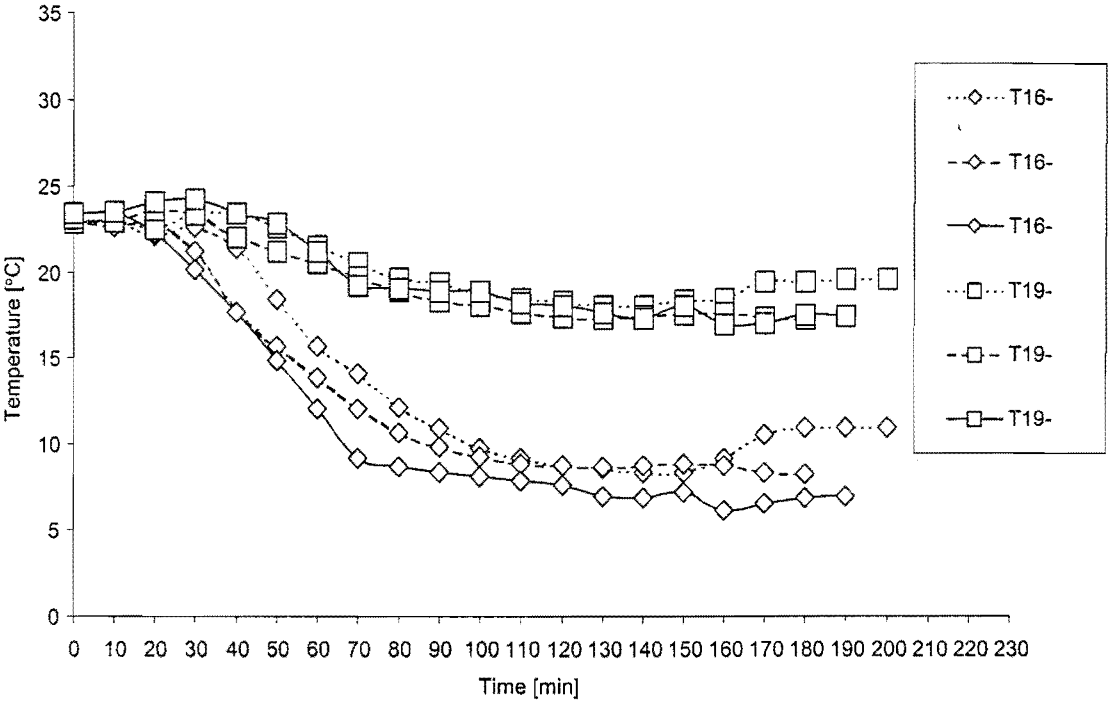


Figure 5.30 High temp. pre-cooler's time response at 12.5 bar hydrogen

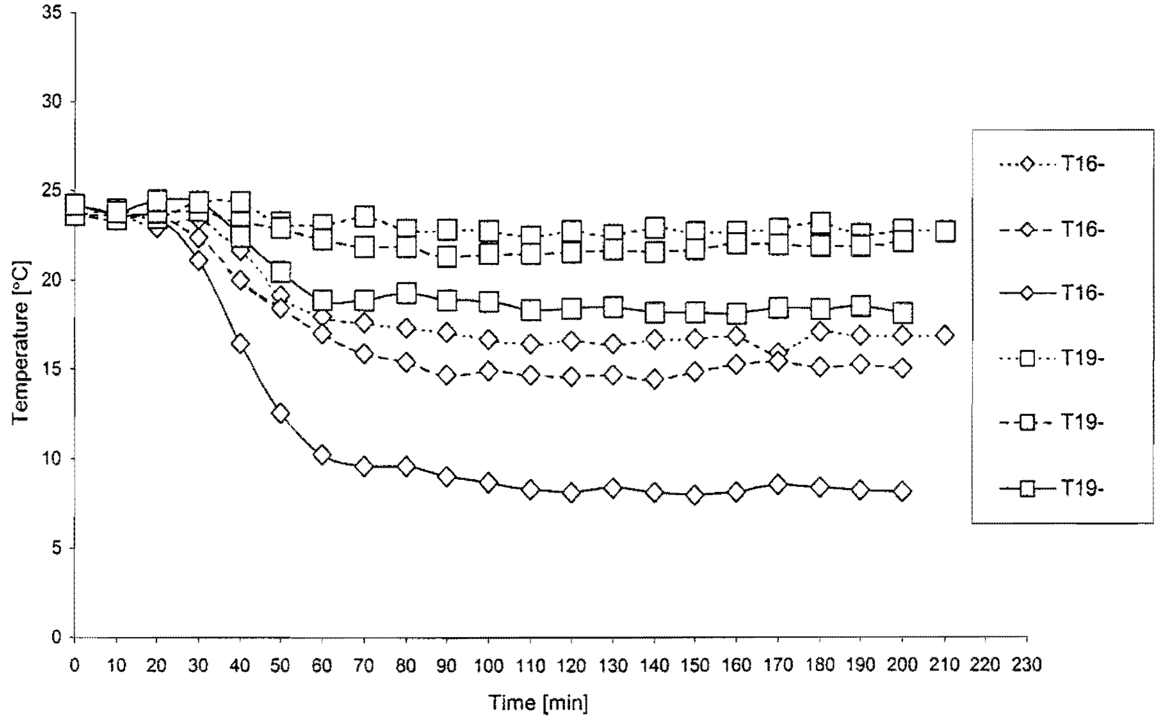


Figure 5.31 High temp. pre-cooler's time response at 17.5 bar hydrogen

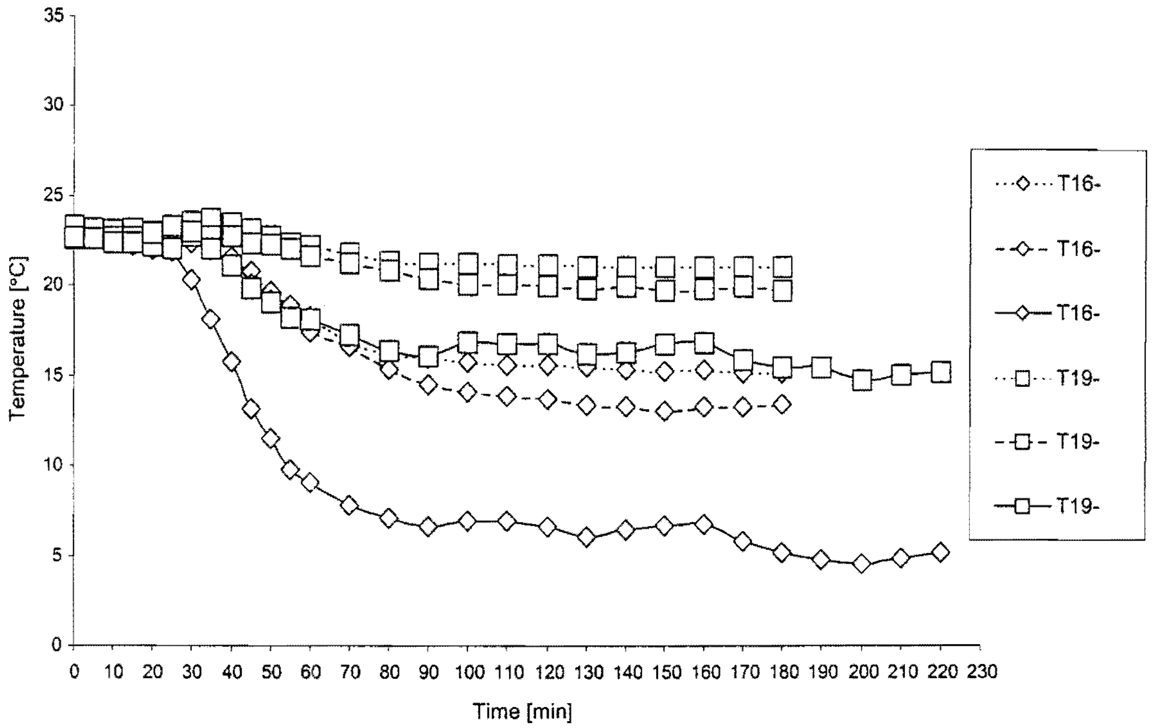


Figure 5.32 High temp. pre-cooler's time response at 22.5 bar hydrogen

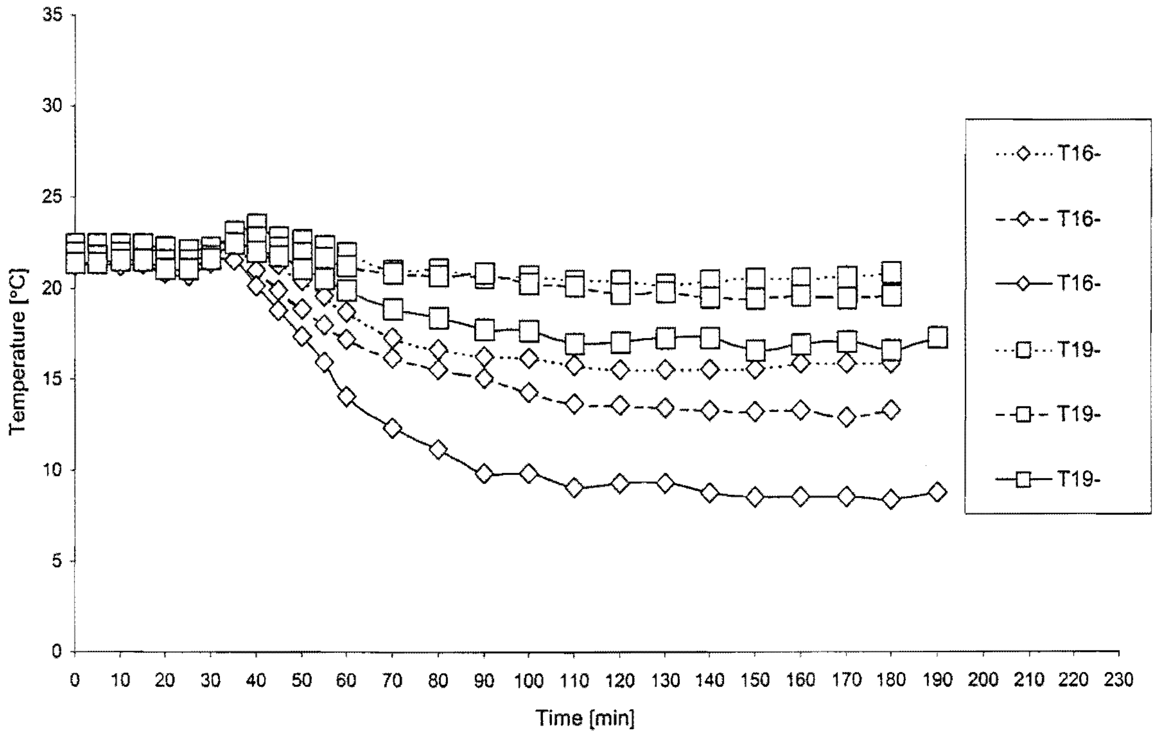


Figure 5.33 High temp. pre-cooler's time response at 27.5 bar hydrogen

5.4.3 Performance of the pre-coolers

Figure 5.34 shows the effectiveness of the low temperature pre-cooler. The values have been calculated according to equation (2.4) and are tabulated in appendix 2. It is observed that the effectiveness of the low temperature pre-cooler rises sharply with pressure until the pressure of 10 bar. Then it remains almost constant with the effectiveness ranging between 0.6 and 0.8. This value is as expected for a gas-to-liquid heat exchanger.

The effectiveness profile for the high temperature pre-cooler shows a non-conclusive pattern, and hence it is not shown in this work.

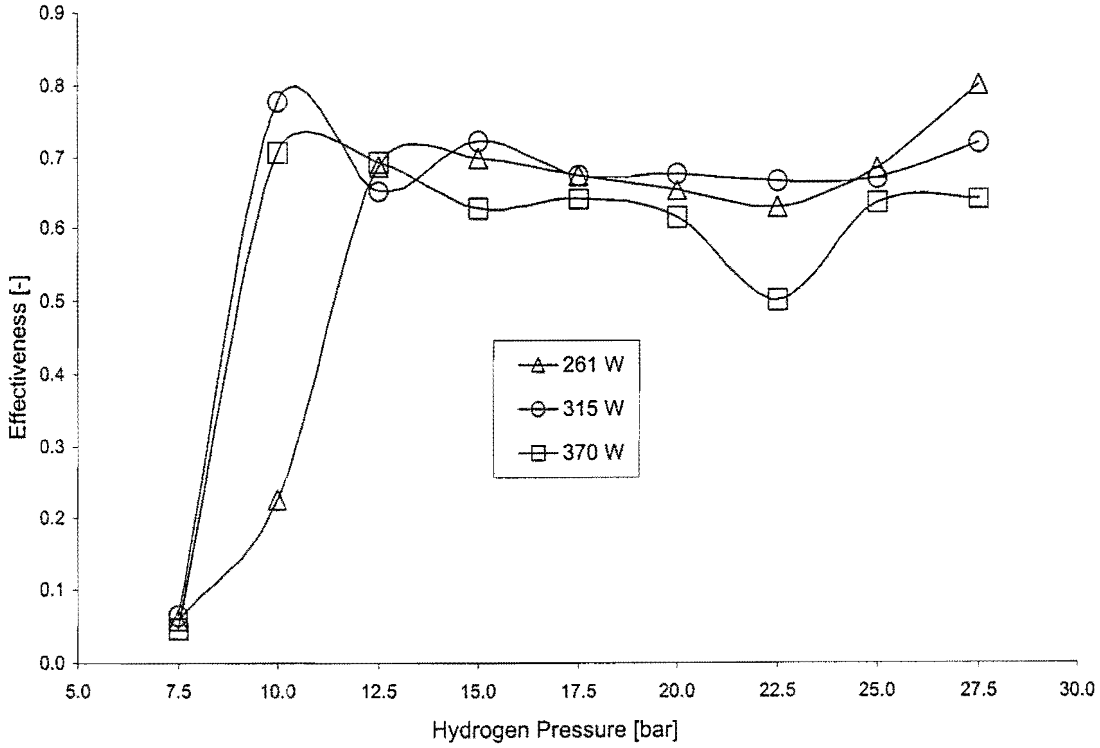


Figure 5.34 Low temp. pre-cooler effectiveness as a function of hydrogen pressure

5.5 SOLUTION HEAT EXCHANGER

The temperature-time profile of the solution heat exchanger is shown in figures 5.35-5.39. It is observed that the "cold side" (T_{13} and T_{10}) temperatures rise steadily with increase in hydrogen pressure to steady state conditions. This reaction time is around 10-15 minutes and 15-20 minutes for the lower and higher hydrogen pressures respectively. The time response of the "hot-side" stream (temperature T_8) has been observed in the boiler, while temperature T_9 will be observed in the absorber in paragraph 5.6; hence these two temperatures have not been included in the figures.

From figure 5.38, which represents a pressure of 22.5 bars, the steady state temperature T_{10} is in the region of 180°C. These two conditions in the enthalpy-concentration diagram of figure 5.40, give a concentration value of the solution in the region of 0.13. This means that having assumed an original concentration of 0.34 at point 13, the solution approaching the boiler after having passed through the heat exchanger is at much lower concentration. This is because the heat received from the weak solution (hot stream) is sufficient to boil the strong solution and to release ammonia vapour prior to its exit from the heat exchanger tube [22]. The ammonia that has been liberated rises directly to the inlet of the rectifier (point 12).

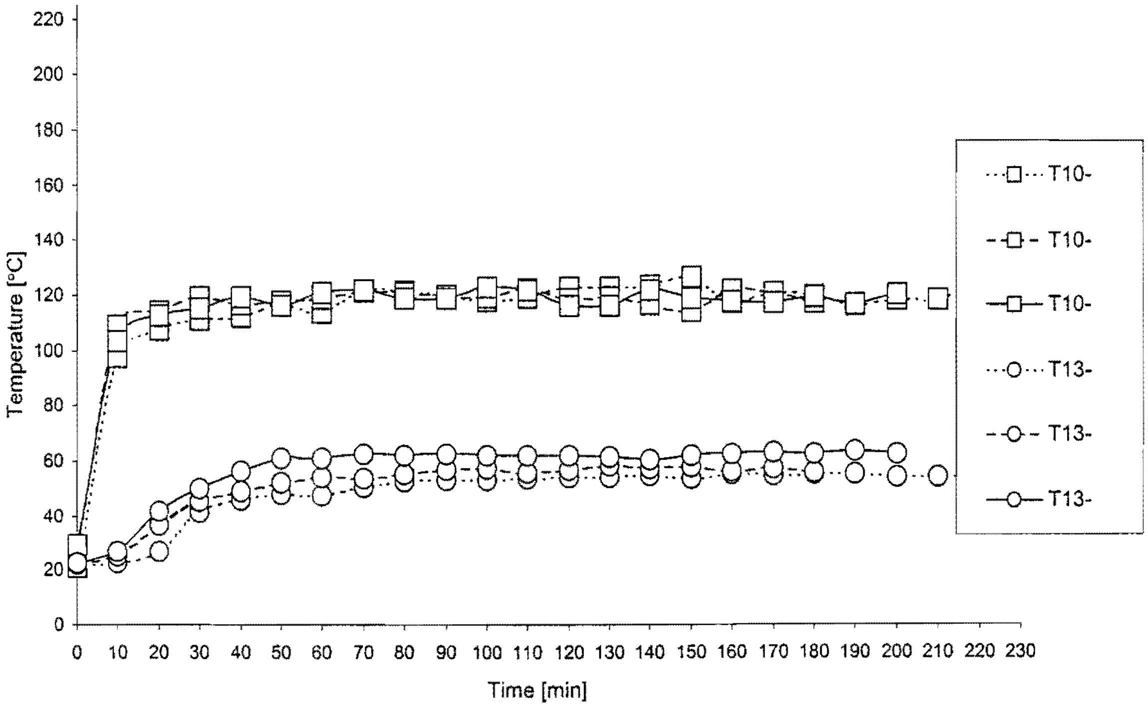


Figure 5.35 Heat exchanger's time response at 7.5 bar hydrogen

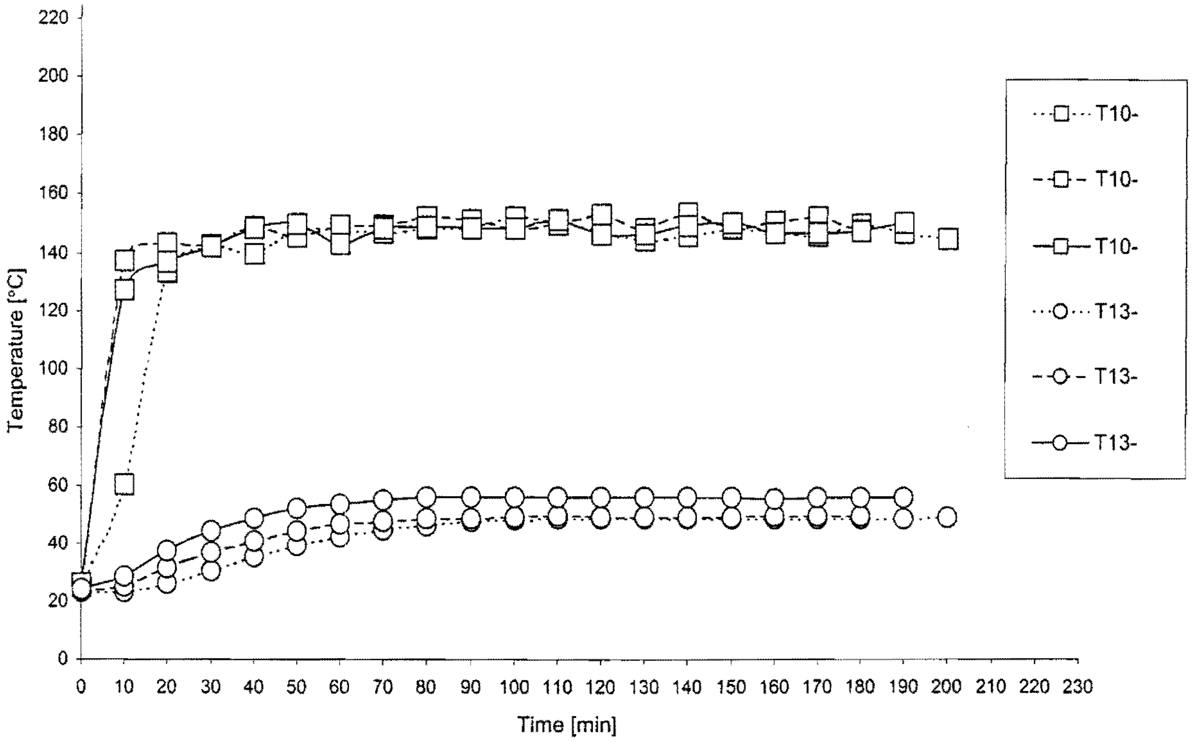


Figure 5.36 Heat exchanger's time response at 12.5 bar hydrogen

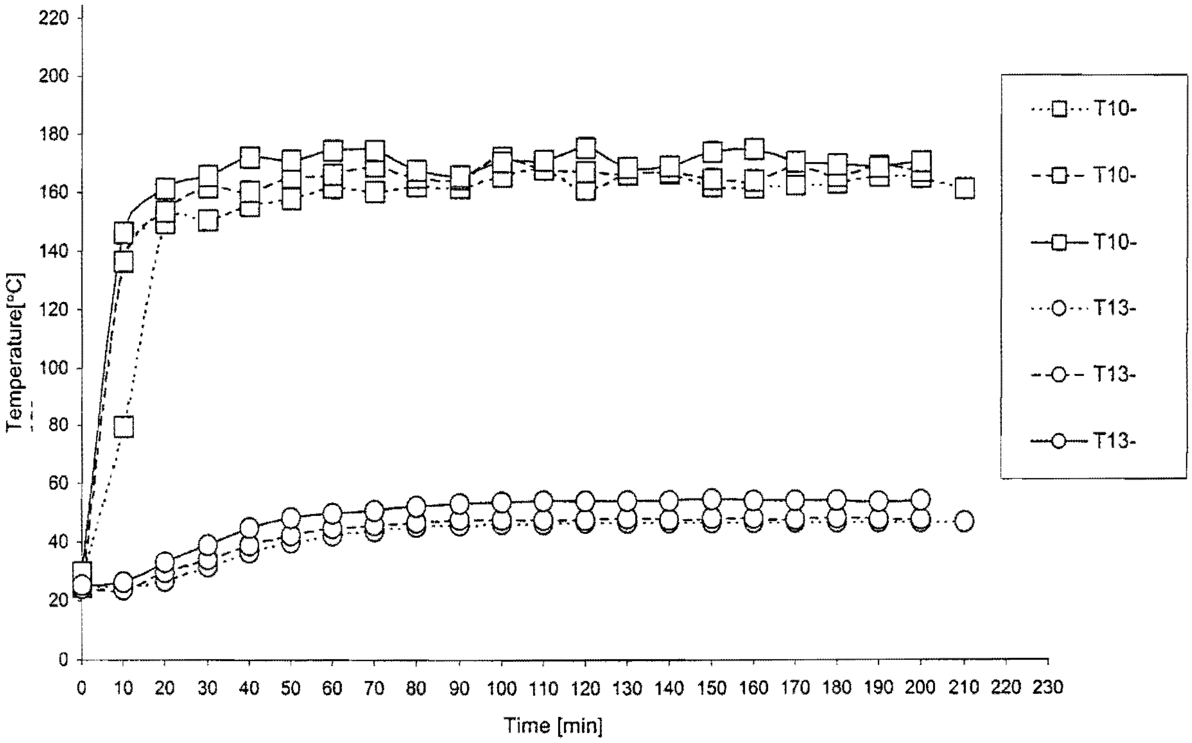


Figure 5.37 Heat exchanger's time response at 17.5 bar hydrogen

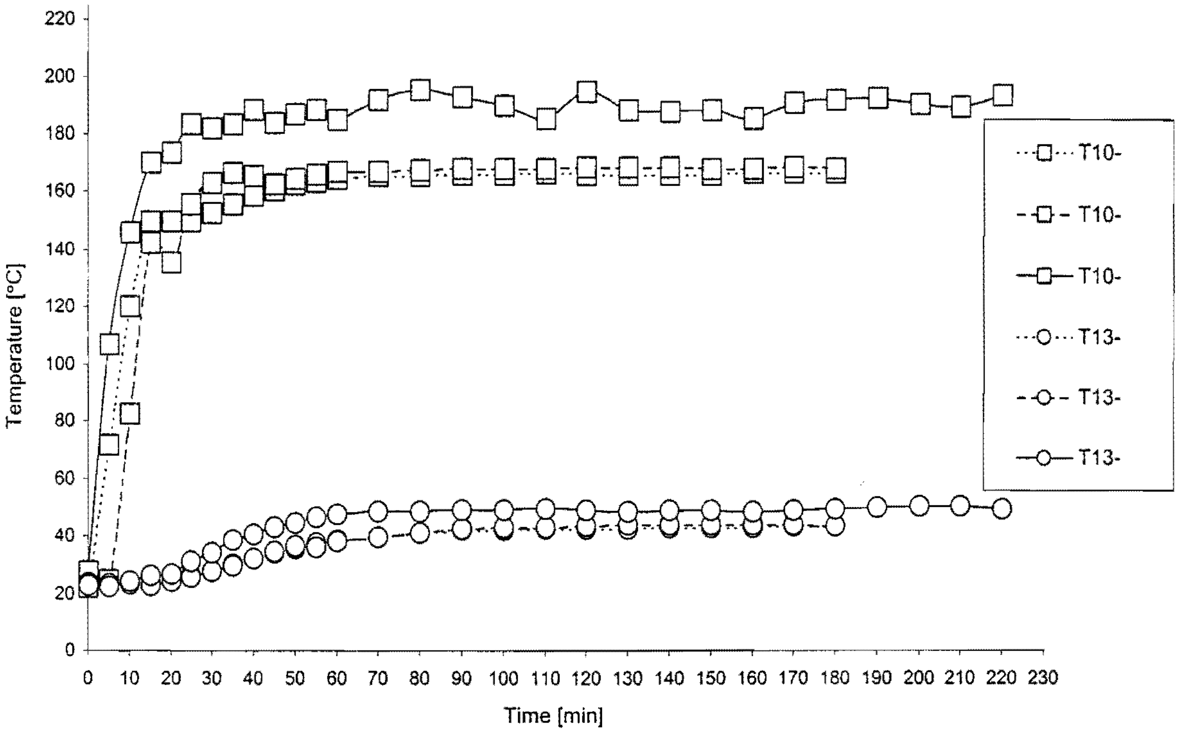


Figure 5.38 Heat exchanger's time response at 22.5 bar hydrogen

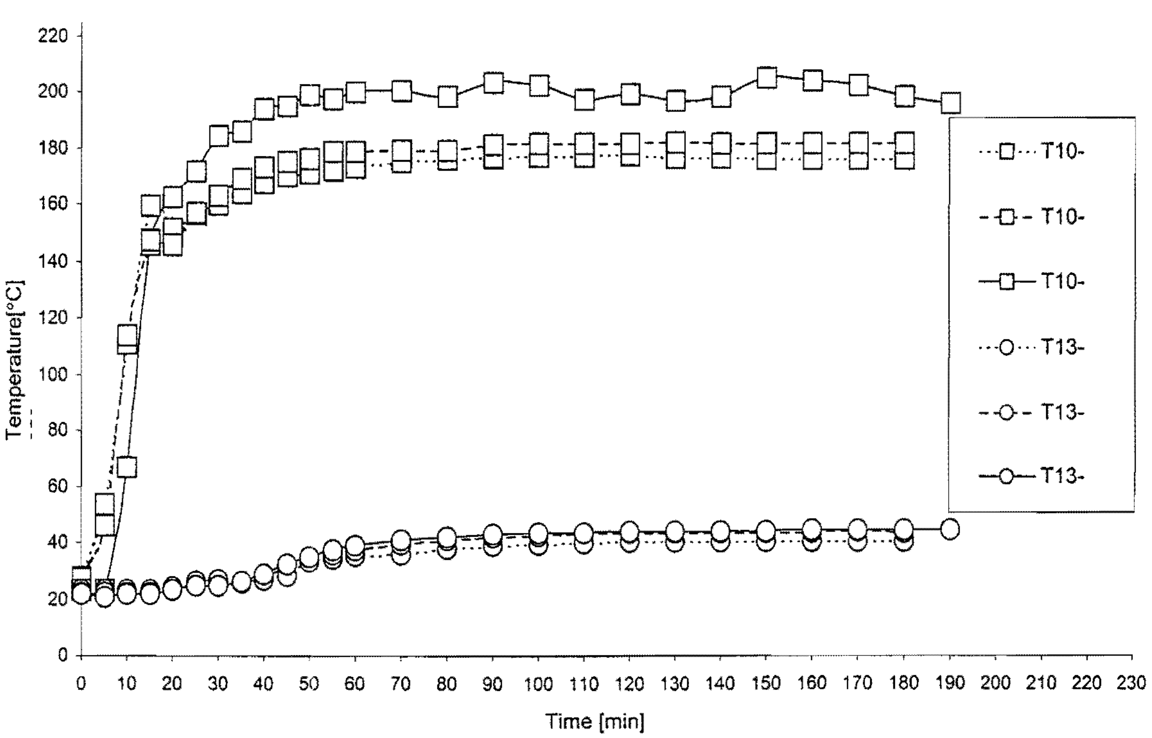


Figure 5.39 Heat exchanger's time response at 27.5 bar hydrogen

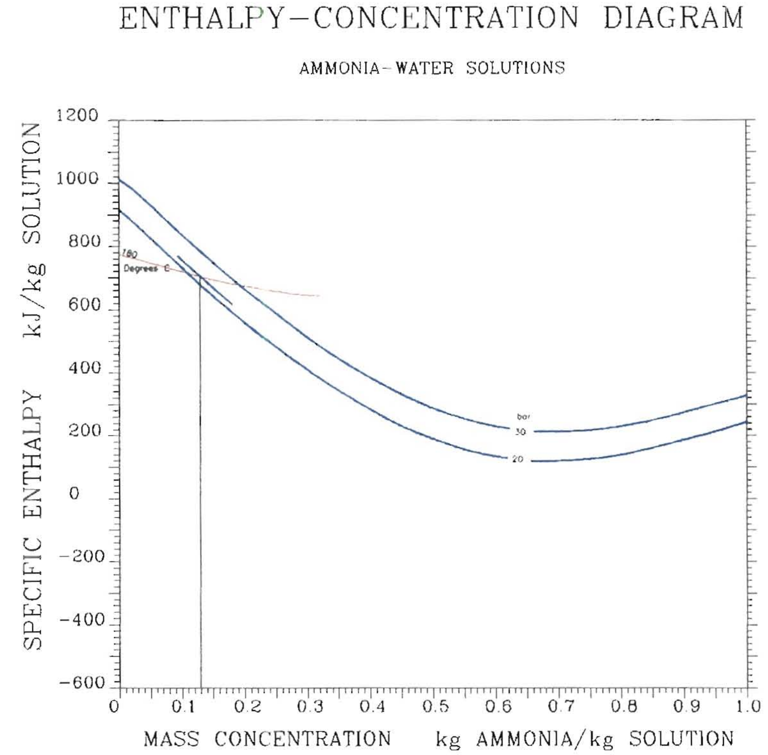


Figure 5.40 Conditions at heat exchanger

5.6 ABSORBER

The temperature-time response for the absorber is shown in figures 5.41-5.45. The temperature rise from initial state is gradual and it takes 50-60 minutes to reach steady state conditions.

In the absorber the refrigerant has to diffuse from the hydrogen-refrigerant mixture into the absorbent. This diffusion process occurs between two pressure regimes, i.e. the total pressure of the unit and the saturation pressure of the strong solution (formed in the absorber) at the absorber's temperature. The later pressure is the same as the partial pressure in the evaporator [21].

It can also be observed that the temperature T_7, in all power inputs and all hydrogen pressures, is exceptionally high i.e. in the region between 50°C and 60°C. This reflects to a high saturation pressure of the strong solution in the absorber. Since this pressure is the same as the partial pressure of the refrigerant, it affects its boiling temperature in the evaporator.

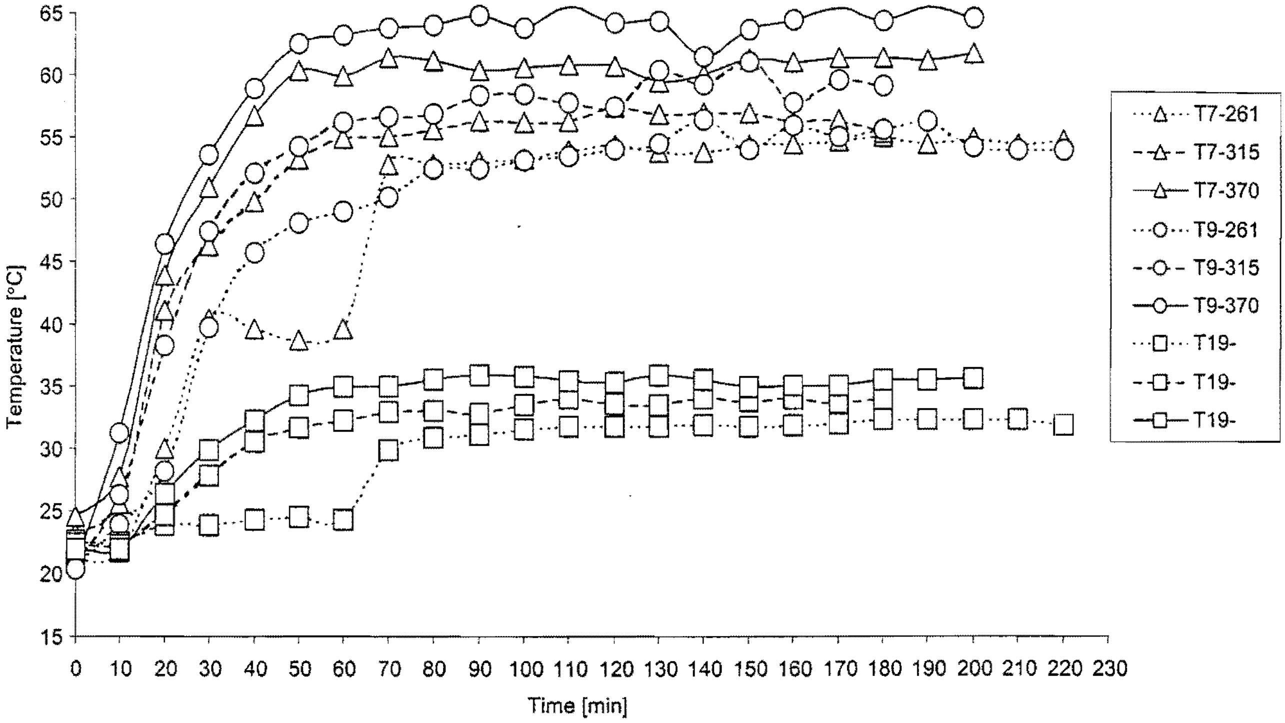


Figure 5.41 Absorber's time response at 7.5 bar hydrogen

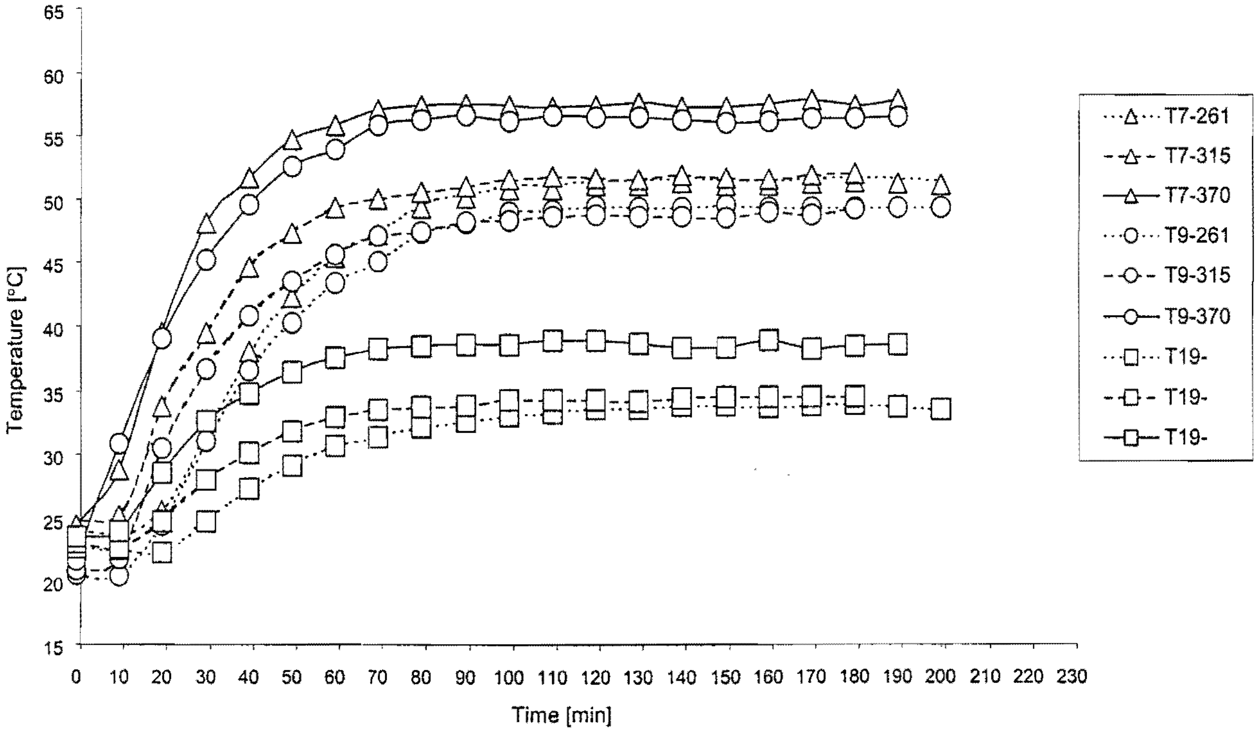


Figure 5.42 Absorber's time response at 12.5 bar hydrogen

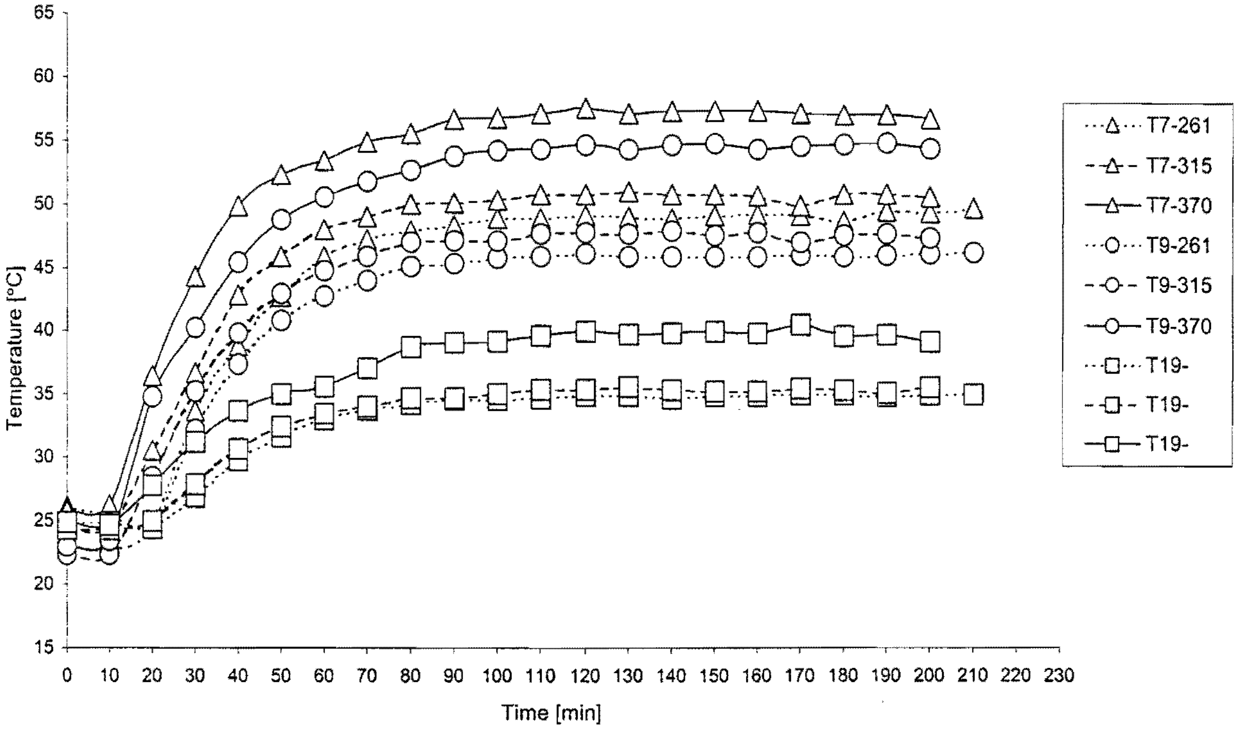


Figure 5.43 Absorber's time response at 17.5 bar hydrogen

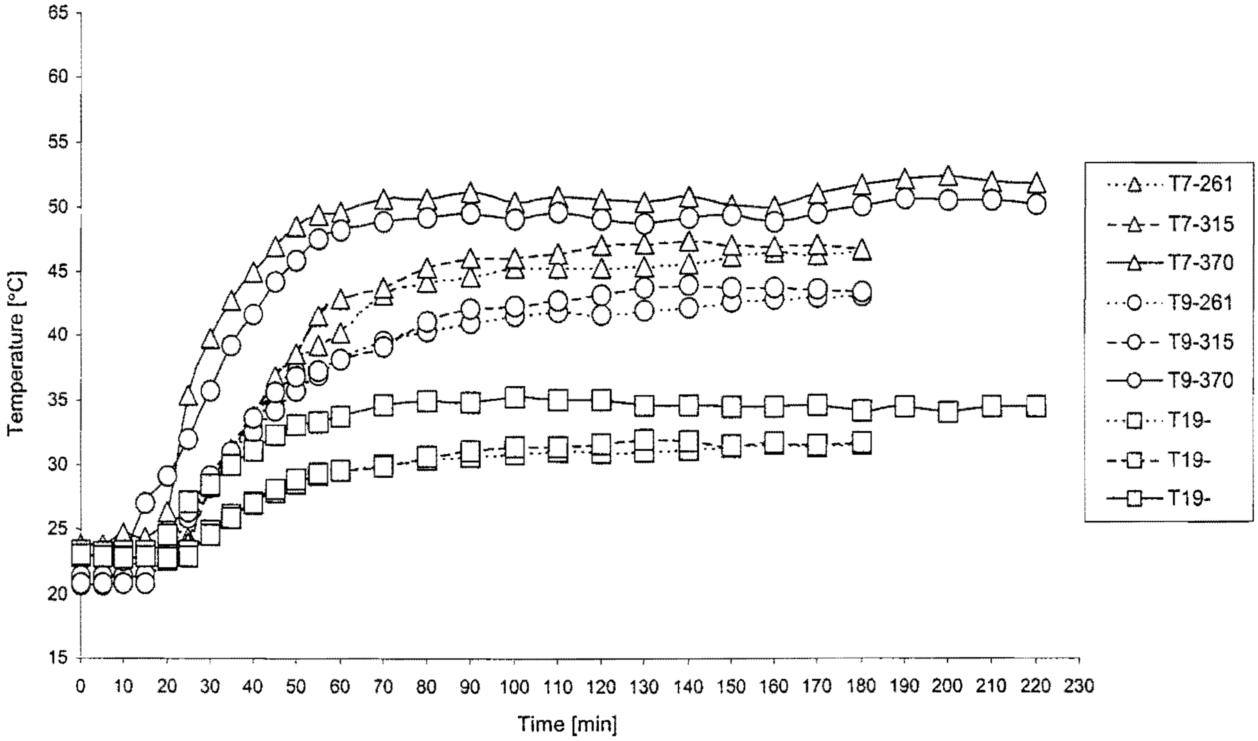


Figure 5.44 Absorber's time response at 22.5 bar hydrogen

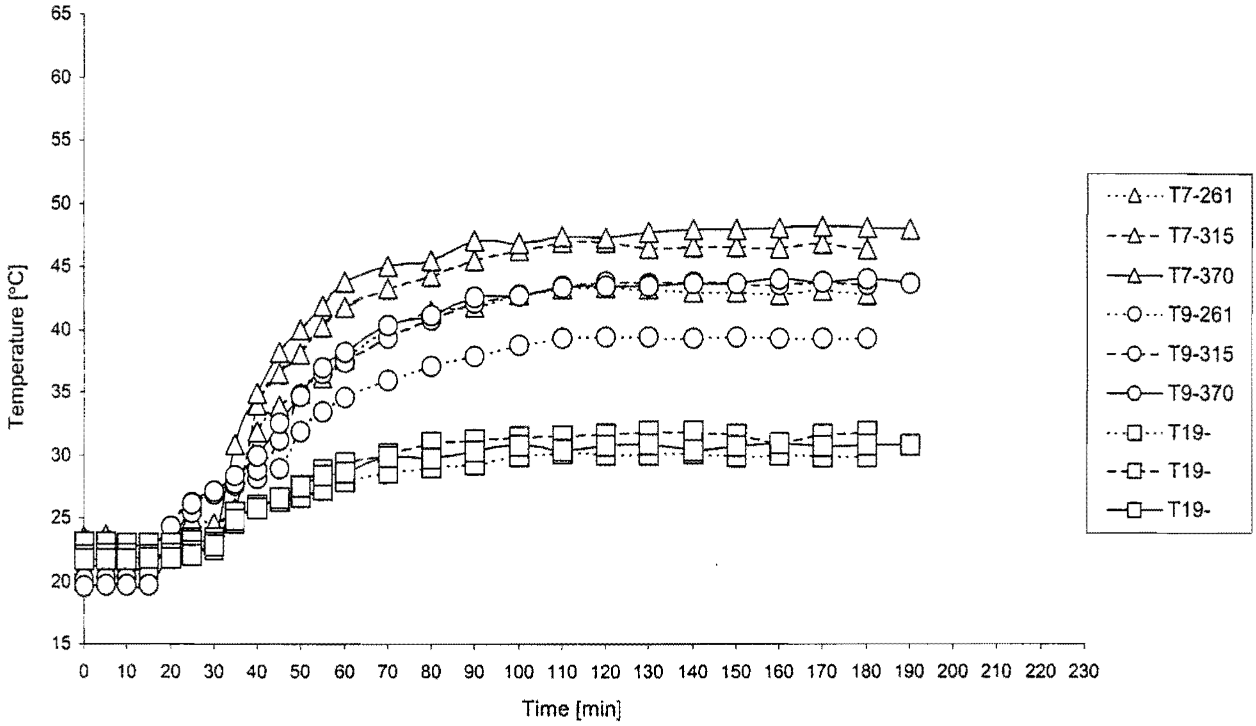


Figure 5.45 Absorber's time response at 27.5 bar hydrogen

Despite the unit's much faster time response, its performance is not satisfactory. This is evident from Table 5.1 in which the lowest and the average temperatures in the evaporator for the entire experiment are tabulated. This low refrigeration performance could be explained by the possibility that the ammonia partial pressure in the evaporator is high, which is affected by the saturation pressure of the strong solution in the solution reservoir.

Table 5.1 Lowest and average evaporator temperatures

	EVAPORATOR'S TEMPERATURES					
Hydrogen Pressure bars	**Power input**					
	261 W		**315 W**		**370 W**	
	Lowest	**Average**	**Lowest**	**Average**	**Lowest**	**Average**
7.5	-2.7	-1.18	-0.3	0.6	0.4	1.8
10.0	1.9	2.6	-3.2	-1.1	-3.3	-0.7
12.5	-7.6	-6.7	***-8.2***	***-7.8***	-7.3	-6.3
15.0	-4.3	-3.3	-4.2	-2.9	-4.2	-4.0
17.5	-3.3	-2.0	-2.9	-2.5	-3.3	-2.4
20.0	-2.3	-1.1	-3.1	-2.4	-3.5	-3.2
22.5	-0.3	1.0	***-1.6***	***-0.9***	-3.6	-2.8
25.0	0.5	2.1	0.0	0.6	-4.3	-2.9
27.5	3.8	4.6	-0.7	0.3	-0.7	-0.6

With reference to the absorber's response (figures 5.41-5.45) and in particular to the curves for T_7, the steady state conditions reveal that the temperatures of the strong solution are relatively high. This can be looked at in two different ways:

A. Assume that the absorber could maintain a constant concentration of 34% aqua-ammonia solution in the reservoir. According to the enthalpy-concentration diagram for ammonia-water solutions, figure 5.46, a solution at 50°C[1] and 34% ammonia concentration is saturated at approximately 3bars absolute pressure. This pressure in the evaporator should sustain a temperature of −10°C. During the experiment the average steady-state temperature was −7.8°C, while the lowest recorded was −8.2°C as it is shown in table 5.1. A worse discrepancy is observed at 22.5bars hydrogen pressure and 315W power input. In a similar diagram as that of Figure 5.46, the saturated pressure of a 34% ammonia solution at 47.5°C is approximately 2.8bars. This pressure in the evaporator should sustain a temperature of −12°C. During this experiment, the average steady state temperature was −0.9°C with a lowest recorded temperature of −1.6°C, as it is shown in Table 5.1.

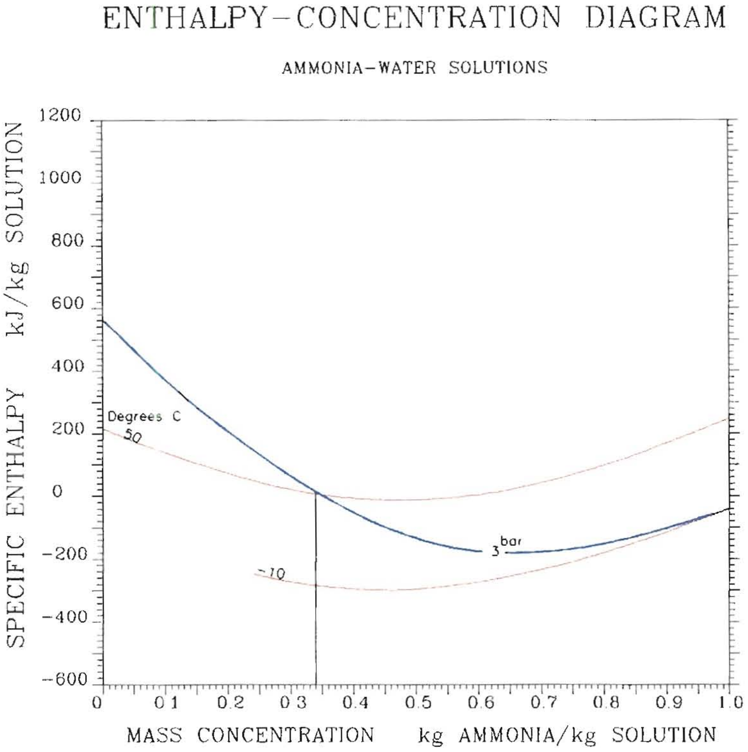


Figure 5.46 Conditions at the absorber

---

[1] 50°C was the absorber's steady state temperature T_7 at 12.5bars of hydrogen and 315W power input, see figure 5.42

B. Assume that the partial pressure of ammonia in the evaporator is the difference between the total pressure and the hydrogen pressure, Table 5.2. For the same conditions as above (i.e. 12.5bars hydrogen and 315W power), the 3.5bars partial pressure and the 50°C temperature in the absorber, sustain a 36% concentration of ammonia in the solution. While the 4.25bars partial pressure and 47.5°C temperature in the absorber sustain a 42% concentration of ammonia in the solution.

Table 5.2 Ammonia partial and total pressures

Hydrogen Pressure Bars	Power W	Absolute pressures Bars Total	Partial
7.5	261	11.50	4.00
	315	11.50	4.00
	370	12.00	4.50
12.5	261	15.75	3.25
	315	***16.00***	***3.50***
	370	16.25	3.75
22.5	261	26.75	4.25
	315	***26.75***	***4.25***
	370	27.25	4.75
27.5	261	31.50	4.00
	315	32.00	4.50
	370	32.00	4.50

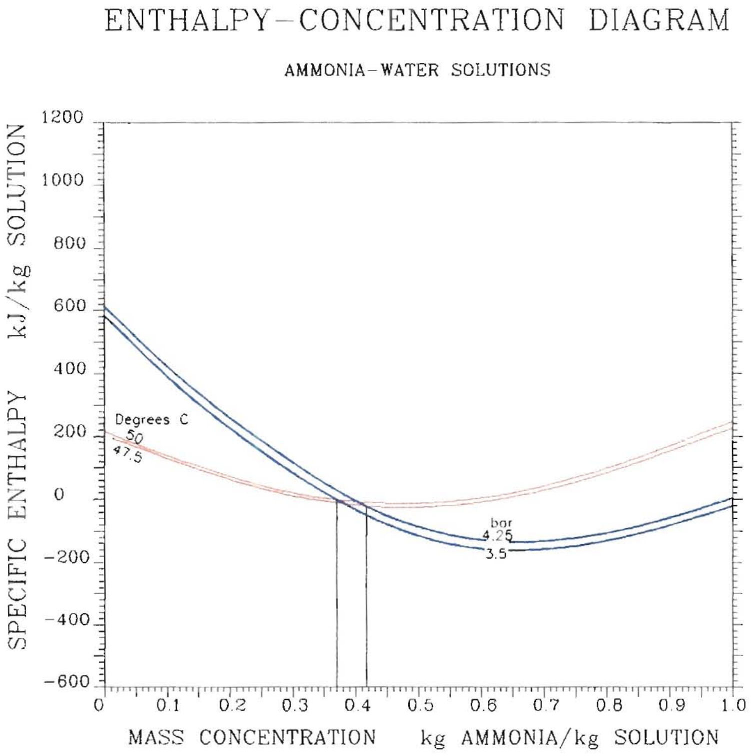


Figure 5.47 Conditions at the absorber

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The modifications made to the unit's components successfully established a working unit. The pressure at which refrigeration occurred was reduced significantly to 7.5 bar of hydrogen, whereas the lowest evaporator temperature was obtained at hydrogen pressure of 12.5 bar despite the manufacturer's claim of 21.5 bar.

The time response to attain refrigeration was also significantly reduced from 6-hour recommended by manufacturers to 20-30 minutes (boiler and solution heat exchanger); 40-45 minutes (condenser and low temperature evaporator) and 50-60 minutes (absorber). This reduction in time is attributed to the modified boiler and solution heat exchanger design. The new boiler received heat directly from the element whereas the new heat exchanger had the weak solution in the inner tube and strong solution in the annular space, hence exchanging heat with very little loss to the surroundings.

Despite the much faster time response, the refrigeration capacity was measured to be only 11W at an average temperature of –7.8°C, which was obtained at 12.5 bar hydrogen pressure and 315W power input. This gives an insignificant Coefficient of Performance. Because of this, refrigerant mass rates could not be established and thus component loads could not be determined.

Since there were no changes made to the condenser, it is appropriate to say that the design was sufficient for both the original and the present experimental unit. Therefore the "no working" condition of the original unit and the low performance of the modified unit are not due to the condenser's design.

The temperature of the strong solution in the absorber was observed to be high throughout the experimental ranges of hydrogen pressure and power input.

From the discussions A and B in paragraph 5.6, it is evident that whichever case is considered to explain the reason behind the high temperatures, the absorber coils do not dissipate the heat of reaction fast enough and hence are not capable of maintaining the 34% ammonia solution as charged. This causes an undesirably high ammonia partial pressure and temperature in the evaporator.

Therefore, although the modifications made to the unit showed a marked improvement to the refrigeration performance and time response, it is felt that the absorber is the main cause of low refrigeration.

For example, if the absorber were to maintain the 34% ammonia solution as charged, and at the same time were able to dissipate the heat of reaction keeping the strong solution at 30°C, then the partial pressure of ammonia would have been approximately 1.5 bar absolute. At this pressure, the ammonia in the evaporator would boil at approximately –25°C, as it would have been expected inside the "freezer" space.

In section 4.2.1.1, paragraph III on charging with hydrogen, the effects of hydrogen pressure on the boiler and absorber were discussed. Therefore, it is up to the system-designer to perform an energy balance on the absorber, such that, for given hydrogen pressure[1] the absorber will maintain the same concentration of the charge.

---

[1] The hydrogen pressure acts as a "lid" to the boiler, affecting the boiling rate and hence the mass flow of ammonia to the condenser. This in turn affects the solution rates form the boiler to the absorber and vice versa

REFERENCES

[1] **Althouse A.D, Turnquist C.H, Bracciano A.F,** *Modern Refrigeration and Air Conditioning,* 1st edition, The Goodheart-Willkox Co. Inc, Chicago, 1943.

[2] **ASHRAE,** *Ammonia as a Refrigerant: Position Paper,* http://204.7.184.20/about/amm%5Fpapr.htm; Jan. 1993.

[3] **Bhaduri S.C, Varma H.K,** *P-T-X behaviour of refrigerant-absorbent pairs,* International Journal of Refrigeration. vol. 8, no. 3, May 1985, pp. 172-176.

[4] **Bulgan, A.T,** *Organisation of the thermodynamic model of aqua-ammonia absorption refrigeration systems,* Energy Conversion and Management, vol.36, no.2, 1995, pp.135-143.

[5] **Cengel Y.A, Boles M.A,** *Thermodynamics – An Engineering Approach,* McGraw-Hill International Edition, Singapore, 1989.

[6] **Chen Jincan, Schouten Jan A,** *Optimum performance characteristics of an irreversible absorption refrigeration system,* Energy Conversion and Management. vol. 39, no. 10, 1998, pp. 999-1007.

[7] **Dalichaouch M,** *Energy analysis of absorption refrigeration cycles,* Journal of the Institute of Energy. vol. 63, December 1990, pp. 167-176.

[8] **Dincer Ibrahim, Dost Sadik,** *Energy analysis of an ammonia-water absorption refrigeration system,* Energy Sources vol. 18, 1996, pp. 727-733.

[9] **Jain P.C, Gable G.K,** *Equilibrium property data equations for aqua-ammonia mixtures,* ASHRAE transactions, January 24-28, 1971.

[10] **Jordan R.C, Priester G.B,** *Refrigeration and Air Conditioning,* 2nd edition, Prentice-Hall, Englewood Cliffs, New Jersey, 1956, pp.3-15.

[11] **Kaushik S.C, Bhardwaj S.C,** *Theoretical analysis of ammonia-water absorption cycles for refrigeration and space conditioning systems,* Energy Research (Journal). vol 6, 1982, pp.205-225.

[12] **Lin Guoxing, Yan Zijun,** *The optimal performance of an irreversible absorption refrigerator,* Journal of Physics D: Applied Physics. vol. 30, 1997, pp. 2006-2011.

[13] **Lister G.D.S,** *The design and evaluation of a pumping system for a three-fluid absorption refrigeration plant,* BSc. Thesis, University of Cape Town, Nov.1996.

[14] **Nickling A.T,** *The air-lift pump:theory and optimisation* Trans. Institute Chemical Engineers. vol. 41, 1963, p.29.

[15] **Perry RH, Green D,** *Perry's Chemical Engineer's Handbook, 6^{th} edition ,* Mac Graw Hill Book co, Singapore, 1985.

[16] **Rescorla Charles L,** *An absorption refrigeration system may be your answer,* Refrigerating Engineering, March 1953.

[17] **Scatchard G, Epstein L.F, Warburton J, Coddy P.J,** *Thermodynamic properties – saturated liquid and vapour of ammonia-water mixtures,* Refrigerating Engineering, May 1947.

[18] **Schulz S.C.G,** *Equations of state for the system ammonia-water for use with computers,* Proceedings IIF Congress, Washington D.C. vol 2, 1971, paper 206, pp. 431-436.

[19] **Smith M.v.B,** *Robust design of triple fluid refrigeration systems.,* Journal of the South African Institute of Refrigeration and Air Conditioning, vol.7, no.6, Nov. 1991, pp. 27-31.

[20] **Tyagi K.P, Shankar V.,** *Effect of operating variables on COP for certain absorbent-refrigerant mixtures,* ASHRAE Journal, May 1976.

[21] **Vicatos G,** *Absorption Refrigeration Machines–Heat and Mass Transfer Characteristics*, Ph.D. Thesis, University of Cape Town, 1995.

[22] **Vicatos G,** *Performance characteristics of a domestic size absorption refrigeration machine,* Conference Proceedings of FRIGAIR 2000, Johannesburg, March 2000.

[23] **Yaron I, Borde I, Jelinek M,** *Performance characteristics of absorption cooling cycle operated by low thermal potential energy sources,* Journal of Engineering for Industry [ASME trans.] vol. 105, May 1983.

[24] **Ziegler B, Trepp Ch,** *Equation of state for ammonia-water mixtures,* International Journal of Refrigeration vol. 7, no. 2, March 1984, pp. 101-106.

BIBLIOGRAPHY

[1] **Beasley D, Hester J Ch,** *Short communications analysis of a pressure driven absorption refrigeration cycle,* International Journal of Energy Research, vol 12, 1988, pp 175-184.

[2] **Bhaduri S.C, Varma H.K,** *Thermodynamic properties of refrigerant-absorbent pairs,* Transactions of the ASME vol. 109, February 1987.

[3] **Bogart MJP,** *Pitfalls in ammonia absorption refrigeration,* International Journal of Refrigeration vol. 5, no. 4, July 1982, pp. 203-208.

[4] **Chiou J.S, Liu C.J, Chen C.K,** *The performance of an irreverisble Carnot refrigeration cycle,* Journal of Physics D: Applied Physics vol. 28, 1995, pp. 1314-1318.

[5] **De Laminat Paul,** *Expanding the use of Ammonia,* ASHRAE Journal, vol. 42, no. 3, March 2000.

[6] **Feng Xu, Goswami D. Yogi,** *Thermodynamic properties of ammonia-water mixtures for power cycle applications,* Energy Journal vol. 24, 1999, pp. 552-536.

[7] **Kinzie P.A,** *Thermocouple Temperature Measurement,* 1st edition, John Wiley & Sons, New York, 1973.

[8] **Kumar R, Kaushic S.C,** *Thermodynamic evaluation of a modified aqua-ammonia absorption refrigeration system,* Energy Conversion and Management, vol.32, no.2, 1991, pp.191-195.

[9] **Macintre H.J,** *Handbook of Mechanical Refrigeration,* 1st edition, John Wiley & Sons, New York, 1928.

[10] **Mohand A. Ait-Ali,** *Finite-time optimum refrigeration,* Journal of Applied Physics, vol. 77, no. 9, 1 May 1995, pp. 4280-4284.

[11] **Orbey Hasan, Sandler Stanely I,** *Equation of state modelling of refrigerant mixtures,* Industrial Engineering Chemistry Research vol. 34, 1995, pp. 2520-2525.

[12] **Richard R.G, Sharkland I.R,** *Flammability of alternative refrigerants,* ASHRAE Journal, vol.32, no.4, April 1992, pp.20-24.

[13] **Saghiruddin, Siddiqui M.A,** *The effect of using a heat recovery absorber on the performance and optimum cost of the solar ammonia absorption cycle,* Journal of Solar Energy Engineering, vol.119, Feb.1997, pp. 19-23.

[14] **Shaefer L.A, Delano A, Shelton S.V,** *Second law study of the Einstein refrigeration cycle,* ASME Proceedings of the Renewable and Advanced Energy Systems for the 21st century, April 11-15, 1999.

[15] **Steyn M.R,** *CFC phase-out – possible effects,* South African Refrigeration and Air-conditioning Journal, vol. 9, no. 4, July 1993.

[16] **Stickney A.B,** *Graphs help to solve ammonia absorption system problems,* Refrigerating Engineering, November 1947.

[17] **Stoecker W.F, Reed L.D,** *Effect of operating temperatures on the coefficient of performance of aqua-ammonia refrigeration systems,* ASHRAE Journal, January 1971, pp.163-171.

[18] **Watts F.G, Gulland C.K,** *Triple-fluid vapour-absorption refrigerators.,* The Journal of Refrigeration, July/August 1958.

[19] **Whitlow E.P,** *Trends of effectiveness in absorption refrigeration machines.,* ASHRAE Journal, December 1966, pp.44-48.

[20] **Woolrich W.R,** *Handbook of Refrigerating Engineering Volume 1: Fundamentals,* 4th edition, The Avi Publishing Co inc, Westport, Connecticut, 1965.

APPENDIX 1: EXPERIMENTAL RESULTS

POWER 261 Watts HYDROGEN PRESSURE 7.5 Bars STEADY-STATE PRESSURE 10.5 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	S/S
T1	20.8	27.2	29.6	31.9	31.9	32.5	32.9	34.1	33.3	33.1	33.3	34	34.1	34.1	34.2	34	34.6	34.8	34.3	35.3	34.2	33.6	33.9	34.26
T2	20.8	21	27.7	27.4	27.3	28.2	30.1	29.7	29.3	29.8	29.7	29.8	29.9	30.3	30	30.3	30	30.2	29.7	30.2	30.2	30.1	30	30.04
T3	21.1	21.1	22.4	23	23.7	23.4	23.7	24.6	24.8	25.1	24.9	25.7	26	25.8	26.1	25.9	26	26	26.2	26.1	26.3	26.3	25.9	26.16
T4	21	21.3	22.4	22.8	22.5	19.4	17.6	9.5	8	7	6.6	5.8	5.5	5.6	5.7	6.4	5.6	6.2	5	5.5	5.8	5.3	6.1	5.54
T5	20.8	21.1	21.4	21.7	21.3	21.3	22.6	22.1	22.6	22.6	22.7	22.5	22.8	22.8	23	22.5	22.7	22.5	21.9	22.1	22.2	22.1	22.1	22.08
T6	20.8	21.2	21.4	21.5	21.1	21.3	22.9	21.2	20.7	21.1	20.7	20.2	20.7	20.9	20.9	20.7	20.7	20.8	20.3	20.8	20.7	20.7	20.7	20.64
T7	21	21.7	30	40.4	39.6	38.7	39.6	52.7	52.8	53	53.2	53.9	54.3	53.8	53.8	54.3	54.4	54.7	55	54.4	54.9	54.5	54.8	54.72
T8	21.4	107	123	123	126	130	136	136	135	136	138	138	137	138	132	138	137	138	135	138	139	138	138	137.58
T9	20.7	23.9	28.1	39.7	45.7	48.1	49	50.1	52.4	52.4	53.1	53.4	54	54.5	56.4	54	55.9	55	55.6	56.3	54.2	54	54	54.82
T10	21.1	97.6	108	111	112	117	114	122	121	120	118	120	123	123	124	127	118	121	120	116	119	119	123	119.32
T11	21.3	107	123	123	126	131	135	136	135	136	138	137	137	138	131	138	137	137	134	136	139	138	138	136.96
T12	21.3	86.6	99.9	102	105	108	113	113	113	114	114	114	114	115	113	115	114	114	114	113	115	116	115	114.4
T13	22.4	22.9	26.9	41.4	46.2	47.9	47.6	50.5	53	53.1	53.5	53.9	54.4	54.5	54.9	53.9	55.1	54.7	55.1	55.2	54.5	54.4	54.2	54.68
T15	22.6	22.6	23.1	23.3	23.4	18	14.1	3.5	1	0.2	-0.4	-1	-1.7	-1.9	-2.7	-2.2	-2.8	-2.3	-2.6	-2	-1.7	-2	-2.2	-2.1
T16	22.6	22.6	22.8	22.6	22.3	22.1	22.2	22.2	22.6	22.1	21.9	21.8	21.8	21.8	21.7	21.7	21.7	21.8	21.6	21.8	21.8	21.7	21.6	21.7
T17	22.6	22.6	22.9	23.1	22.7	22.6	23.1	23.7	23.2	23.3	22.9	22.8	23	22.8	22.9	22.9	23	23.1	22.9	23	23	22.8	22.9	22.92
T18	22.6	22.5	22.8	23.9	23	23.8	24	23.9	23.3	23.4	23.1	22.9	23.2	22.9	22.9	23	23	23.2	23	23.3	23.2	23	23.1	23.12
T19	22.6	22.5	23.9	23.9	24.3	24.5	24.3	29.9	30.9	31.1	31.6	31.8	31.8	31.8	31.9	31.8	31.9	32	32.3	32.4	32.3	32.3	31.9	32.24

POWER 315 Watts HYDROGEN PRESSURE 7.5 Bars STEADY-STATE PRESSURE 10.5 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	20.5	26.8	29.9	33.6	34.8	36.5	36.7	36	36.5	37.3	37	36.4	37.5	37.4	37.5	37.5	36.8	37.4	35.7	36.98
T2	20.4	23.9	28.1	29.1	30.1	30.5	30.3	30.6	31.1	30.8	31	31	31	30.9	31.2	30.9	30.9	30.7	31	30.94
T3	20.7	21	21.7	23.5	24.8	26	26	26.3	26.7	26.6	26.8	27	27	27.1	27.1	27	26.7	26.4	26.7	26.78
T4	18.4	18.9	7.1	6.5	6.6	6.3	6.5	7.4	7.7	6.7	7.6	7.3	8	6.2	8	7.5	7.4	6.5	7.5	7.38
T5	20.7	20.5	21.1	21.3	21.3	21.7	22.2	22.7	22.7	22.7	22.7	21.9	21.8	22	21.9	22.2	22	22.2	22.3	22.12
T6	20.7	21.1	20.7	20.8	20.9	20.7	20.6	20.7	21.1	20.8	20.9	20.7	20.6	20.8	20.6	20.7	20.6	20.7	21	20.72
T7	23.2	25.6	41.1	46.3	49.8	53.2	54.9	55	55.6	56.3	56.2	56.3	57.4	56.8	57	56.9	56.3	56.4	55.4	56.4
T8	42.7	121.8	130.7	132.1	136.7	135.5	137.5	138.6	138.3	136	135.5	138.8	140.1	136.3	138	135	136.8	134.3	136.4	136.1
T9	20.6	26.2	38.2	47.4	52.1	54.2	56.2	56.6	56.8	58.3	58.4	57.8	57.4	60.3	59.2	61	57.8	59.6	59.1	59.34
T10	28	109	114.3	119.6	116.8	118.1	118.8	121.6	120.8	120.2	119.5	122.4	118.9	119.5	116.8	114.5	122.2	120.9	117.5	118.38
T11	45.5	121.5	130.2	131.8	135.7	133.8	137	138.2	138.3	135.2	135.2	138.2	139.2	135.5	137	134	135.7	133.4	135.9	135.2
T12	24.9	88.7	107.5	109.5	112.6	112.8	114.2	114.8	115.4	114	114.3	115.6	115.8	113.8	114.9	113.4	114.8	112.9	114.6	114.12
T13	22.9	25.3	36.5	45.3	49.1	52.1	54.5	53.6	55.5	57.1	57.2	56	56.9	58.4	57.3	57.9	56.6	57.4	56	57.04
T15	20.6	20.8	0.4	-0.8	0.6	0.5	0.5	0.7	1.3	0.5	0.8	1.1	0.4	-0.3	0.8	0.5	0.8	0.2	0.6	0.58
T16	22.3	22.3	22.5	22.3	22.2	22	21.9	21.9	22.1	21.9	21.8	21.9	21.6	21.5	21.6	21.6	21.8	22	22	21.8
T17	22.2	21.9	22.6	22.7	22.8	22.8	22.9	23	23.3	23.2	22.4	22.9	22.6	22.7	22.8	27.8	22.9	23.1	23.2	23.96
T18	22.2	22.2	22.6	22.7	22.9	23	23.1	23.2	23.4	23.4	23.2	23.1	22.8	22.7	23	23	23.1	23.3	23.3	23.14
T19	22.4	22.3	24.6	27.8	30.5	31.7	32.2	23.9	33	32.8	33.5	34.1	33.6	33.5	34	33.8	34.1	33.7	34	33.92

POWER 370 Watts HYDROGEN PRESSURE 7.5 Bars STEADY-STATE PRESSURE 10.5 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	19.8	27	34.8	39.5	43	45.3	43.6	46	43.3	42.9	42.7	42.7	44.3	42.7	43.3	44.1	43.5	46.4	43.5	43.4	45.5	44.46
T2	19.8	24.8	29	30.4	30.7	31.3	31.4	31.3	31.6	31.8	31.7	31.8	31.3	31.5	31.4	31.2	31.4	31.8	31.6	31.1	31.8	31.54
T3	20.2	20.3	21.3	23.8	25.1	26.3	26.8	26.7	26.6	26.8	27	27.2	26.5	26.7	27	26.9	26.7	26.9	26.9	26.6	27.2	26.86
T4	17.7	15.4	6.5	8.3	7.6	7.8	7.8	7.7	8.3	8.8	8.3	8.4	8.8	8.5	8.4	7.8	8.1	8.3	8.5	7.5	8.9	8.26
T5	20.1	19.6	20.7	21.4	21.3	22.1	22.2	22.2	22.3	22.2	22.5	22.7	22.6	22.5	22.6	22.6	22.7	23	22.8	22.7	22.7	22.78
T6	20.1	19.8	20.3	20.6	20.2	20.7	20.7	20.8	20.7	20.9	21	21	20.7	20.7	20.5	20.8	21	21.3	20.9	20.8	20.8	20.96
T7	24.5	27.7	43.9	50.9	56.7	60.3	59.9	61.4	61.2	60.4	60.6	60.8	60.7	59.5	60	61.3	61	61.4	61.4	61.1	61.7	61.32
T8	46.5	122	133	137	139	140	141	144	143	141	142	140	140	140	140	141	141	141	142	138	142	140.7
T9	20.3	31.2	46.4	53.5	58.9	62.5	63.2	63.7	64	64.8	63.7	65.5	64.2	64.3	61.5	63.6	64.4	65.3	64.3	65.5	64.5	64.8
T10	29.5	104	113	116	120	117	121	122	119	119	123	122	117	117	122	119	118	117	120	117	120	118.48
T11	50.2	122	133	138	140	140	142	143	143	140	142	139	139	139	141	141	141	140	142	138	140	139.94
T12	25.7	93.3	110	113	115	116	116	117	117	116	117	116	116	116	118	117	117	116	117	116	117	116.46
T13	22.8	27	41.8	50	56.2	60.9	61	62.4	62.3	62.5	62.1	62.1	62.1	61.8	60.5	62.3	62.5	63.3	62.8	63.5	62.5	62.92
T15	19.9	15.8	0.4	1.3	1.4	1.7	2	2.2	2.3	2.3	2.7	1.7	1.6	1.8	1.6	1.2	1.3	1.3	1.4	1.4	1.6	1.4
T16	21.8	21.8	21.9	21.9	21.5	21.5	21.4	21.5	21.4	21.4	21.7	21.5	21.4	21.5	21.1	21.3	21.7	21.6	21.4	21.4	21.4	21.5
T17	21.8	21.7	22.3	22.5	22.6	23.2	23	23.2	23.1	23.1	23.6	23.4	23.3	23.1	22.9	23.1	23.6	23.7	23.2	23.2	23.1	23.36
T18	21.7	21.7	22.4	22.8	22.9	23.5	23.4	23.7	23.6	23.4	23.8	23.4	23.5	23.4	23	23.2	23.5	23.8	23.4	23.5	23.4	23.52
T19	21.9	21.9	26.3	29.9	32.2	34.3	35	35	35.5	35.9	35.8	35.4	35.3	35.9	35.5	35	35.1	35.1	35.5	35.5	35.6	35.36

POWER 261 Watts HYDROGEN PRESSURE 10.0 Bars STEADY-STATE PRESSURE 11.25 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	20.5	23.1	32	34	34.3	35	35.4	35.2	35.4	35.1	35.3	34.8	35.4	35.4	35.1	35.5	35.5	36.1	36	36	35.6	35.84
T2	20.4	21.3	30.8	33	32.7	33.1	33.4	33.4	33.6	33	33.3	33	33.4	33.3	33.2	33.4	33.5	33.8	33.6	33.6	33.6	33.62
T3	20.6	20.2	20.7	22.8	24.4	25.4	26.1	25.8	26.3	25.7	26.2	25.9	26.4	26.2	25.9	26.4	26.7	26.6	26.4	26.4	26.5	26.52
T4	17.9	17.7	8.2	8.1	8.5	8.3	9.1	10.4	9.2	8.5	9.5	8.8	8.8	9.1	8.8	9.2	8.3	9.2	9.5	9.5	8.7	9.04
T5	20.4	19.5	20	20.2	19.8	20.1	20.7	19.2	20.4	20	20.5	20.3	20.5	20.1	20.3	20.4	20.2	20.6	20.7	20.7	20.6	20.56
T6	20.6	19.6	19.9	19.5	18.9	18.8	19.2	19.5	19.1	18.5	18.8	18.7	18.7	18.6	18.8	18.9	18.7	19.1	19.1	19.1	18.9	18.98
T7	25.8	29.1	32.7	41.6	44.4	47.1	48.8	49.4	49.9	50	50.3	50.1	50.7	50.9	50.7	51	51.4	51.5	51.4	51.4	51.3	51.4
T8	51	114	139	144	145	147	149	148	149	148	148	148	149	148	149	150	150	149	149	149	149	148.92
T9	20.6	26.7	33.3	38	41.1	44.5	46.1	46.7	47.2	47.7	48	47.9	48.2	48.3	48.4	48.1	48.6	49.1	49.3	49.3	48.9	49.04
T10	31.7	98.4	123	130	130	132	135	132	134	133	137	135	135	132	136	137	133	132	132	132	134	132.44
T11	55.5	114	139	144	146	147	149	148	148	148	148	148	149	148	149	150	149	149	149	149	149	148.82
T12	27.3	89.4	114	119	121	122	124	124	124	123	124	124	125	124	125	125	125	125	125	125	124	124.56
T13	22.8	27.5	31.1	36.8	41.4	44.4	46.5	47.2	48.2	48.5	48.6	48.8	48.8	49	49.2	49.3	49.8	50	49.9	49.9	50.2	49.96
T15	19.7	19.5	2	2.2	1.9	2.2	2.7	4	2.7	2.6	2.8	3	2.7	2.7	2.8	2.5	2.3	2.2	2.4	2.1	2.1	2.22
T16	21.8	21.8	22.6	22.8	22.5	22.1	22	22.5	22.2	22.1	22.2	22.5	22.2	22.4	22.8	22.6	22.5	22.4	22.5	22.5	22.6	22.5
T17	21.7	21.5	22.5	23.1	23.8	23.3	23.3	23.7	23.5	23.6	23.7	24.1	24.2	23.7	24.4	24.3	24	24.4	24.2	23.9	23.8	24.06
T18	21.6	21.6	22.5	23.2	23.7	23.4	23.6	23.8	23.6	23.6	23.7	24	23.8	23.9	24.2	24.1	23.9	24	24	23.9	23.9	23.94
T19	21.8	21.6	24.4	26.6	28.4	29.8	30.7	31	31.2	31.9	32	32	32	32.3	32.4	32.3	32.6	32.3	32.2	32.7	32.6	32.48

POWER 315 Watts HYDROGEN PRESSURE 10.0 Bars STEADY-STATE PRESSURE 12.0 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	S/S
T1	20.7	29.7	32.7	35.1	36.8	38.4	36.7	38	38.2	39.8	38.1	39.1	39.7	39.5	39.1	38.3	39.3	39.9	40.1	39.1	39.34
T2	20.7	23	30.7	31.7	32.1	32.1	32.6	32.1	32.9	33	33.2	33.2	33	33.3	33	33.1	33	33	33.3	33.2	33.12
T3	20.9	20.8	21	23.3	25.1	25.6	26.2	26.2	26.4	27.3	27.4	27.4	27.3	27.6	27.4	27.4	27.4	27.4	27.5	27.5	27.44
T4	18.9	16.5	7	8	7.9	6.8	7.2	5.3	7.5	6.5	6.5	7.6	6.7	7.3	7	7.8	6.9	6.7	7.5	7.4	7.26
T5	20.8	20.4	20.7	20.3	20.6	20.5	20.1	19.4	8.1	16.7	19.4	3.4	5.3	3.6	7.2	2.5	2.5	4.1	2.3	4.3	3.14
T6	20.8	20.2	20.4	19.6	19.5	19.3	19.1	19.2	19.5	18.3	17.8	17.3	17	17	16.8	16.7	16.5	16.7	16.7	16.7	16.66
T7	24.3	26.7	37.8	45.2	49.5	52.1	52.3	53.4	53.4	55.2	54.6	55.3	55.3	56.2	55.7	55.3	55.5	55.8	55.5	55.4	55.5
T8	43.9	131.8	138.6	143	145.2	142.6	147.3	145.8	148	147	148.1	148.4	144.4	148.7	146.7	147	147.3	144.8	147.4	146.9	146.68
T9	20.9	25.9	34.9	42.1	47	51.8	51	53.6	53.1	55.1	55.3	54	56.8	55.5	56.9	56.1	56.1	57.5	56.5	57	56.64
T10	28.8	116.6	120.2	129.3	124.9	121.5	133.4	133.2	130.4	125.5	132.3	128.4	128.2	130	129.2	133.5	131.9	129	123.9	131.1	129.88
T11	47.4	132	138.3	143.3	145.8	141	147.6	146.1	148.4	145.7	148.1	148.7	143	148.7	146.9	146.8	146.8	144.4	144.9	147.1	146
T12	26	99.8	114.2	117.9	120	118.8	122.7	121.1	123.3	121.3	122.6	123.5	121.6	124.5	122.6	123.1	122.9	122	121.6	122.7	122.46
T13	22.9	26.4	34.3	41.8	47.4	50.9	51.1	53.4	53.6	54.4	54.6	54.5	55.6	55.5	56	55.4	55.6	55.7	55.9	56	55.72
T15	20.4	16.1	0.9	1.4	1.3	0.9	0.5	-2.5	0.1	-2.6	-3.2	-1.6	-1.7	-1.6	-1.8	-1.3	-1.5	-1.5	-1.4	-1.4	-1.42
T16	22.1	21.9	22.7	22.7	22	21.9	21.7	21.9	22.2	18.8	16.8	15.9	15.2	15.1	15.1	15	14.9	15.1	14.9	15	14.98
T17	22	21.9	22.9	23.6	23.1	23.1	23	23.3	23.7	23.1	22.1	21.8	21.6	21.4	21.6	21.4	21.4	21.7	21.4	21.4	21.46
T18	22	21.9	22.8	23.4	23.3	23.1	23.2	23.2	23.5	23.3	22.4	22	21.8	21.7	21.8	21.6	21.5	21.7	21.7	21.6	21.62
T19	22.1	21.9	24	27.7	30	31.7	32.8	33.1	32.9	33.2	33.4	33.7	33.6	33.8	34.3	34.4	34.1	34.7	34.3	34.7	34.44

POWER 370 Watts HYDROGEN PRESSURE 10.0 Bars STEADY-STATE PRESSURE 12.0 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	S/S
T1	20.6	29.9	36.9	43.3	44.5	47	44.7	46.4	48.5	46.9	46.5	48.2	49.2	45.9	47.6	45.5	46.5	48.5	46.5	50.8	48.6	49.2	48.7
T2	20.5	22.1	31.4	32.4	33.2	33.4	33.6	33.6	33.9	33.6	33.9	34	33.7	33.8	33.8	34	33.6	33.7	33.9	34.2	33.6	33.6	33.8
T3	20.6	20.7	22	25.1	26.4	27.3	27.4	27.7	28.1	27.8	27.9	28	27.9	28	28.2	28.4	28.2	28.1	28.2	28.6	28.5	28.2	28.3
T4	18.9	17.9	4.9	4.8	7.1	6.5	7.7	8.1	8.5	8	8.4	7.7	7.5	8.3	7.7	7.5	6.6	7.6	7.2	7.4	6.8	7.5	7.3
T5	20.1	19.2	20.4	20.1	20.1	20.9	18.1	0.3	0.3	1.7	1.5	-1	2.3	1.3	0.5	-0.9	-0.4	0	0.4	0.1	1.9	3.5	1.18
T6	20.2	18.6	19.7	18.7	18.3	18.3	17.8	16.9	16.8	16.7	16.7	16.7	16.4	16.8	16.6	16.7	15.9	16.1	16.1	16.4	16.3	16.4	16.3
T7	22.6	26.4	40.1	49.5	53.7	55.3	55.8	58	59.2	59	58.3	59.5	60.7	59.2	59.3	58.5	58.3	60.3	58.6	61.4	59.2	61	60.1
T8	32	128	135	144	148	143	149	147	148	150	149	153	151	149	146	151	148	148	150	152	147	150	149
T9	20.4	27.7	45.4	49.9	54.6	62.3	60	61.6	63.4	61.8	64.1	61.8	62.3	63.2	65	61.5	62.5	62.8	64.3	62.6	63.3	63.6	63.3
T10	23.7	109	115	119	122	120	127	125	123	129	125	126	127	127	124	135	133	131	125	125	132	130	129
T11	33.5	129	134	143	149	141	149	148	147	151	150	151	151	150	146	151	148	149	148	150	146	151	149
T12	22.5	92.9	112	118	121	120	123	123	124	125	123	126	125	125	123	126	125	124	124	125	123	124	124
T13	22.5	25.2	37.5	47.1	52.9	57.1	56.7	58	59.6	59.2	60.3	59.3	60.9	60.1	60.5	58.3	60.1	60.7	60.2	60.7	61.7	61.2	60.9
T15	21.1	21	-3.3	-3.3	-2.2	-2.3	-1	0.5	-0.2	-0.1	0	0.1	-0.7	-0.1	-0.4	0.3	-0.4	-0.4	-0.4	-0.4	-0.2	-0.7	-0.42
T16	22.2	21.8	21.9	21	19.9	18.1	16.8	16	15.2	15	14.9	15.1	14.6	14.8	14.7	15	14.8	14.7	15	15.2	15.1	15	15
T17	22.2	22	22.8	22.4	23.2	23	22.6	22.1	21.9	22	21.9	22	21.5	21.9	21.9	22	22	22.1	21.9	21.9	22.2	21.9	22
T18	22.1	22	22.5	22.4	23.3	23.2	23	22.4	22.1	22.3	22.1	22.3	21.9	22.2	22	22.3	22.1	22.2	22	22	22.2	22.1	22.1
T19	22.3	22	25.8	29.8	32.4	34.5	35.5	36.5	36.6	36.9	37.2	37.4	36.6	37.2	37.7	37.9	37.4	37.1	37.8	37.1	37.4	37.3	37.3

POWER 261 Watts HYDROGEN PRESSURE 12.5 Bars STEADY-STATE PRESSURE 14.75 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	21	21.3	38	39.7	40.3	40.8	40.9	41.1	41.4	41.6	41.7	41.6	41.7	41.6	41.7	41.7	41.6	41.8	41.9	41.8	41.7	41.76
T2	20.9	20.7	21.1	27.1	28.2	28.3	28.4	28.8	29.2	29.3	29.5	29.4	29.6	29.5	29.5	29.4	28.8	29.7	29.9	29.5	29.8	29.54
T3	21	21	21.1	21.9	23.9	25	25.2	25.5	26.1	26.4	26.5	26.5	26.7	26.4	26.6	26.8	26.4	26.6	26.8	26.8	26.7	26.66
T4	19.1	19.4	19.4	7.4	6.7	7.9	5.7	3.6	1.7	1.1	1	0.8	1	1	0.7	1	1.4	1.6	1.8	1.5	1.5	1.56
T5	20.6	20	19.7	20.1	18.5	2.6	-4	-5.8	-6.8	-7	-7.3	-7.3	-7.4	-7.5	-7.6	-7.6	-6.3	-6.1	-6.1	-6.5	-6.5	-6.3
T6	20.5	20.7	18.8	19.4	17	16.3	11.6	7.4	4.2	0.7	0	0	-0.2	-0.3	-0.5	-0.4	1.2	1.7	1.8	2.1	1.9	1.74
T7	24.2	23.8	26	32.4	38.4	42.7	45.8	47.6	49.7	50.5	51.2	51.2	51.6	51.5	51.8	51.6	51.5	51.7	51.8	51.7	51.6	51.66
T8	35.3	34.4	143	152.3	155	158.4	160	161.9	161.6	162.2	161.6	162.4	162.2	162.5	161.6	161.7	161.4	162.1	161.9	162	161.7	161.8
T9	20.9	20.8	24.9	31.5	37	40.7	43.8	45.5	47.7	48.5	49.4	49.5	49.9	49.8	49.8	50	49.8	49.7	49.8	49.7	49.7	49.74
T10	25.5	60.2	133.4	142.1	139.7	147.6	147.9	147	148.7	248.8	152.2	150.9	147.6	144.8	146.3	148.4	147.5	146	149.9	147	145.3	147.1
T11	37.3	76.7	142.9	151.4	154.1	157.6	158.8	160.8	160.6	161	160.3	161.3	160.9	161.6	160.5	160.6	160.4	160.8	160.7	161.1	160.7	160.7
T12	23.9	25.3	101.2	126	130.3	133.1	135.1	137	136.6	137.2	137	137.4	137.7	137.2	136.9	136.5	136.8	137.4	137.3	136.8	136.7	137
T13	23.4	23.3	26.4	30.8	35.5	39.3	42.6	44.6	46.5	47.6	48.2	48.5	48.9	48.8	48.9	48.9	48.7	48.8	48.8	48.8	49	48.82
T15	21.6	21.5	21.5	-0.2	-0.5	0.4	-0.6	-1.5	-2.2	-2.6	-2.6	-2.7	-2.7	-2.5	-2.6	-2.7	-1.4	-1.3	-1.3	-1.3	-1.4	-1.34
T16	22.8	23	22.1	22.6	21.4	18.4	15.7	14.1	12.2	10.9	9.8	9.2	8.8	8.6	8.4	8.4	9.2	10.6	11	11	11	10.56
T17	22.8	23	22.5	23.3	23.4	22.6	21.5	20.5	19.6	19.4	18.7	18.5	18.3	18.1	18.1	18.4	18.5	19.5	19.5	19.6	19.6	19.34
T18	22.7	22.7	22.4	23.3	23.4	22.7	21.6	20.2	19.2	18.8	18.2	18	17.8	18	17.9	17.9	18.1	19	18.9	19.1	18.9	18.8
T19	23.1	23	22.7	25.2	27.8	29.6	31.1	31.8	32.6	33.1	33.5	33.7	34.1	34.1	34.3	34.3	34.2	34.3	34.4	34.2	33.9	34.2

POWER 315 Watts HYDROGEN PRESSURE 12.5 Bars STEADY-STATE PRESSURE 15.0 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	21.6	39.1	40.4	42	43.8	43	44	44.2	44.3	44.4	44.6	45.2	45.2	44.8	45	44.9	44.4	45.1	45.4	44.96
T2	21.5	21.7	34.8	35.9	37.2	35.8	37.5	36.5	36.1	36.6	36.8	37.5	37.4	37.5	37.9	38	37.1	37.5	37.7	37.64
T3	21.6	21.6	22	26.5	27.1	27.2	27.3	27.8	27.8	27.6	28	28.2	28.3	27.8	28.2	28.1	28.2	28	28.4	28.18
T4	19.4	19.5	7.9	7.7	6.9	2.9	1.8	1.5	1.9	1.5	1.7	1.2	1.3	0.8	0.9	0.8	0.4	0.3	0.5	0.58
T5	20.7	19.5	20.2	18.4	-4.8	-6.7	-7.1	-7.7	-7.6	-7.6	-7.6	-7.7	-7.8	-7.9	-7.9	-7.9	-7.9	-8.2	-8.1	-8
T6	20.6	19.4	18.8	16.1	13.4	7.7	1.7	-0.1	-0.4	-0.4	-0.5	-0.6	-0.6	-0.7	-0.8	-0.9	-1.1	-1.3	-0.9	-1
T7	24.9	25.6	34.2	39.9	45.1	47.7	49.7	50.4	51	51.4	52	52.2	52.1	52	52.3	52.1	52	52.3	52.4	52.22
T8	40.1	142.5	156.6	160.7	163.1	165	166.3	166.5	166.7	166.8	167.1	167.1	167.2	167.2	166.9	167.2	167.1	167.2	167.4	167.2
T9	21.3	22.2	30.9	37.1	41.2	43.9	46.1	47.5	47.9	48.6	48.8	49.1	49.2	49.1	49.1	49	49.4	49.2	49.6	49.26
T10	25.8	137.1	143.1	142.9	148.8	145.6	149.4	149.6	152.5	151.4	148.4	149.8	153.4	148.3	153.8	148.8	150.8	152.2	148.2	150.8
T11	42.9	152.5	157.5	161.3	163.1	165.4	166.3	165.9	166.6	166.6	166.9	166.6	167.1	166.5	166.3	167	167.3	167	167.3	167
T12	23.9	62.2	129.2	134.4	136.2	137.9	139.1	139.4	139.7	139.7	139.4	139.7	139.9	140	139.9	139.8	140	140	140.3	140
T13	23.7	25.3	31.8	37.1	40.8	44.4	46.7	47.9	48.5	48.9	49.2	49.5	49.3	49	49.3	49.2	49.5	49.6	49.8	49.48
T15	21.6	21.8	0.5	0.1	0.9	-0.4	-1.1	-0.9	-1.1	-1.1	-1.1	-1.3	-1.2	-1.3	-1.3	-1.2	-1.3	-1.4	-1.4	-1.32
T16	23	22.6	22.9	21.2	17.7	15.7	13.9	12.1	10.7	9.9	9.3	8.9	8.8	8.7	8.8	8.9	8.8	8.4	8.3	8.64
T17	23.1	22.9	23.6	23.3	22	21.2	20.5	19.7	18.9	18.3	18.1	17.7	17.4	17.3	17.5	17.6	17.7	17.4	17.3	17.5
T18	22.7	22.8	23.5	23.3	21.7	20.7	19.3	18.8	18.1	17.4	17.2	17	16.6	16.3	16.6	16.5	16.7	16.4	16.6	16.56
T19	23.5	23.1	25.2	28.4	30.6	32.3	33.4	34	34.2	34.3	34.7	34.7	34.7	34.6	34.8	34.9	35	34.9	35	34.92

POWER 370 Watts HYDROGEN PRESSURE 12.5 Bars STEADY-STATE PRESSURE 15.25 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	S/S
T1	22.2	39.5	44	48.8	50.5	52.4	52.8	53.4	54.2	54.3	53.8	52.4	52.8	52.5	53.3	52.9	52.1	52.8	53.2	53.2	52.84
T2	22.2	26.5	39.3	40	39.9	40.4	40.3	40.4	40.6	40.4	40.5	40.4	40.4	40.6	40.5	40.4	40.4	40.4	40.5	40.5	40.44
T3	22.2	22.3	26.2	30.3	30.6	31.3	31.3	31.5	31.6	31.7	31.6	31.8	31.6	31.8	31.7	31.6	31.6	31.8	31.8	31.8	31.72
T4	19.9	15.1	7	9	4	2.3	1.8	1.3	1.5	1.2	0.9	1	0.8	0.8	0.6	0.7	0.6	0.4	0.6	0.6	0.58
T5	21.5	20.8	20.4	-1.2	-4.5	-5.6	-6	-6.1	-6.1	-6.2	-6.2	-6.2	-6.2	-6.3	-6.2	-6.3	-7.3	-6.7	-6.5	-6.8	-6.72
T6	20.9	20.8	17.8	15.3	9.4	1.2	0.5	0.1	0.1	-0.1	-0.1	0	-0.1	-0.4	-0.1	-0.2	-0.4	-0.6	-0.3	-0.4	-0.38
T7	24.9	29.2	39.9	48.5	52.1	55.1	56.3	57.5	57.8	57.9	57.8	57.7	57.8	58	57.7	57.7	57.9	58.3	57.8	58.3	58
T8	36	147.4	158.4	164.1	165.8	167.2	167.8	168.7	169.1	169	168.9	168.5	168.7	169.1	168.9	169.2	169.6	168.7	169.1	168.8	169.1
T9	22.1	31.3	39.4	45.6	50	53	54.4	56.3	56.7	57	56.6	57	56.9	56.9	56.7	56.5	56.6	56.8	56.8	56.9	56.72
T10	26.3	127.1	136.7	142.3	148.4	149.8	143.4	148.6	149.2	148.4	148.7	151.3	146.6	146.5	149.4	150.6	146.9	147.3	147.6	150.7	148.6
T11	37.8	147.9	159	164.6	166.2	167.5	168.3	169.1	169.5	169.3	169.4	168.6	168.9	169.6	169.1	169.9	170.5	169.4	169.5	169.1	169.7
T12	24.6	118.8	131.5	136.6	138.4	139	141.1	141.4	141.3	141.2	141.8	141.4	141.8	142	141.6	141.5	142.5	142	141.3	142.1	141.9
T13	24.4	28.8	37.4	44.1	48.7	52	53.6	55.2	55.8	56.1	56	56	56	55.8	55.9	55.8	55.7	55.9	55.9	55.9	55.84
T15	22.3	9.6	-0.3	2.3	0.2	-0.7	-0.8	-0.6	-0.6	-0.4	-0.5	-0.4	-0.5	-0.6	-0.6	-0.8	-0.7	-0.8	-0.9	-0.8	-0.8
T16	23.3	23.4	22.3	20.1	17.7	14.9	12.1	9.2	8.7	8.4	8.1	7.9	7.6	7	6.9	7.2	6.2	6.6	6.9	7	6.78
T17	23.4	23.5	24.1	24.2	23.4	22.8	21.2	19.2	19.1	18.9	18.9	18.2	18.1	17.7	17.3	18.1	17	17.1	17.6	17.5	17.46
T18	22.8	23.1	23.6	23.8	22.9	21.7	20.7	18.6	18.4	18.3	17.9	17.8	17.7	17.4	16.8	17.5	17.1	16.7	17.2	17	17.1
T19	24	24.4	29	33.1	35.2	36.9	38	38.7	38.9	39	39	39.3	39.3	39.1	38.8	38.8	39.3	38.7	38.9	39	38.94

POWER 261 Watts HYDROGEN PRESSURE 15.0 Bars STEADY-STATE PRESSURE 17.25 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	22.2	22.8	44.8	45.6	46.3	46.7	46.8	47	47	47	47	47.3	47.2	47.4	47.2	47.2	47.2	47.1	47.1	47.2	47.2	47.16
T2	22.2	22.2	24.7	26.6	26.9	27	27.1	27.2	27.3	27.3	27.3	27.8	27.6	27.6	27.7	27.7	27.5	27.4	27.5	27.4	27.4	27.44
T3	22.1	22.2	22.2	23.9	25.1	25.5	25.9	26.3	26.5	26.6	26.5	26.8	26.7	26.9	26.8	26.9	26.8	26.7	26.8	26.9	26.8	26.8
T4	20.1	20.2	9.8	6.3	7.3	7.9	6.4	5	4.8	4.3	4	3.5	3.1	4	2.8	2.7	3	3.5	3.8	3.1	3.8	3.44
T5	21.7	21.4	21	19.5	18.6	1.4	-1.1	-1.6	-2.1	-3.2	-3.4	-3.6	-3.8	-3.9	-4	-4.3	-4.1	-3.8	-4.2	-4	-4	-4.02
T6	20.7	20.7	19.7	17.3	15.2	14.2	12.9	11.2	10.1	9.4	9.3	8.4	8.5	8.7	8.3	8	8.4	8.9	8.9	9.1	9.2	8.9
T7	24.9	24.5	30.4	36	41.2	44.2	46	47.4	48	48.5	48.7	49.1	49	49.2	49.2	49.4	49.1	48.7	48.9	49	48.8	48.9
T8	36.4	77.4	156.5	161.5	165	167.5	168.3	169.3	171	171.1	171.7	172.5	172	172.3	172.7	172.5	171.7	171.7	171.6	170.9	171.5	171.5
T9	21.9	21.8	30.4	36.1	39.9	42.6	44.3	45.3	45.7	45.7	46	46.5	46.4	46.4	46.4	46.5	46.5	46.1	46.1	46.2	46.2	46.22
T10	26.4	134.7	139.5	143.5	150.3	149.7	149.8	156.2	154.2	153.9	152.9	153.9	152.4	156.1	158	158	153.6	156.9	156	156.5	152.6	155.1
T11	38.1	143.3	156	161.1	164.9	167.2	168.6	169.2	171.1	171	172	172.4	171.7	171.9	172.4	172	171.3	171.7	171.5	170.6	171.2	171.3
T12	24.7	62.8	127.7	134.8	138.5	141	142	143	144.5	144.8	145.6	145.4	145.2	145.8	145.8	145.5	144.5	144.9	144.9	144.5	144.6	144.7
T13	24.5	24.1	30	34.1	38.3	41.2	43.4	44.3	45.3	45.6	46.1	46.4	46.5	46.3	46.5	46.6	46.5	46.4	46.2	46.3	46.2	46.32
T15	22.7	22.7	3.8	-0.7	0.2	1.2	0.8	0.5	0.1	0	-0.2	-0.4	-0.5	-0.5	-0.7	-0.9	-0.8	-0.8	-0.8	-0.9	-0.8	-0.82
T16	23.4	23.5	23.5	22.3	19.9	18.1	16.9	16.3	15.8	15.4	15.2	15.1	15.1	15.2	15.1	15.1	15.1	15.1	15.3	15.2	15.3	15.2
T17	23.5	23.6	23.8	24.2	23.6	23	22.5	22.4	22.4	22.1	22	21.9	21.9	22	22	22.1	21.9	21.9	22	22.3	22	22.02
T18	22.7	22.8	23.1	23.6	23	22.3	21.7	21.7	21.4	21.1	21	20.9	20.7	20.8	21	21.1	20.9	20.8	20.9	20.9	20.9	20.88
T19	24.1	24.2	25.2	28.5	30.8	32.3	33.1	33.8	34	34	34	34.2	34.1	34.2	34.2	34.3	34.2	34.1	34.1	34	34	34.08

POWER 315 Watts HYDROGEN PRESSURE 15.0 Bars STEADY-STATE PRESSURE 17.5 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	S/S
T1	23.4	23.7	45.4	46.5	47	47.1	46.9	47.7	48.2	48.3	48.4	48.2	48.2	47.6	48	48.3	48.6	48.6	48.6	48.6	48.54
T2	23.3	23.4	27.3	31.7	30.3	30.5	30	30.4	30.6	30.3	30.6	30.2	30.3	30.1	30.9	30.7	30.9	30.6	30.6	30.4	30.64
T3	23.2	23.3	23.1	25	26.4	26.4	26.1	27.6	28.2	28	28.3	28.2	28.2	27	27.9	28.3	28.6	28.9	28.9	28.2	28.58
T4	21.5	21.6	11	8.3	9.8	7.8	5.4	4.3	4.2	4.1	3.9	3.8	4.1	4.1	3.7	4.1	3.5	3.1	3.5	3.2	3.48
T5	22.9	23	21.8	20	1.3	-2.6	-3.3	-2.3	-2.1	-2.8	-2.2	-2.3	-2.8	-4.2	-2.8	-2.4	-3.8	-3.4	-3.7	-3.8	-3.42
T6	22.6	22.6	21	18.3	16.3	13.5	11.3	8.4	8.1	7.5	8	7.8	7.8	8.4	8	7.9	7.7	6.5	5	4.8	6.38
T7	25.1	25.1	31.1	37.8	43.4	45.9	46.9	49.8	50.9	50.9	51.7	51.5	51.9	50.2	51.2	51.8	52	52.5	52.5	51.6	52.08
T8	37	117.8	164.6	166.5	170.1	171.4	172.3	174.6	175.7	175.6	176	176.9	176.6	175.7	176.4	176.3	177	177.4	177.2	176.8	176.9
T9	23	23.2	28.7	36.3	40.5	43.4	44.4	47	47.9	48	48.6	48.5	48.8	46.7	48	48.6	49.1	49.4	49.3	48.7	49.02
T10	27.3	131.9	144.4	149.6	154	157.1	152.2	158.5	156.2	159.9	159.9	161.1	159	161.9	156.8	157.2	160.4	158.7	162.3	156.5	159
T11	39	142.1	163.6	166.4	170.2	171.4	172.1	174.3	175.8	175.9	176.1	176.7	176.5	175.2	176.3	176.1	176.6	177.2	176.7	176.3	176.6
T12	26	62.3	135.4	139	143	144.3	145.7	147.6	148.7	148.6	148.9	149.5	149.2	147.8	149.1	148.9	149.3	150	149.8	149.1	149.4
T13	25	24.9	29.8	35.4	39.7	43	44.2	46.6	47.8	48.1	48.6	49	49	47.4	48.6	48.9	49.4	49.5	49.7	49.2	49.34
T15	23.4	23.6	4	1.5	3.4	2.4	1.4	0.7	0.7	0.8	0.6	0.5	0.5	1	0.3	0.4	0.7	0.5	0.8	0.7	0.62
T16	24.3	24.4	24.5	23.7	21.6	19.6	18.2	17.1	16.5	15.8	16	15.9	15.8	16.2	15.7	15.9	16.2	15.9	15.8	15.2	15.8
T17	24.4	24.6	24.6	25	24.7	23.8	23.3	23.4	23.6	23.2	23.5	23.5	23.4	22.8	23.2	23.4	22.9	22.6	22.6	23.2	22.94
T18	24.3	24.4	24.6	24.7	24	22.8	22.1	22.5	22.6	21.7	22.5	22.5	22.4	21.2	21.9	22.6	21.4	20.9	20.9	21	21.36
T19	24.9	25	25.6	28.7	31.4	32.4	33.1	34.6	35.6	35.1	35.9	35.9	35.9	34.7	35.1	35.9	36.1	36.5	36.8	36	36.26

POWER 370 Watts HYDROGEN PRESSURE 15.0 Bars STEADY-STATE PRESSURE 18.25 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	23.2	23.3	48.2	55.7	60.5	61.4	62.6	63.1	63.5	63.3	63.6	63.9	63.9	63.7	63.9	64.3	65.6	65.2	63	64.4
T2	23.2	23.2	36.7	39.2	40.6	40.4	40.1	40.3	40.1	40.2	40.3	40.5	40.4	40.1	40.7	40.9	41.2	41.3	40.2	40.86
T3	23.2	23.2	24	30.3	31.7	31.8	32	32.2	32.5	32.3	32.2	32.2	32.1	32.4	32.6	32.5	32.5	32.7	32.7	32.6
T4	21.3	21.3	10.9	10.4	4.2	3.6	3.1	2.8	2.6	2.9	2.3	2.6	2.3	2.1	2.8	2.6	2.4	2.6	2.3	2.54
T5	22.7	21.4	21.3	0	-4	-3.6	-3.9	-3.8	-4	-4	-4	-4.1	-3.9	-4.1	-3.9	-4	-4	-4	-4.2	-4.02
T6	22.1	21.8	19.2	15	1.6	1.1	0.8	0.4	0.3	0.9	0.3	0	0.1	0	0.1	0.1	0.2	0.2	0.2	0.16
T7	26.1	26.5	36.6	45.6	52.1	55.6	57	57.9	58.6	58.7	58.7	58.9	58.9	59.1	58.9	59.1	59.3	59.1	58.8	59.04
T8	41.1	132.4	168.4	177.7	180.4	181.8	183.6	184.2	184.3	184.4	184.6	184.5	184.2	185.4	184.4	184.9	184.6	185.3	184.5	184.7
T9	23.1	23.4	35.5	42.9	48.8	52.8	54.8	56	57	57.3	57.2	57.1	57.2	57.2	57.4	57.2	57.5	57.4	57	57.3
T10	29.7	125.6	148.7	155.3	161.1	160.8	165.2	160.1	162.9	163.9	164.9	163.3	163.9	164.2	164.6	166.6	160.8	165.5	165.7	164.6
T11	43.6	162.1	170.4	178.9	181.1	182.5	184.4	185	185	185.1	185.4	185.1	185	186.3	185.3	186.2	185.4	186	185.5	185.7
T12	27.5	52.8	139.8	149.3	151.9	153.4	155.1	156.2	156	155.9	156.1	156.4	156.6	157.2	156.9	156.4	156.5	156.5	156.3	156.5
T13	25.4	26.1	33.8	41.5	48.3	52.4	54.3	55.6	56.8	56.7	56.8	56.9	56.9	57	57	57.2	57	57.2	57.2	57.12
T15	23.7	23.9	3.9	4.9	1.5	1.4	1.2	1.2	1.2	0.9	0.8	0.9	0.8	0.9	0.8	0.7	0.7	0.9	1	0.82
T16	24.4	24.5	24.4	22	16.4	11.7	7.9	6.9	6.5	6.4	6.2	6.4	6.2	6.3	6.2	6.1	6.2	6.5	6.3	6.26
T17	24.6	24.3	25.2	25.2	23.4	20.8	18.6	17.4	16.3	16.6	15.6	15.8	16.1	15.7	15.7	15.8	15.7	15.8	15.8	15.76
T18	24.4	24.4	25	24.6	22.6	19.9	17.7	16.2	14.5	14.3	13.8	14	14	13.9	13.6	13.8	13.7	13.6	13.5	13.64
T19	25.1	25.1	28.1	32.9	36	37.9	39	39.7	39.9	40	39.6	40.1	40.1	40.1	40.1	40.1	40	40.3	40.5	40.2

POWER 261 Watts HYDROGEN PRESSURE 17.5 Bars STEADY-STATE PRESSURE 19.75 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	S/S
T1	23	23.3	49.8	50.8	51.3	51.7	51.9	52.1	52.1	52.2	52.3	52.4	52.4	52.2	52.3	52.4	52.4	52.5	52.6	52.5	52.5	52.7	52.6
T2	23	23.1	23.3	26.7	27.2	27.4	27.5	27.8	28	28	28	28.2	28.3	28	28.1	28.2	28.2	28.2	28.2	28.3	28.3	28.5	28.3
T3	22.9	22.9	23	23.8	25.4	26.2	26.6	27	26.9	27.1	27.4	27.5	27.2	27.3	27.1	27.2	27.1	27.1	26.5	27.3	27	27.3	27
T4	21	21.1	20.9	8.9	8.2	8.3	8	7.3	6.3	6.3	5.6	5.7	5	4.8	5	4.8	4.7	4.9	4.6	4.6	4.7	4.7	4.7
T5	22.5	22.1	21.3	21.2	19.2	9.3	0.5	-0.3	-1.4	-1.4	-1.7	-1.7	-2.1	-2.2	-2	-2.4	-2.9	-2.8	-3.2	-3.1	-3.3	-2.9	-3.06
T6	21.3	21.3	20.6	19.2	16.5	15.4	14.1	13	11.6	11.1	10.4	10.3	10	9.6	9.9	9.7	9.7	9.9	10.3	9.6	9.7	9.6	9.82
T7	26.1	25.5	25	33.7	38.8	42.7	45.8	47.2	47.9	48.3	48.8	48.9	49.1	49	48.9	49.1	49.2	49.1	48.6	49.4	49.3	49.6	49.2
T8	32.7	32.1	171	170	175	177	179	180	181	182	183	183	183	183	183	183	183	183	184	183	184	183	183
T9	23	22.8	24.3	32.3	37.4	40.8	42.7	44	45.1	45.3	45.7	45.9	46.1	45.9	45.8	45.9	45.9	46	45.9	46	46.1	46.2	46
T10	27.8	79.9	150	151	155	158	162	160	163	162	166	168	162	167	167	163	162	163	164	166	165	162	164
T11	34.4	94.8	173	170	174	177	179	180	181	182	182	183	182	183	183	183	183	183	184	183	183	183	183
T12	25.7	28.2	115	141	147	150	152	153	153	154	154	155	154	155	155	155	155	155	155	155	155	155	155
T13	25.3	25	26.7	32	36.5	39.9	42.5	44	45.3	45.8	46.4	46.6	47	46.8	46.9	46.8	46.8	47	46.8	47	47.1	47	47
T15	23.4	23.3	23.1	2.5	1.5	2.2	2.6	2.3	2	1.8	1.4	1.3	1.3	1.1	1.5	1.4	1.5	1.4	1.6	1.3	1.4	1.3	1.4
T16	23.7	23.8	23	23.4	21.7	19.1	17.9	17.6	17.3	17.1	16.7	16.4	16.6	16.4	16.7	16.7	16.8	15.9	17.1	16.8	16.8	16.8	16.7
T17	24	24	23.5	24.4	24.4	23.3	23.1	23.6	22.9	22.9	22.8	22.5	22.8	22.6	23	22.7	22.7	22.9	23.2	22.6	22.8	22.7	22.8
T18	23.6	23.7	23.5	24.2	23.9	22.6	22	22	21.6	21.8	21.6	21.4	21.4	21.2	21.5	21.5	21.4	21.2	20.9	20.7	20.4	20.8	20.8
T19	24.8	24.9	24.5	26.9	29.8	31.7	33	33.8	34.3	34.6	34.6	34.7	34.9	34.9	34.7	34.9	34.9	35	35	34.9	35	35.1	35

POWER 315 Watts HYDROGEN PRESSURE 17.5 Bars STEADY-STATE PRESSURE 20.0 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	22.5	22.6	50.4	51.3	52.1	52.1	52.3	52.5	52.8	52.8	52.8	52.9	53	52.9	52.8	52.8	52.8	52.8	53	52.9	52.9	52.9
T2	22.5	22.5	25.3	27.1	27.6	27.9	27.8	28.3	28.5	28.2	29	28.9	29.1	29.1	28.7	28.6	29.1	29	29.6	29.4	29.6	29.3
T3	22.5	22.4	22.6	24.1	25.4	26.4	26.9	27	27.4	27.4	27	27.7	27.8	28	27.8	27.4	27.7	27	28	27.9	27.6	27.6
T4	20.6	20.6	11.4	7.7	8.7	7.3	5.1	4.6	4.2	4.8	4.3	4	3.6	4.2	4	4.4	4	4	4	4	3.6	3.92
T5	22	21.9	20.9	19.2	2.1	-0.7	-1.7	-2.1	-2.1	-2.3	-2.6	-2.6	-2.5	-2.6	-2.5	-2.4	-2.5	-2.8	-2.6	-2.5	-2.9	-2.66
T6	21.3	21.3	20.2	17	15.1	12.9	9.9	8.5	7.5	6.9	6.7	4.8	6.6	6.3	6	7	6.9	7.3	6.9	6.4	6.6	6.82
T7	24.7	24.5	30.6	36.7	42.8	45.8	48	49	50	50.1	50.3	50.8	50.7	51	50.8	50.7	50.6	49.8	50.8	50.8	50.5	50.5
T8	33.8	69.9	171	175	179	181	183	184	185	186	185	185	186	186	186	186	185	185	186	186	185	186
T9	22.3	22.3	28.5	35.3	39.8	42.9	44.7	45.9	47	47.1	47.1	47.6	47.7	47.6	47.8	47.5	47.7	47	47.5	47.6	47.3	47.4
T10	24.8	137	154	162	161	166	167	169	165	165	172	168	168	167	167	165	165	169	166	169	168	167
T11	35.6	147	171	175	179	181	182	184	185	185	185	185	186	186	185	185	185	185	186	185	185	185
T12	25.8	59.3	141	147	151	153	155	155	156	157	157	157	157	157	157	157	157	157	157	157	157	157
T13	24.5	24.2	29.6	34.4	39	42.5	44.8	46.2	47.1	47.7	47.9	48	48	48.2	48.1	48.2	48.2	47.8	48.2	48.1	48.1	48.1
T15	22.8	22.8	5.5	1.2	2.9	2.2	1.4	0.9	0.7	0.5	0.9	0.7	0.7	0.8	0.5	0.6	0.8	1.1	0.8	0.8	0.6	0.82
T16	23.7	23.7	23.7	22.4	20	18.4	17	15.9	15.4	14.7	14.9	14.7	14.6	14.7	14.4	14.8	15.2	15.4	15.1	15.2	15	15.2
T17	23.7	23.4	23.8	23.9	23.3	23	22.3	21.9	21.9	21.4	21.5	21.5	21.6	21.8	21.6	21.8	22.1	22	21.9	21.9	22.2	22
T18	23.3	23.4	23.7	23.6	22.6	22.2	21.5	20.9	20.7	20	20	20.5	20.1	20.1	19.9	20	19.8	19.5	19.4	19.5	19.6	19.6
T19	24.3	24.3	25	27.9	30.7	32.5	33.5	34	34.7	34.7	35	35.4	35.4	35.6	35.4	35.3	35.3	35.5	35.4	35.2	35.6	35.4

POWER 370 Watts HYDROGEN PRESSURE 17.5 Bars STEADY-STATE PRESSURE 20.5 Bars

Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	S/S
T1	23.2	50.2	52	54.9	56.8	57.4	58.9	59.6	60.1	60.4	61	62.5	62.5	61.5	62.5	60.9	60.6	60.5	60.2	60.8	60.1	60.4
T2	23.1	23.3	30.6	31.9	33.2	33.6	35.1	33.8	33.8	34.2	34.6	34.8	34.7	34.6	34.6	34	33.8	33.5	33.3	33.8	33.2	33.5
T3	23.1	23.1	24.3	27.8	28.8	29.6	29.5	30.4	30.2	30.7	30.8	31	30.9	30.9	31	31	30.6	30.3	30.2	30.3	29.6	30.2
T4	21	20.8	11.3	11.7	6.9	6.3	6.3	4.7	4.8	4.9	4.7	4.6	4.3	4.6	4.5	4.3	4.4	4.4	4.3	4.3	3.4	4.16
T5	22.6	21.3	21	2	-1.3	-1.6	-2.1	-2.3	-2.8	-2.1	-2.1	-2.1	-2.3	-2.3	-2.3	-2.2	-2.5	-2.6	-2.4	-2.4	-3.3	-2.64
T6	21.6	20.8	18.6	15.4	4.1	3.2	2.8	1.9	1.7	1.9	1.9	1.9	1.8	1.7	1.7	1.8	1.6	1.6	1.9	1.9	0.9	1.58
T7	25.8	26.3	36.5	44.3	49.8	52.3	53.4	54.9	55.5	56.6	56.8	57.1	57.5	57.1	57.3	57.3	57.3	57.1	57	57	56.7	57
T8	36.5	171	177	185	187	189	189	190	191	191	191	192	192	192	192	192	192	192	192	191	191	191
T9	23	23.5	34.8	40.3	45.4	48.7	50.5	51.7	52.6	53.7	54.2	54.3	54.6	54.3	54.6	54.7	54.3	54.5	54.6	54.7	54.3	54.5
T10	29.7	146	161	166	172	171	175	175	168	166	171	171	176	169	169	174	175	171	170	169	171	171
T11	38.8	182	178	185	188	189	190	190	192	192	192	193	192	192	192	193	193	192	192	192	191	192
T12	26.6	94.8	148	156	159	161	161	162	163	163	163	163	163	163	163	164	163	163	163	164	163	163
T13	25.3	26.3	33.4	39.2	44.8	48.3	49.9	50.9	52.3	53.3	53.8	54.3	54.5	54.5	54.5	54.6	54.5	54.5	54.1	54	54.2	54.3
T15	23.1	23.1	3	4.5	1.3	0.7	0.7	0.4	1	1.1	1.2	1.1	1.4	1.5	1.3	1.2	1.4	1.6	1.2	1.1	1.1	1.28
T16	24.2	23.6	23.5	21.1	16.4	12.5	10.2	9.6	9.6	9	8.7	8.3	8.1	8.4	8.1	8	8.1	8.5	8.4	8.2	8.1	8.26
T17	24.2	23.8	24.5	24.4	22.5	20.5	18.9	18.9	19.3	18.9	18.8	18.3	18.4	18.5	18.2	18.2	18.1	18.4	18.3	18.5	18.1	18.3
T18	23.8	23.7	24.3	23.7	21.4	19.1	17.3	17.6	18	17.7	17.5	16.8	16.7	16.6	16.3	16.3	16.2	16.5	16.4	16.4	16.2	16.3
T19	24.9	24.7	27.8	31.3	33.7	35.1	35.6	37.1	38.7	39.1	39.2	39.6	39.9	39.7	39.8	39.9	39.8	40.5	39.6	39.7	39.2	39.8

POWER 261 Watts HYDROGEN PRESSURE 20.0 Bars STEADY-STATE PRESSURE 23.0 Bars

Time[m]	0	5	10	15	20	25	30	35	40	50	55	60	65	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	22.5	22.5	22.5	39	55.5	55.7	55.8	56.1	56.4	56.5	56.6	56.8	56.8	56.9	56.8	56.9	57	56.9	57	57.2	57.1	57.4	56.9	56.9	57	57.1
T2	22.3	22.4	22.4	23.3	24.1	24.9	25.6	26.1	26.3	26.4	26.4	26.5	26.6	26.8	26.5	26.5	26.4	26.3	26.4	26.5	26.4	26.8	26.3	26.5	26.6	26.5
T3	22.2	22.3	22.4	22.5	22.6	22.6	22.6	23.2	24.4	24.6	25	25.2	25.5	25.8	25.8	25.6	25.7	25.1	25.7	26	26	26.2	25.6	25.8	26	25.9
T4	20.3	20.4	20.5	19.5	18.4	13.4	8.4	7.5	7.4	7.4	7.2	8.2	7.9	7.4	6.7	6.6	6.3	5.7	6	6.3	5.8	6.3	5.7	5.6	5.6	5.8
T5	21.6	21.7	21.7	21.7	21.6	21.3	20.9	19.5	17.8	17.5	14.5	3.3	1.5	0.6	0	-0.6	-0.8	-1.5	-1.4	-1.2	-1.6	-1.4	-1.9	-2.1	-2.3	-1.9
T6	20.4	20.4	20.4	20.6	20.7	19.9	19	17.2	15.3	14.9	14.8	14.6	14.1	13.9	13.4	12.6	12.5	12.2	11.5	11.4	11.4	11.5	11.4	11.7	11.2	11.4
T7	25.3	25.4	25.5	26.3	27.1	29.3	31.4	32.1	37.2	39.6	41.2	43.1	44.1	44.5	44.9	45.3	45.8	45.8	46	46.5	46.4	46.8	46.1	46.9	46.9	46.6
T8	34.8	39.1	43.4	108	173	174	175	179	184	185	186	186	187	187	187	188	189	189	189	189	189	189	189	189	190	189
T9	22.2	22.3	22.3	24.6	26.8	28.2	29.6	32.1	35.8	37.5	39.2	40.2	41.3	42.1	42.7	43.1	43.8	43.8	43.9	44.3	44.3	44.6	44.1	44.5	44.4	44.4
T10	26.6	79	131	142	152	154	156	158	162	163	166	170	169	165	168	168	171	166	169	167	168	169	167	168	171	168
T11	36.5	88.2	140	156	172	173	175	179	184	185	186	186	187	187	187	188	189	190	189	189	189	189	189	190	190	189
T12	25.1	39.3	53.5	89.9	126	133	140	146	153	155	156	157	157	157	157	158	159	158	159	159	159	159	159	159	160	159
T13	22.5	23.4	24.2	26.1	28	29.1	30.1	35.4	37	38.7	40.1	41.1	42.1	42.9	43.4	44	44.2	44.4	44.6	44.7	44.7	44.6	45	45.2	45.3	45
T15	22.4	22.4	22.3	19.3	16.3	10.1	3.9	1.3	1.5	1.8	2.8	2.5	2.5	2.2	1.9	1.8	1.6	1.5	1.3	1	1.1	1.3	1.4	1.4	1.5	1.34
T16	22.8	22.9	22.9	22.7	22.4	22.5	22.6	20.4	19.1	18.4	17.9	17.3	16.9	16.6	16.3	16.1	16	15.9	15.5	15.3	15.5	15.6	15.9	15.9	15.9	15.8
T17	23	23	22.9	23	23	23.3	23.5	23.1	22.6	22.4	22.4	22.3	22	22.1	21.9	21.9	21.9	21.8	21.5	21.5	21.5	21.8	22	22	22.1	21.9
T18	22.8	22.8	22.7	22.8	22.9	23.2	23.4	21.9	21.2	21.1	21.1	20.9	20.7	20.8	20.3	20.2	20.3	20.1	20	19.8	19.9	20.1	20.3	20.3	20.4	20.2
T19	23.8	23.9	24	23.9	23.8	24.6	25.4	29	29.7	30.6	31.3	31.9	32.1	32.6	32.8	33.2	33.2	33	32.9	32.8	33.1	33	33.6	33.7	33.8	33.4

POWER 315 Watts HYDROGEN PRESSURE 20.0 Bars STEADY-STATE PRESSURE 23.0 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	S/S
T1	22.2	22.3	22.4	55.7	55.7	56.3	55.8	56.3	57	57.4	57	57.8	57.2	57.3	57.2	57.3	57.4	57.4	57.6	57.5	57.8	58.3	57.4	58.2	57.8
T2	22.1	22.2	22.3	22.7	24.7	25.8	26.1	26.2	26.7	27	27	26.5	28.8	26.5	26.5	26.7	26.9	26.9	27.1	27.1	26.5	26.6	25.7	25.7	26.3
T3	22.1	22.2	22.3	22.2	22.2	22.6	23.2	24.8	25.9	25.8	25.9	25.8	25.8	25.4	25.5	25.7	25.9	26.2	26.3	26.3	26.2	25.8	24.8	24.3	25.5
T4	20.4	20.6	20.7	12.4	19.4	9.2	7.8	8.5	4.3	7.2	7	6.1	4.3	3.9	4	3.8	4.2	4.2	4.3	4.9	5.3	6.1	4.8	3.2	4.86
T5	21.3	21.3	21.4	25.5	20.5	19.6	18.6	18	3	1.3	0.6	-0.1	-2.4	-2.9	-2.8	-3.1	-2.9	-2.5	-2.6	-2.4	-1.7	-0.8	-2.5	-2.4	-2
T6	21.4	21.4	21.5	20.6	20.1	18.3	17.1	16.1	12	12.9	13.4	9.9	9.9	9.7	9.2	9.3	9.7	10.1	10.3	10.4	9.7	10.3	9.4	8.3	9.62
T7	24.5	24.5	24.5	25.3	28.9	32	34.8	37.9	43	45.6	45.5	46.5	48	47.9	48.8	48.7	48.9	48.8	48.9	49	48.8	48.6	48	47.6	48.4
T8	38	37.8	87.7	176	177	180	184	187	187	188	187	188	189	192	192	192	191	191	190	190	190	192	192	192	191
T9	22.1	22.2	22.3	28.9	28.9	31.6	34.1	36.9	42.2	42	43.1	44.4	44.4	44.1	44.3	45	45.6	45.8	45.8	46	45.9	45.4	44.3	43.7	45.1
T10	28.2	82.8	147	158	159	162	165	167	172	169	166	169	171	172	174	173	174	168	172	169	170	174	170	169	171
T11	40.1	98.3	156	175	176	181	185	186	187	188	188	187	191	191	192	191	191	191	190	189	191	192	192	192	191
T12	26.2	26.9	57.6	138	138	149	153	156	158	158	158	158	162	162	162	161	161	160	160	159	159	162	161	161	161
T13	24.4	24.2	26.5	28.8	30.8	33.1	35.5	37.7	39.3	41.2	42.8	43.7	44.5	44.5	44.4	45.2	45.3	45.5	45.6	45.8	45.5	45.3	44.4	44.5	45.1
T15	22.6	22.6	21.6	6.4	2.8	1	1.8	3.1	2.8	2	1.1	0.7	0.6	0.4	0.1	0	-0.1	0.1	0.3	0.4	0.4	0.4	0.4	0.4	0.4
T16	23.4	23.4	22.6	23.4	23.2	22.4	21.4	20.4	19.1	18.1	17	16	15	14.6	14.1	14.1	14.2	14.5	14.7	14.9	14.9	14.5	14.5	14.6	14.7
T17	23.5	23.5	23.1	23.9	24	24	23.8	23.6	23.2	22.7	22.4	21.9	21.5	21.1	20.8	20.8	20.8	20.9	21.3	21.4	21.3	20.5	21.1	21.1	21.1
T18	23.4	23.3	23.1	23.7	23.8	23.7	23.5	22.8	22.3	21.5	21.1	20.5	19.8	19.3	18.8	18.8	18.8	19	19.3	19.4	19.5	18.9	19.1	19.3	19.2
T19	23.9	23.9	23.7	24.9	26.2	27.8	29.1	30.2	30.9	31.3	31.8	32.7	33.2	33.2	32.9	33.1	33.3	33.4	33.7	33.8	33.4	32.2	32.6	32.7	32.9

POWER 370 Watts HYDROGEN PRESSURE 20.0 Bars STEADY-STATE PRESSURE 23.25 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	22.1	22	22.2	55.5	56.6	57.6	58.3	58.7	59.5	59.8	59.8	59.4	59.9	61	60.7	60.8	61	61.5	61.3	61.4	61.8	61.6	61.3	61.3	61.4	61.5
T2	22	22	22.1	23	26	27.8	27.8	28.2	28.4	28.3	28.6	28.1	28.5	29.2	28.7	29.1	29	29.1	29.2	29.4	29.3	29.4	29.2	29.2	29.4	29.3
T3	21.9	21.9	22	22	22.5	23.7	24.7	25.1	25.5	25.9	26.3	26.4	26.5	27.1	27.1	27	27.2	27	27.1	27.2	27.3	27.4	27.4	27.4	27.7	27.4
T4	20.3	20.3	20.3	17.5	11.8	11.3	11.3	8.7	5.8	4.7	4.2	4.4	4.4	4.4	4.3	4.3	4.5	4.9	4.8	4.2	4.2	4.3	4.2	4.4	4.4	4.3
T5	21.3	21.3	20.2	20.5	20.1	19.4	6.3	-0.4	-2.2	-3.1	-3.2	-3	-3.2	-2.9	-3.1	-3.2	-3.2	-2.7	-2.8	-3.2	-3.4	-3.4	-3.4	-3.4	-3.5	-3.4
T6	21.3	20.9	20.7	21.1	18.7	17	15.6	13	7	2.4	2.1	2.1	2	2.5	1.8	1.9	1.9	2.2	1.9	2.2	1.9	1.9	2.1	1.8	2	1.94
T7	24.3	24	24.5	25.8	31.8	36.4	40.3	43.6	46.6	47.9	49.6	50.5	51.2	52.3	52.9	53.2	53.7	53.2	53.5	53.8	54.1	54.2	54.3	54.3	54.5	54.3
T8	37.9	37.8	141	179	185	189	192	195	195	196	196	197	197	198	198	198	198	199	198	199	199	199	199	198	198	199
T9	22	21.9	22.3	26.5	30.6	34.2	37.7	40.4	43.3	45.4	47.4	48.5	49.4	50.9	51.6	52	52.4	51.9	52	52.6	52.9	53	53.2	53.1	53	53
T10	27.8	95.1	143	165	170	173	172	174	177	172	173	181	175	178	186	175	180	182	182	175	178	176	182	177	184	179
T11	39.9	111	178	180	186	189	192	194	195	195	196	197	196	197	198	198	198	198	197	198	198	199	198	198	198	198
T12	25.6	27.1	60.2	144	156	160	164	165	167	167	168	168	169	169	170	170	169	171	170	170	170	171	170	170	170	170
T13	24.1	23.8	24.4	27.1	29.6	32.9	36.6	39.3	42.6	44.6	46.6	47.7	48.7	50	50.7	51.1	51.1	51.1	51.2	51.5	51.7	51.9	52.1	52.1	52	52
T15	22.4	22.4	21.7	14.7	5	3.6	4.5	4	2.3	1.8	1.7	1.8	1.6	1.5	1.4	1.5	1.5	1.3	1	1.2	1.3	1.4	1.5	1.4	1.4	1.4
T16	23.2	23.2	23.2	23.1	23.2	22.3	21	19.5	17.2	14.9	12.7	11.6	10.7	9.5	9	8.8	8.4	8	7.8	8	7.9	7.7	7.6	7.7	7.8	7.74
T17	23.4	23.3	23.1	23.2	23.8	23.7	23.7	23.3	22.9	22	21.2	20.6	20.3	19.8	19.3	19.3	18.8	18.1	18	18.6	18.8	18.5	18.8	18.7	18.8	18.7
T18	23.1	23.1	23.2	23.1	23.6	23.6	23.2	22.4	21.6	20.4	19.6	19	18.4	17.7	17.3	17.4	17	16.4	15.8	16.6	16.8	16.7	16.7	16.6	16.8	16.7
T19	23.7	23.7	23.7	23.9	25.4	27.2	29	30.6	32.3	33.2	34.5	35.2	35.5	36.4	36.6	36.9	36.7	36.1	35.7	36.6	37	37.2	37.4	37.3	37.4	37.3

POWER 261 Watts HYDROGEN PRESSURE 22.5 Bars STEADY-STATE PRESSURE 25.75 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	22.4	21.9	21.8	22	61	60.9	61.5	61.8	62	62.5	62.5	62.7	63	63.2	63.2	63.3	63.4	63.4	63.2	63.2	63.2	63.2	63.2	63.2	63.2	63.2
T2	21.6	21.6	21.7	21.7	22.2	24.4	26.3	26.9	27.2	27.4	27.5	27.5	27.6	27.4	27.7	27.8	27.9	27.9	27.8	27.7	27.5	27.6	27.5	27.6	27.5	27.5
T3	21.5	21.5	21.6	21.5	21.6	21.5	22	22.7	23.4	24	24.3	24.5	24.7	25.1	25.1	25	25.3	25.3	25.2	25.2	25.2	25.7	25.8	25.6	25.6	25.6
T4	20.8	20.8	20.8	20.8	21	18.7	10.3	8.4	7.2	7.2	8.2	7.3	8.2	8.4	8.4	8.1	7.7	7.4	7.1	7.8	7.1	7.3	7	7	7	7.08
T5	20.5	21.1	21.2	21.3	20.7	21.1	20.7	19.4	18.7	18	17.8	17.7	10	3.6	2.3	1.9	1.6	1.1	0.8	0.6	0	0.2	-0.3	-0.2	-0.2	-0.1
T6	20.9	20.9	20.8	20.7	20.4	20.9	19.4	17.6	16.6	15.6	14.8	14.6	14.7	14.3	13.6	13.4	13	12.6	12.5	12.7	12.5	12.5	12.3	12	12	12.3
T7	23	22.4	22.4	22.4	22.6	24.4	28.6	30.8	33.3	35.4	38.1	39.3	40.3	43.3	44.3	44.7	45.4	45.4	45.4	45.5	45.7	46.2	46.6	46.4	46.7	46.3
T8	24.8	25	32.4	142	190	184	185	188	191	193	195	196	197	198	198	198	198	198	198	198	198	199	198	199	199	198
T9	21.4	21.4	21.4	21.5	23	25.9	28.2	30.7	32.5	34.2	35.7	37	38.2	39.6	40.4	41	41.6	41.9	41.7	42	42.3	42.7	42.9	43	43.1	42.8
T10	22.5	71.6	120	150	150	150	153	156	159	161	163	164	165	166	166	166	166	167	166	166	166	166	167	167	167	166
T11	24.9	87.8	131	169	189	184	185	189	191	194	195	196	197	198	198	199	199	199	199	198	199	199	199	199	199	199
T12	23.1	23.3	35.4	64.6	87.6	102	118	130	140	150	155	158	161	162	163	163	163	164	163	163	163	164	164	164	164	164
T13	23.5	23.4	23.5	23.5	24.1	26.2	27.8	30.2	32.1	34.1	35.8	37.4	38.6	39.7	41	41.8	42.2	42.4	42.6	42.6	43	42.9	43.1	43.4	43.6	43.2
T15	22.9	22.8	22.8	22.8	22.8	18.2	6.1	2.9	1.3	1.5	1.8	1.5	2.3	2.7	2.1	1.9	1.8	1.7	1.7	1.7	1.8	1.7	1.7	1.7	1.7	1.72
T16	23.2	23	22.9	23	22.5	22.6	22.8	22.6	21.6	20.8	19.7	18.9	18.3	16.9	16.2	16	15.8	15.6	15.6	15.5	15.4	15.3	15.4	15.2	15.2	15.3
T17	23.3	23.2	23.1	23.2	23	23.1	23.6	23.7	23.5	23.2	22.8	22.4	22.2	21.8	21.4	21.3	21.3	21.2	21.2	21.1	21.1	21.1	21.1	21.1	21.1	21.1
T18	23.1	23.1	23.1	23.1	22.9	23.1	23.4	23.4	23.1	22.5	22	21.5	21.2	20.1	19.7	19.6	19.5	19.4	19.3	19.3	19.3	19.3	19.5	19.2	19.2	19.3
T19	23.4	23.3	23.4	23.4	23.3	23.4	24.9	26.2	27.1	27.9	28.6	29.2	29.6	30	30.5	30.7	30.9	31.1	31	31.1	31.2	31.4	31.7	31.4	31.7	31.5

POWER 315 Watts HYDROGEN PRESSURE 22.5 Bars STEADY-STATE PRESSURE 25.75 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	21	21	21	21	61	61.2	61.6	61.8	62.1	62.5	62.9	63	63.1	63.1	63.2	63.3	63.2	63.4	63.2	63.4	63.5	63.4	63.2	63.4	63.2	63.3
T2	20.9	20.9	20.9	20.9	21.3	23.2	25	25.6	26	27.1	27.3	27.5	27.6	27.5	27.7	27.6	27.7	27.7	27.4	27.7	27.7	27.7	27.8	27.9	27.7	27.8
T3	20.9	20.9	20.9	20.9	21.1	21.1	21.4	21.9	22.6	23.4	23.6	24.1	24.4	24.3	24.5	24.5	24.6	24.6	24.8	25	25	25	24.6	24.8	24.5	24.8
T4	19.5	19.5	19.4	19.4	19.7	17.4	9.7	8.8	7.3	8.8	8.7	8.8	8.5	7.5	6.3	6.2	5.7	5.4	5.2	4.9	4.9	4.9	4.8	5.3	4.7	4.92
T5	20.3	20.3	20.4	20.3	19.4	20.1	19.5	18.5	17.7	17.5	9.8	2.8	1.6	0.7	-0.3	-0.3	-0.4	-0.7	-1.4	-1.1	-1.3	-1.4	-1.6	-1.3	-1.6	-1.4
T6	20.3	20.3	20.4	20.3	19.5	20.7	18.7	16.8	15.9	14.9	14.8	14.1	13.1	11.9	10.4	9.5	9	8.9	9	8	8.3	8.3	8.4	8.8	8.2	8.4
T7	22.3	22.3	22.3	22.2	22.7	23.9	28.4	31.2	33.8	36.8	38.6	41.6	42.9	43.8	45.3	46.1	46.1	46.5	47.1	47.2	47.4	47.1	47	47.1	46.8	47.1
T8	31.6	31.6	31.7	56.5	175	179	186	190	193	196	197	199	199	199	200	200	200	200	201	201	200	200	200	200	200	200
T9	20.7	20.7	20.8	20.8	23.5	26.4	29.1	31	33.7	35.6	36.9	37.3	38.2	39.2	41.2	42.1	42.4	42.8	43.3	43.8	44	43.8	43.8	43.7	43.5	43.8
T10	24.8	24.8	82.7	143	136	156	163	167	166	163	165	166	167	167	168	168	168	168	169	169	169	168	168	168	168	168
T11	33	33	97.6	152	175	179	187	191	193	197	199	200	201	200	201	202	201	201	201	201	202	201	201	201	201	201
T12	23.2	23.2	24.5	47.6	69.4	78.5	135	153	159	161	163	165	165	165	166	167	166	166	167	167	167	167	167	167	166	167
T13	23.1	23.1	23	22.9	24	25.8	27.6	29.6	32	34.4	36.4	36.3	37.9	39.4	41.1	42.4	42.9	43.1	43.5	44	44.2	44.1	44	43.9	43.7	44
T15	22	22	22.7	21.8	21.9	15.7	4.4	2.8	1.6	1.8	2.5	2.8	2.3	1.9	1.5	1.2	0.9	0.8	0.8	0.7	0.5	0.3	0.3	0.3	0.3	0.34
T16	22.7	22.7	22.6	22.7	22	22.1	22.4	22	21.2	20.1	19.2	18.3	17.4	16.6	15.4	14.5	14.1	13.9	13.7	13.4	13.3	13.1	13.3	13.3	13.5	13.3
T17	22.6	22.6	22.7	22.7	22.2	22.1	22.8	22.8	22.8	22.4	22.3	22.1	21.7	21.3	20.9	20.4	20.1	20.1	20	19.9	20	19.8	19.9	20	19.8	19.9
T18	22.1	22.1	22.1	22.3	22	28	22.5	22.5	22.2	21.8	21.3	20.8	20.2	19.7	19.1	18.4	18.2	18.1	17.8	17.8	17.8	17.5	17.7	17.7	17.7	17.7
T19	22.9	22.9	22.9	22.9	22.8	22.9	24.6	25.9	27	28.1	28.9	29.4	29.6	29.9	30.7	31.1	31.4	31.5	31.7	32	31.9	31.6	31.8	31.6	31.8	31.7

POWER 370 Watts HYDROGEN PRESSURE 22.5 Bars STEADY-STATE PRESSURE 26.25 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	S/ST
T1	22	22	59	62	63	63	64	65	65	65	65	66	66	66	66	66	66	66	66	66	66	66	66	67	68	68	69	68	67	68
T2	22	22	22	24	25	28	28	28	28	28	28	28	28	28	27	27	27	27	27	27	28	28	28	29	29	29	29	29	28	29
T3	21	21	21	21	22	23	25	25	25	25	26	26	25	26	25	25	24	24	24	25	24	24	24	26	26	27	27	26	26	26
T4	20	20	20	18	19	13	12	8.4	6.6	6.1	5.5	5.2	4.7	4.9	4.6	4.7	3.9	4.1	4.2	4.9	4.3	3.8	4	4.2	4.5	4.6	4.4	4.5	4.5	4.5
T5	21	21	20	21	20	19	4.4	0.3	-1	-2	-2	-2	-2	-2	-2	-3	-4	-3	-3	-3	-3	-4	-4	-2	-2	-2	-2	-2	-2	-2
T6	20	20	19	19	20	17	15	11	4.9	2.6	2.2	2.6	2.2	3.3	1.7	1.7	1.2	2.2	1.2	1.4	1.3	0.9	1.9	1.6	1.6	1.8	1.7	1.5	1.9	1.7
T7	24	24	25	24	26	35	40	43	45	47	49	49	50	51	51	51	50	51	51	50	51	50	50	51	52	52	52	52	52	52
T8	38	39	170	185	196	201	203	204	205	207	208	208	209	208	208	209	209	209	209	210	209	208	209	209	210	210	210	210	210	210
T9	21	21	23	27	29	32	36	39	42	44	46	48	48	49	49	50	49	50	49	49	49	49	49	50	50	51	51	51	50	50
T10	28	107	146	170	174	184	182	184	189	184	187	188	185	192	195	193	190	185	195	188	188	189	185	191	192	192	191	190	193	191
T11	40	120	175	187	196	200	203	204	205	207	208	208	208	208	208	208	209	209	209	210	208	208	208	209	210	210	210	209	209	210
T12	25	28	69	137	165	172	174	175	176	177	178	178	180	180	181	180	181	180	181	180	180	180	180	181	181	181	181	181	180	181
T13	23	23	24	26	27	31	34	39	41	43	45	47	47	48	49	49	49	49	49	48	49	49	49	49	50	50	50	50	49	50
T15	22	22	22	16	18	7.4	5.8	3.7	2.7	1.7	1.7	1.4	1.8	1.9	2.2	2.2	2.6	2.5	2.6	2.2	2.3	2.6	2.8	1.7	1.2	1	0.8	0.9	1	1
T16	23	23	23	22	23	22	20	18	16	13	12	9.8	9.1	7.8	7.1	6.6	6.9	6.9	6.6	6.1	6.5	6.7	6.8	5.8	5.2	4.8	4.6	4.9	5.2	4.9
T17	23	23	22	22	23	23	23	22	21	20	19	18	18	17	16	16	17	17	17	16	16	17	17	16	16	16	15	15	15	15
T18	22	22	22	22	23	23	22	20	19	18	17	15	15	15	14	13	13	13	13	12	12	13	13	12	11	11	11	11	11	11
T19	23	23	23	23	25	27	29	30	31	32	33	33	34	35	35	35	35	35	35	35	35	35	35	35	34	35	34	35	35	34

POWER 261 Watts HYDROGEN PRESSURE 25.0 Bars STEADY-STATE PRESSURE 28.0 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	95	105	115	125	135	145	155	165	175	185	195	S/S T
T1	21	21	21	21	21	65	65	65	66	66	66	66	66	66	66	67	66	66	67	67	67	67	67	67	67	67	67	67	67	67
T2	20	20	21	21	21	22	25	26	26	26	26	26	26	26	27	26	26	26	27	27	27	27	27	27	26	26	27	27	27	27
T3	20	20	20	20	21	21	21	21	22	22	23	23	23	23	24	24	24	24	24	25	25	25	24	25	25	25	25	25	25	25
T4	19	19	19	19	19	20	16	17	15	8.1	7.1	7	7.2	7.3	7.7	7.9	7.1	7	6.4	6.3	6.5	6	5.9	6.6	6.6	6.6	6.1	6.2	6.3	6.4
T5	20	19	20	20	19	19	19	20	19	19	17	17	14	6.6	4.8	3.9	2.8	2.5	1.9	1.5	1.7	1	0.5	0.6	0.8	1.9	0.9	0.9	1.7	1.2
T6	19	19	19	19	19	19	19	19	18	15	14	13	13	13	13	13	12	12	12	11	11	11	11	11	11	11	11	11	11	11
T7	22	23	22	22	22	25	24	26	33	35	37	38	39	40	41	42	42	43	44	44	44	44	44	45	45	45	45	45	45	45
T8	35	35	36	52	191	188	191	196	197	199	200	201	202	203	204	204	204	204	205	205	204	204	204	204	204	204	204	204	204	204
T9	20	20	20	20	21	25	27	28	29	30	33	35	36	37	37	38	38	39	40	40	40	40	40	41	41	42	41	41	41	41
T10	26	39	101	151	152	153	158	163	164	166	167	168	169	170	171	181	171	171	172	172	172	171	171	171	171	171	172	171	171	171
T11	37	56	113	159	193	188	191	197	198	200	201	201	203	203	205	204	205	205	206	205	205	205	204	205	206	205	205	205	205	205
T12	24	24	30	63	73	84	95	99	127	139	147	151	153	156	158	162	165	166	168	168	166	165	166	167	168	168	168	167	167	168
T13	23	23	23	23	24	26	26	26	28	30	34	36	36	37	38	38	39	40	41	41	42	42	42	42	42	42	42	42	42	42
T15	22	22	22	22	22	22	15	20	11	2.7	0.7	0.4	0.5	1.7	2	1.9	1.6	1.5	1.2	1	1	0.7	0.7	0.4	0.9	0.9	0.9	0.5	0.5	0.7
T16	22	22	22	22	22	22	22	22	21	20	19	18	17	16	16	16	15	15	15	15	15	14	14	14	14	15	15	15	14	14
T17	22	22	22	22	22	22	22	22	23	22	22	21	21	20	20	20	20	20	20	20	20	20	19	20	20	20	20	20	20	20
T18	22	22	22	22	22	22	22	22	22	21	21	20	19	18	18	18	18	18	18	17	17	17	17	17	17	18	18	18	18	18
T19	23	23	23	23	23	23	23	24	26	26	27	27	28	29	29	29	29	29	30	30	30	30	30	30	31	31	31	31	31	31

POWER 315 Watts HYDROGEN PRESSURE 25.0 Bars STEADY-STATE PRESSURE 28.25 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	95	105	115	125	135	145	155	165	175	185	195	S/ST
T1	21	21	21	65	65	65	66	66	66	66	67	66	66	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67
T2	21	21	21	21	23	25	26	26	26	26	26	26	26	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
T3	21	21	21	21	21	21	22	23	23	24	24	24	24	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
T4	19	19	19	20	18	17	16	11	8.1	8.8	8.2	7.7	6.8	6.7	6.5	6.5	6.2	5.9	5.6	5.7	5.9	5.1	5.6	5.5	5.9	5.9	5.9	6	6	5.9
T5	20	20	20	19	19	19	19	19	18	4.6	2.4	1.9	1.4	1.2	1.3	1.2	1	0.8	0.8	0.7	1.1	0.1	0	0.3	0.4	0.8	0.2	0.3	0.1	0.4
T6	20	20	20	19	19	20	19	16	14	14	13	12	10	9.8	9.6	9.3	9.2	9	8.8	8.8	9.2	8.4	8.3	8.6	9	9.4	9	9	8.9	9.1
T7	23	23	23	25	24	24	32	36	38	41	43	44	45	46	46	47	47	47	48	48	48	48	48	48	48	48	47	47	47	47
T8	36	36	57	177	187	192	199	202	203	205	206	207	207	207	207	207	207	207	208	207	208	208	208	207	207	207	206	207	206	206
T9	21	21	21	25	28	29	30	31	34	36	37	39	40	41	42	43	43	44	44	44	45	44	45	44	44	44	44	44	44	44
T10	26	79	146	140	152	159	166	169	170	172	173	174	174	174	174	175	175	175	175	175	175	175	175	175	174	174	174	174	174	174
T11	38	96	156	178	188	194	201	202	205	206	208	208	208	208	208	208	208	208	209	208	209	208	200	208	208	208	207	208	207	208
T12	24	25	49	73	102	134	155	165	169	171	172	173	173	173	173	173	173	173	174	174	174	174	174	173	173	173	172	173	172	172
T13	23	23	23	25	26	26	27	29	33	35	37	39	40	42	42	43	43	44	44	45	45	45	45	45	45	44	45	44	44	44
T15	22	22	22	22	18	16	14	4.5	1.8	3.1	2.6	1.9	1.6	1.2	1.2	1.2	1.2	1.2	1	1.1	1.2	0.7	0.5	0.9	0.9	1.1	0.9	0.9	0.7	0.9
T16	22	22	22	22	22	22	22	21	19	18	17	16	16	15	15	15	14	14	14	14	14	14	13	13	14	14	14	14	14	14
T17	22	22	22	22	22	22	24	23	22	22	21	21	21	21	20	20	20	20	20	20	20	20	20	19	20	20	20	20	20	20
T18	22	22	22	22	22	22	23	22	21	20	20	19	19	18	18	18	18	18	18	18	18	17	17	17	17	18	17	17	17	17
T19	23	23	23	23	23	23	26	27	27	28	29	30	30	31	31	32	32	32	32	32	33	32	32	32	32	33	32	32	32	32

POWER 370 Watts HYDROGEN PRESSURE 25.0 Bars STEADY-STATE PRESSURE 28.5 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	95	105	115	125	135	145	155	165	175	185	195	S/S
T1	21	21	21	64	65	66	66	66	67	67	67	67	68	68	68	68	68	67	67	67	67	67	67	67	67	68	68	68	68	68
T2	21	21	21	21	23	25	27	26	27	26	27	27	27	27	27	27	27	27	27	27	27	27	28	27	27	27	27	27	27	27
T3	21	21	21	21	21	20	21	22	23	23	23	24	25	25	25	24	23	22	22	22	22	22	22	22	23	25	25	24	25	25
T4	19	19	19	20	17	18	13	12	9.5	7.3	5.4	5.2	4.9	4.9	5	5.1	4.3	3.5	3.4	2.7	4.2	4.3	3.7	3.8	3	3.5	2.9	3.2	3.2	3.3
T5	20	20	20	20	20	20	19	6	1.1	-0	-1	-1	-1	-1	-1	-2	-3	-4	-4	-4	-4	-4	-4	-3	-3	-2	-3	-3	-2	-2
T6	19	20	19	19	19	19	16	15	11	8.5	5.4	2.3	2	2	1.9	1.8	0.9	0	0	-1	4.6	5.2	2.4	5	0.4	1.2	0.8	1.3	0.8	1.1
T7	23	23	23	25	23	25	33	37	40	42	44	46	48	49	49	49	47	46	46	45	46	45	45	44	48	50	51	51	52	51
T8	37	36	67	179	191	199	204	207	208	209	210	211	212	213	213	213	212	211	211	211	211	211	210	211	212	214	215	215	216	215
T9	21	21	21	25	28	29	31	33	35	37	40	42	44	45	45	46	45	43	43	43	42	42	42	41	44	46	47	48	48	48
T10	27	74	148	156	171	179	183	190	190	190	192	192	190	188	189	189	191	194	190	188	193	187	191	192	188	195	190	192	199	193
T11	38	95	162	182	192	200	205	208	208	209	211	211	213	214	213	213	212	211	211	211	210	211	210	211	213	214	215	215	216	216
T12	24	24	48	69	111	165	174	178	178	180	181	182	183	184	184	184	183	182	181	182	181	181	181	182	183	185	186	186	187	186
T13	23	23	22	24	25	25	28	30	32	35	39	40	42	44	44	44	43	42	41	41	42	42	42	41	43	45	46	48	48	47
T15	21	21	21	21	14	17	7.8	5.1	4	2.6	1.1	0.8	0.3	0.2	0.5	0.7	0.8	0.9	0.6	0.2	0.8	0.9	0.5	0.7	-0	0.2	0.4	0.9	1.1	0.8
T16	22	22	22	21	21	22	21	20	18	17	15	13	11	9.7	9.4	9	9	9	8.5	7.9	8.5	9.2	9	9	8	7.5	7.2	7.5	7.4	7.4
T17	22	22	22	21	21	22	23	22	22	21	20	19	19	18	18	17	17	18	17	17	17	17	17	17	16	17	17	17	18	17
T18	22	22	22	21	21	22	22	21	20	19	18	17	16	15	15	15	15	15	14	14	15	15	14	15	13	13	13	13	13	13
T19	22	23	22	22	22	24	26	27	28	28	29	30	31	32	32	32	32	32	32	31	30	29	29	27	31	33	34	35	35	34

POWER 261 Watts HYDROGEN PRESSURE 27.5 Bars STEADY-STATE PRESSURE 30.5 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	21.3	21.6	21.2	21.3	21.8	68.8	69.4	69.5	70	69.4	69.7	69.9	70.1	70.3	70.6	70.5	70.5	70.7	70.8	70.6	70.6	70.7	70.5	70.6	70.6	70.6
T2	21.3	21.2	21	21.1	21.5	22.7	25	25.7	26.1	25.8	26.2	26.4	26.6	26.6	26.9	26.8	26.7	26.9	26.8	26.8	26.7	26.6	26.5	26.6	26.5	26.6
T3	21.3	21.2	21.1	21.1	21.3	21.1	21.3	21.2	21.7	22.1	22.6	22.5	23	23.9	24.1	23.6	24.1	24.5	24.6	24.5	24.3	24.5	24.2	24.4	24.3	24.3
T4	19.9	19.9	19.7	19.9	20.3	20.3	16.6	17.4	15.3	7.4	5.8	7	6.3	6.8	7.4	7.3	7.1	7.1	7.2	7	6.8	6.6	7.2	7.1	7.2	6.98
T5	20.8	20.8	20.6	20.7	20	20	20.7	20.4	20.2	18.8	17.5	16.7	16.7	16.9	6.9	5.3	4.8	4.2	4.3	4.2	3.8	4.3	4.3	4.3	4.1	4.16
T6	20	20	19.6	19.4	19.3	19.4	20	19.6	18.2	15.6	14.4	13.6	13.3	12.8	12.9	12.9	12.4	12.3	12.4	12.2	12.2	12.3	12.5	12.5	12.5	12.4
T7	23.5	23.6	23	22.8	22.9	25	24.5	25.8	31.9	33.9	34.9	36.1	37.6	39.9	41.4	41.7	42.7	43.2	43.3	43.2	43	43	42.8	43.1	42.8	42.9
T8	39.2	38.6	40.5	59.6	194	193	195	199	202	204	205	206	207	209	210	211	211	211	211	211	210	210	210	210	210	210
T9	21.3	21.2	20.9	21.1	22.4	25.5	27.1	27.6	28.2	28.9	31.8	33.4	34.5	35.9	37	37.8	38.7	39.3	39.4	39.4	39.3	39.4	39.3	39.3	39.3	39.3
T10	27.8	53.6	111	160	151	157	160	164	168	170	171	172	174	176	177	177	177	178	178	177	177	177	176	177	177	177
T11	41.6	71.6	123	168	197	194	196	199	203	205	206	207	208	210	211	211	211	211	211	211	211	211	211	211	211	211
T12	24.7	24.9	32.5	67.9	75.7	81.4	87.2	90.6	90.7	96.2	113	106	120	135	141	140	152	156	153	151	152	142	141	139	146	144
T13	23.3	23.3	23.2	23.1	24.4	26.5	26.7	26.6	27.5	28.3	33.5	34.3	35.3	36.1	37.9	38.9	39.7	40.1	40.3	40.6	40.5	40.4	40.5	40.3	40.3	40.4
T15	22	21.9	21.8	21.9	22	22.2	15	17	12.1	1.8	-0.4	0.6	0	-0.4	1.1	1.5	1.4	1.2	1	1	0.9	0.9	1.1	1.2	1.3	1.08
T16	22.4	22.3	22.3	22.2	21.9	21.7	21.8	22.2	22.3	21.3	20.4	19.6	18.7	17.3	16.7	16.3	16.2	15.8	15.6	15.6	15.6	15.6	15.9	15.9	15.9	15.8
T17	22.4	22.4	22.4	22.4	22.2	22.1	22.2	22.7	23.5	22.8	22.6	22.3	21.9	21	21.1	20.6	20.7	20.4	20.4	20.2	20.4	20.5	20.5	20.6	20.8	20.6
T18	22.3	22.3	22.2	22.2	22.1	22	22.2	22.4	22.7	22.1	21.7	21.2	20.5	19.4	19.1	18.5	18.6	18.3	18.2	18	18.2	18.2	18.4	18.3	18.4	18.3
T19	23.1	23.1	23	23	23	23.2	23.4	24.7	26	26.4	26.7	27.2	27.9	28.6	29.1	29.3	30	30.2	30.1	30.1	30.2	30	30.1	30	29.9	30

POWER 315 Watts HYDROGEN PRESSURE 27.5 Bars STEADY-STATE PRESSURE 31.0 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	20.3	20.4	20.4	20.6	68.3	68.4	68.8	69.2	69.2	69.4	69.7	69.9	70	70	69.9	70.7	70.8	71.1	71.1	71.1	71	71.1	71.2	71	70.6	71
T2	20.2	20.2	20.2	20.4	20.7	22.6	24.6	25.3	25.5	26.1	26	25.9	26	25.9	25.8	26.7	26.7	26.9	26.8	27	26.9	26.8	26.7	26.9	26.4	26.7
T3	20.3	20.4	20.4	20.4	20.4	20.1	20.1	20.7	21.4	22.4	22.8	23.1	23.2	23.5	23.6	24.3	24.5	24.8	24.6	24.3	24.3	24.2	24.1	24.5	23.7	24.2
T4	18.7	18.8	18.9	19	19.4	18.1	16.6	18.1	9.3	7.8	7.3	7.8	7.5	6.9	6.3	6.3	5.4	4.8	5.4	4.9	4.5	4.9	4.3	4.2	4.7	4.52
T5	19.5	19.8	19.7	19.2	19	19.2	19.4	19.4	18.7	17.5	15.7	4.2	2.7	1.8	1.4	1.3	0.8	0.4	0.5	0.2	0.1	0	-0.3	-0.2	-0.7	-0.2
T6	19.3	19.5	19.5	19.4	18.6	18.7	19.3	20.9	15.4	13.7	12.9	12.9	12.2	11.1	10.1	9.6	8.6	7.9	8.1	8.2	7.9	8.1	7.6	7.5	7.6	7.74
T7	22.2	22.3	22.2	22.5	24	22.5	22.5	25.5	34	36.5	38	40.2	41.7	43.2	44.2	45.4	46.2	46.9	46.9	46.5	46.6	46.6	46.5	46.8	46.3	46.6
T8	33.2	33.1	35.9	138	183	193	198	203	207	208	210	212	212	212	212	214	215	215	215	215	215	215	215	215	215	215
T9	20.2	20.3	20.3	20.6	24.3	26.2	26.9	27.8	28.8	31.2	34.8	36.5	37.4	39.3	40.7	42.1	42.8	43.4	43.8	43.6	43.8	43.7	43.5	43.8	43.5	43.7
T10	27.2	46.2	114	146	146	157	163	169	174	175	177	179	179	179	180	181	102	182	182	182	182	182	182	182	182	182
T11	36.3	67.9	126	172	185	195	200	205	209	210	211	213	213	213	214	216	216	216	217	216	217	217	216	216	215	216
T12	23.7	23.6	33	73.4	75.6	90.3	113	128	147	165	171	174	176	177	177	180	180	181	181	181	181	181	181	181	181	181
T13	22.4	22.4	22.4	22.5	24.1	24.9	24.7	25.7	27.1	32.4	35.2	35.9	37.5	39.4	41.1	42.3	42.8	43.4	43.7	43.6	43.8	43.7	43.7	43.9	43.7	43.8
T15	21	21.1	21.1	21.1	21.1	18.4	15.6	17.7	4.6	0.7	1	2.1	1.6	1.3	1.1	0.7	0.4	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.2
T16	21.7	21.8	21.8	21.8	21.1	21	21.7	22.2	21	19.9	18.9	18	17.2	16.2	15.6	15.1	14.3	13.7	13.6	13.5	13.3	13.2	13.3	12.9	13.3	13.2
T17	21.9	21.8	21.9	21.6	21.5	21.5	21.8	23.1	22.8	22.2	21.9	21.7	21.2	20.8	20.7	20.8	20.3	20.1	19.7	19.8	19.5	19.4	19.6	19.4	19.6	19.5
T18	21.9	21.8	21.8	21.8	21.5	21.5	21.6	22.3	22.1	21.3	20.7	20	19.4	18.7	18.4	18.3	17.7	17.3	17	17	16.9	16.7	16.8	16.6	16.8	16.8
T19	22.1	22.2	22.2	22.1	22.2	22.4	23.1	25.5	26	26.6	27.6	28.8	29.4	30.1	30.9	31.2	31.4	31.5	31.6	31.8	31.8	31.6	31	31.6	31.9	31.6

POWER 370 Watts HYDROGEN PRESSURE 27.5 Bars STEADY-STATE PRESSURE 31.0 Bars

Time[m]	0	5	10	15	20	25	30	35	40	45	50	55	60	70	80	90	100	110	120	130	140	150	160	170	180	190	S/S
T1	20	20	20	20	68	69	69	70	70	70	71	71	71	71	71	71	71	72	71	72	72	72	72	72	72	72	72
T2	20	20	20	20	20	22	25	25	26	26	26	26	26	26	26	26	27	26	26	26	26	26	26	27	26	26	26
T3	20	20	20	20	20	20	20	21	22	22	22	22	23	23	22	24	23	24	23	23	24	24	24	24	23	23	24
T4	19	19	19	19	19	17	17	15	9.9	9	8.3	6.2	5.3	4.7	4.6	4.5	4.2	4.3	4.1	4.5	4.5	4.5	4.5	4.2	4.2	4.2	4.3
T5	19	20	20	20	19	19	19	19	17	3	1.3	0.4	-0.1	-0.4	-0.6	-0.5	-0.8	-0.4	-0.7	-0.6	-0.7	-0.6	-0.4	-0.4	-1	-1	-0.7
T6	19	19	19	19	18	19	19	17	14	12	11	8.3	4.8	4.3	2.6	2.1	2	2.2	2	1.9	1.9	1.9	1.9	2.1	2	1.9	2
T7	21	21	21	21	23	23	23	31	35	38	40	42	44	45	45	47	47	47	47	48	48	48	48	48	48	48	48
T8	28	27	27	39	183	197	204	211	214	216	217	218	219	220	219	221	221	221	222	221	222	221	222	222	222	222	222
T9	20	20	20	20	23	26	27	28	30	33	35	37	38	40	41	43	43	43	43	43	44	44	44	44	44	44	44
T10	23	23	67	148	163	172	185	186	194	195	199	198	200	201	199	204	203	197	200	197	199	205	204	203	198	196	201
T11	29	29	87	157	187	198	205	212	216	217	218	219	220	220	220	221	222	221	222	222	222	222	222	223	222	222	222
T12	22	22	22	39	79	89	158	177	184	187	188	190	191	190	191	191	191	192	192	192	192	193	192	193	192	192	192
T13	22	21	22	22	23	25	25	26	29	32	35	37	39	41	42	43	44	44	44	44	44	44	44	45	45	45	45
T15	21	21	21	21	21	16	17	12	4.6	4.3	3.1	2.3	1.6	1.5	1.3	1.7	1.3	1.2	1.1	1.4	1.2	1.1	0.9	1.1	1.1	1.4	1.1
T16	21	21	21	21	21	21	21	22	20	19	17	16	14	12	11	9.9	9.9	9.1	9.3	9.3	8.8	8.5	8.5	8.5	8.4	8.8	8.6
T17	21	21	22	22	21	21	22	23	22	22	21	21	20	19	18	18	18	17	17	17	17	17	17	17	17	17	17
T18	21	21	21	21	21	21	22	22	22	21	20	19	17	16	16	15	15	14	14	14	14	13	13	13	13	14	13
T19	22	22	22	22	22	22	23	25	26	27	28	28	29	30	30	30	31	30	31	31	30	31	31	31	31	31	31

POWER 315 Watts HYDROGEN PRESSURE 0.0 Bars [No Hydrogen] STEADY-STATE PRESSURE 0.5 Bars

											[No Hydrogen]								
Time[m]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	S/S
T1	19.5	29.3	53.9	58.2	85.5	76	82.7	74.6	74.6	71.6	77.6	71.8	78.2	69.2	81.3	84.1	80.5	71.5	84.9	
T2	19.4	20.7	26.2	25.8	38.2	40.9	37.3	42.6	34.6	36.2	35.1	40.5	41	37.9	37.2	36.1	33.7	33.4	35.7	
T3	19.4	21.3	22.9	24	31.5	28.7	26.4	26.8	25.4	24.8	24.6	27.1	25.1	26.9	24.9	25	25.3	25.5	24.7	
T4	19.4	20.1	20.7	20.8	21.3	20.7	20.5	20.7	21.2	21.3	21.9	22	22.2	22.1	22.6	22.5	23.1	22.4	22.5	
T5	19.4	19.8	19.9	20.1	19.8	19.5	19.3	19.6	20.5	21.9	22.5	23.1	22.1	22.7	22.2	22.6	23	23.2	22.7	
T6	19.4	19.6	19.5	19.4	19.2	19	18.8	19.2	20.2	20.7	21.2	22	21	22	21.1	21.4	21.6	21.9	21.5	
T7	20.2	28.2	31.8	34.6	31.2	28.9	27.5	28.9	29.1	27.9	27.1	27.4	26.7	27.4	26.6	26.3	27.7	27.3	26.5	
T8	26.4	92.3	108.5	115.9	117.9	115.4	113.7	115.1	113.5	112.9	112.3	111.6	110.5	111.7	111.3	110.5	110.7	111.2	110.4	
T9	19.4	21.3	23	26.2	25.9	25.3	24.5	24.9	25.1	24.5	23.6	23.3	22.6	23.2	22.7	22.7	22.8	23.5	22.8	
T10	22.9	71.6	78.9	91.3	102.1	99.7	103.7	98.4	101.3	99.5	101.8	94.2	100.8	95.8	104.3	100.1	101.6	97	100.8	
T11	26.9	97.1	109.7	118	120	116.3	115.7	114.7	114.8	114	113.5	112.8	111.9	113	112.2	111	112.4	112.2	111	
T12	21.5	65	67.5	77.4	85.7	98.2	97	76.9	89.4	76.8	89.3	77.7	86.1	83.9	92.8	90.6	87.8	79.6	95.8	
T13	21.3	24	27.6	31.1	30.6	29.5	28.7	29.1	29.7	28.2	27	26.8	26.9	26.7	26.6	26.2	27.3	27.3	26.6	
T15	21.1	21.3	21.6	21.8	22.4	22.8	22.9	23.7	24.8	25.6	26	26.1	26.1	26.1	26.4	26.2	26.5	26.5	26.2	
T16	21.3	21.4	21.2	21.1	21.2	21.5	21.8	21.8	21.9	22.2	22.1	22.5	21.8	22.3	22	22	22	22.1	22	
T17	21.2	21.6	21.6	21.4	21.7	21.9	22	22.3	22.7	22.2	22.2	22.4	22.5	22.3	22.2	22.3	22.4	22.5	22.6	
T18	21.1	21.5	21.7	21.9	22	22.5	22.9	23.3	23.2	22.5	22.6	22.8	22.9	22.8	22.8	22.7	22.9	22.9	22.9	
T19	21.2	22.7	24.1	26	26.5	26.6	26.4	26.8	26.9	25.3	25	24.9	24.9	24.9	24.9	24.6	24.9	25	24.7	

APPENDIX 2: SELECTED COMPUTED RESULTS

Heat exchanger effectivenesses at various hydrogen pressures and power inputs

POWER [W]	P1 [bar]	P2 [bar]	Ehex [-]	Epcl [-]	Epch [-]
261	7.5	3.835	0.998	0.059	0.682
315	7.5	4.14	0.971	0.065	0.731
370	7.5	4.365	0.976	0.048	0.623
261	10	4.329	0.999	0.227	0.642
315	10	3.943	0.99	0.777	0.467
370	10	4.096	0.973	0.707	0.467
261	12.5	3.955	0.992	0.687	0.488
315	12.5	3.958	0.999	0.651	0.595
370	12.5	4.037	0.992	0.694	0.586
261	15	4.034	0.999	0.7	0.51
315	15	4.034	0.999	0.722	0.565
370	15	4.259	0.999	0.629	0.72
261	17.5	4.291	0.999	0.675	0.602
261	17.5	4.291	0.999	0.675	0.602
370	17.5	4.034	0.999	0.642	0.632
261	20	4.365	0.999	0.653	0.563
315	20	4.375	0.993	0.678	0.578
370	20	4.224	0.999	0.617	0.544
261	22.5	4.385	0.999	0.63	0.611
315	22.5	4.438	0.997	0.667	0.618
370	22.5	4.214	0.999	0.503	0.713
261	25	4.317	0.999	0.685	0.702
315	25	4.278	0.996	0.672	0.683
370	25	4.304	0.999	0.637	0.667
261	27.5	4.285	0.999	0.801	0.706
315	27.5	4.333	0.999	0.721	0.675
370	27.5	4.192	0.999	0.642	0.688

Legend

P1: Low pressure
P2: High pressure
Ehex: effectiveness of solution heat exchanger
Elpc: effectiveness of low pressure pre-cooler
Ehpc: effectiveness of high pressure pre-cooler

APPENDIX 3: QUICKBASIC PROGRAMMME LISTING

```
'=====================================================================
'          PROGRAMME   "AMOWAT"
' Thermodynamic Properties of Ammonia-Water mixtures
'=====================================================================
DIM C1(50), C2(50), C3(50), P(50), T(50), X(50), Y(50)
DIM HL(50), HG(50), ALPHA(50), LOGALPHA(50)
'---------------------------------------------------------------------------------------------------
' CONSTANTS [for use in subroutines]
'---------------------------------------------------------------------------------------------------
' Coefficients for the equations for the pure components
 A1A = 3.971423E-02: A2A = -1.790557E-05: A3A = -1.308905E-02: A4A = 3.752836E-03   'Specific volume constants for ammonia (liquid)
 A1W = 2.748796E-02: A2W = -1.016665E-05: A3W = -4.452025E-03: A4W = 8.389246E-04   'Specific volume constants for water (liquid)
 B1A = 16.34519: B2A = -6.508119: B3A = 1.448937     'Specific heat constants for ammonia (liquid)
 B1W = 12.14557: B2W = -1.898065: B3W = .2911966#     'Specific heat constants for water (liquid)
 C1A = -1.049377E-02: C2A = -8.288224: C3A = -664.7257: C4A = -3045.352 'Specific volume constants for ammonia (gas)
 C1W = 2.136131E-02: C2W = -31.69291: C3W = -46346.11: C4W = 0 'Specific volume constants for water (gas)
 D1A = 3.673647: D2A = 9.989629E-02: D3A = 3.617622E-02    'Specific heat constants for ammonia (gas)
 D1W = 4.01917: D2W = -.0517555: D3W = 1.951939E-02       'Specific heat constants for water (gas)
 HORLA = 4.878573: HORGA = 26.46888: SORLA = 1.644773: SORGA = 8.339026: TORA = 3.2252: PORA = 2      'Reduced initial ammonia properties: Liquid enthalpy, gas enthalpy, liquid entropy, gas entropy, temperature, pressure resp.
 HORLW = 21.821141#: HORGW = 60.965058#: SORLW = 5.733498: SORGW = 13.45343: TORW = 5.0705: PORW = 3  'Reduced initial water properties: Liquid enthalpy, gas enthalpy, liquid entropy, gas entropy, temeperature, pressure resp.
```

```
' Coefficients for the Gibbs excess energy function
 E1 = -46.26129: E2 = 2.060225E-02: E3 = 7.292369: E4 = -1.032613E-02: E5 =
80.74824
 E6 = -84.61214: E7 = 24.52882: E8 = 9.598767E-03: E9 = -1.475383: E10 = -
5.038107E-03
 E11 = -96.40398: E12 = 122.6973: E13 = -7.582637: E14 = 6.012445E-04: E15 =
54.87018: E16 = -76.67596
'-----------------------------------------------------------------------------------------------------
'              M A I N   P R O G R A M M E
'-----------------------------------------------------------------------------------------------------
5  INPUT "Enter T or P if Temperature or Pressure is constant, respectively"; OK1$
  IF OK1$ = "P" OR OK1$ = "p" THEN GOTO 10
  IF OK1$ = "T" OR OK1$ = "t" THEN GOTO 25
  GOTO 5
10 INPUT "Press RETURN to enter default pressure values
<0.1,0.2,0.4,0.6,1,1.5,2,3,4,6,8,10,15,20,30,40-bars> or enter P to change them";
OK2$
  IF OK2$ = "" THEN : NPV = 16: P(1) = .1: P(2) = .2: P(3) = .4: P(4) = .6: P(5) = 1:
P(6) = 1.5: P(7) = 2: P(8) = 3: P(9) = 4: P(10) = 6: P(11) = 8: P(12) = 10: P(13) = 15:
P(14) = 20: P(15) = 30: P(16) = 40: GOTO 15  'Default pressure values
  INPUT "Number of Pressure values"; NPV     'Number of Pressure Values
  FOR I = 1 TO NPV
  INPUT "Pressure values in bars (enter separately)"; P(I)
  NEXT I
15 INPUT "Press RETURN to enter default X-step <0.02> or enter X to change it";
OK3$
  IF OK3$ = "" THEN XSTEP = .02: GOTO 20    'Increment in X
  INPUT "X-step"; XSTEP
20 FOR I = 1 TO NPV: X = 0: Y = 0
   DO WHILE X <= 1
    P = P(I): GOSUB 110: GOSUB 130: GOSUB 140
    FILENR$ = "C:\qbasic\data\hxyp"
    OPEN FILENR$ FOR APPEND AS #1
    PRINT #1, X, Y, P / 14.696, HL, HG
```

```
    CLOSE #1
    X = X + XSTEP
   LOOP
  PRINT , "Pressure [bars]=", P(I)
  NEXT I
    INPUT "Enter T to evaluate constant Temp. also OR Press RETURN to end";
OK4$
  IF OK4$ = "T" OR OK4$ = "t" THEN GOTO 25
  GOTO 55
25 INPUT "Press RETURN to enter default min. temp.<-60 deg.C> or enter I to
change it"; OK5$
  IF OK5$ = "" THEN T = 213.15: GOTO 30    ' intial temperature
  INPUT "Initial temperature in deg. C"; T: T = T + 273.15
30 INPUT "Press RETURN to enter default max. temp.<220 deg.C> or enter F to
change it"; OK6$
  IF OK6$ = "" THEN TMAX = 493.15: GOTO 35    ' final temperature
  INPUT "Final temperature in deg. C"; TMAX: TMAX = TMAX + 273.15
35 INPUT "Press RETURN to enter default temp. step <10 deg.C> or enter T to
change it"; OK7$
  IF OK7$ = "" THEN TSTEP = 10: GOTO 40    ' temperature increment
  INPUT "Temperature increment in deg. C"; TSTEP
40 INPUT "Press RETURN to enter default X-step <0.02> or enter X to change it";
OK8$
  IF OK8$ = "" THEN XSTEP = .02: GOTO 45     ' increment in X
  INPUT "X-step"; XSTEP
45 DO WHILE T <= TMAX: X = 0
    DO WHILE X <= 1
     GOSUB 100: GOSUB 130
     FILENR$ = "C:\qbasic\data\hxyt"
     OPEN FILENR$ FOR APPEND AS #2
     PRINT #2, X, P, HL
     CLOSE #2
     X = X + XSTEP
    LOOP
```

```
  PRINT , "Temperature [deg.C]=", T - 273.15
  T = T + TSTEP
 LOOP
50 INPUT "Enter P to evaluate constant Pressure also OR Press RETURN to end";
OK9$
 IF OK9$ = "P" OR OK9$ = "p" THEN GOTO 10
'------
55 END
'-----------------------------------------------------------------------------------------------
'                    S U B R O U T I N E S
'-----------------------------------------------------------------------------------------------
100  'Subroutine PTX - Determination of P at constant T, varying X
'-----------------------------------------------------------------------------------------------
   C1 = -14.212 * (X ^ 6) + 54.662 * (X ^ 5) - 81.736 * (X ^ 4) + 59.828 * (X ^ 3) -
23.122 * (X ^ 2) + 5.5525 * X - 2.1928
   C2 = 14.937 * (X ^ 6) - 69.896 * (X ^ 5) + 122.54 * (X ^ 4) - 102.09 * (X ^ 3) +
42.752 * (X ^ 2) - 9.0153 * X + 7.0262
   C3 = 1000 * (C1 / T) + C2
   P = 10 ^ C3
   P = P / 14.696              'Pressure conversion from psia to bars
   RETURN
'-----------------------------------------------------------------------------------------------
110  'Subroutine TPX - Determination of T at constant P, varying X
'-----------------------------------------------------------------------------------------------
   P = P * 14.696              'Pressure conversion from bars to psia
   C1 = -14.212 * (X ^ 6) + 54.662 * (X ^ 5) - 81.736 * (X ^ 4) + 59.828 * (X ^ 3) -
23.122 * (X ^ 2) + 5.5525 * X - 2.1928
   C2 = 14.937 * (X ^ 6) - 69.896 * (X ^ 5) + 122.54 * (X ^ 4) - 102.09 * (X ^ 3) +
42.752 * (X ^ 2) - 9.0153 * X + 7.0262
   DEF FNlogBaseTen (P) = LOG(P) / LOG(10)   'To convert from LN to Log base
10
   C3 = FNlogBaseTen(P)
   T = (1000 * C1) / (C3 - C2)      'To determine T given P and X
   'T = T - 273.15              'Conversion from Kelvin to deg.C
```

```
   RETURN
'----------------------------------------------------------------------------------------------
120 'Subroutine XPT - Determination of X given P and T
'----------------------------------------------------------------------------------------------
125 C1 = -14.212 * (X ^ 6) + 54.662 * (X ^ 5) - 81.736 * (X ^ 4) + 59.828 * (X ^ 3) - 23.122 * (X ^ 2) + 5.5525 * X - 2.1928
   C2 = 14.937 * (X ^ 6) - 69.896 * (X ^ 5) + 122.54 * (X ^ 4) - 102.09 * (X ^ 3) + 42.752 * (X ^ 2) - 9.0153 * X + 7.0262
   C3 = 1000 * (C1 / T) + C2
   PR = 10 ^ C3
   PR = PR / 14.696
   IF (ABS(PR - P) <= .065) GOTO 128
   X = X + .001
   IF (X >= 1) GOTO 127
   GOTO 125
127 X = .999
128 RETURN
'----------------------------------------------------------------------------------------------
130 'Subroutine HLTX - Determination of HL at constant T, varying X
'----------------------------------------------------------------------------------------------
   R = 8.314: TB = 100: PB = 10: TR = T / TB: PR = P / PB    ' Reduced props
   HLRA = -(-HORLA + B1A * TORA + (B2A / 2) * (TR ^ 2 + TORA ^ 2) + (B3A / 3) * (2 * TR ^ 3 + TORA ^ 3) - B1A * TR - B2A * TR ^ 2 - B3A * TR ^ 3 + (-A1A + A4A * TR ^ 2) * (PR - PORA) - (A2A / 2) * (PR ^ 2 - PORA ^ 2))
   HLRW = -(-HORLW + B1W * TORW + (B2W / 2) * (TR ^ 2 + TORW ^ 2) + (B3W / 3) * (2 * TR ^ 3 + TORW ^ 3) - B1W * TR - B2W * TR ^ 2 - B3W * TR ^ 3 + (-A1W + A4W * TR ^ 2) * (PR - PORW) - (A2W / 2) * (PR ^ 2 - PORW ^ 2))
   HRE = (E1 + 2 * (E5 / TR) + 3 * (E6 / (TR ^ 2)) + (E7 + E8 * PR + 2 * (E11 / TR) + 3 * (E12 / (TR ^ 2))) * (2 * X - 1) + (E13 + E14 * PR + 2 * (E15 / TR) + 3 * (E16 / (TR ^ 2))) * ((2 * X - 1) ^ 2)) * X * (1 - X)
   HLR = (1 - X) * HLRW + X * HLRA + HRE
   HL = R * TB * HLR / (17 * X + 18 * (1 - X))
   RETURN
'----------------------------------------------------------------------------------------------
```

```
140 'Subroutine HVTXY - Determination of HV at constant T, varying X and Y
'------------------------------------------------------------------------------------------------
   R = 8.314: TB = 100: PB = 10: TR = T / TB: PR = P / PB   ' Reduced props
   HGRA = -(-HORGA + D1A * TORA + (D2A / 2) * (TR ^ 2 + TORA ^ 2) + (D3A
/ 3) * (2 * TR ^ 3 + TORA ^ 3) - D1A * TR - D2A * TR ^ 2 - D3A * TR ^ 3 - C1A *
(PR - PORA) - C2A * ((PR / (TR ^ 3)) - 4 * (PORA / (TORA ^ 3))) - C3A * ((PR /
(TR ^ 11)) - 12 * (PORA / (TORA ^ 11))) - (C4A / 3) * ((PR ^ 3 / (TR ^ 11)) - 12 *
(PORA ^ 3 / (TORA ^ 11))))
   HGRW = -(-HORGW + D1W * TORW + (D2W / 2) * (TR ^ 2 + TORW ^ 2) +
(D3W / 3) * (2 * TR ^ 3 + TORW ^ 3) - D1W * TR - D2W * TR ^ 2 - D3W * TR ^ 3
- C1W * (PR - PORW) - C2W * ((PR / (TR ^ 3)) - 4 * (PORW / (TORW ^ 3))) -
C3W * ((PR / (TR ^ 11)) - 12 * (PORW / (TORW ^ 11))) - (C4W / 3) * ((PR ^ 3 /
(TR ^ 11)) - 12 * (PORW ^ 3 / (TORW ^ 11))))
   GOSUB 150
   HGR = (1 - Y) * HGRW + Y * HGRA
   HG = R * TB * HGR / (17 * Y + 18 * (1 - Y))
   RETURN
'------------------------------------------------------------------------------------------------
150 'Subroutine YTX - Determination of Y at constant T, varying X
'------------------------------------------------------------------------------------------------
   T = T - 273.15              'Conversion from Kelvin to deg.C
   C1 = .0058 * (X ^ 6) - .0161 * (X ^ 5) + .0167 * (X ^ 4) - .0082 * (X ^ 3) + .002 *
(X ^ 2) - .0001 * X + .000008
   C2 = -.4248 * (X ^ 6) + 1.22 * (X ^ 5) - 1.3412 * (X ^ 4) + .739 * (X ^ 3) - .2217 *
(X ^ 2) + .0045 * X - .0055
   C3 = .0907 * (X ^ 6) + 6.5404 * (X ^ 5) - 12.005 * (X ^ 4) + 1.82 * (X ^ 3) +
4.2909 * (X ^ 2) + 1.2249 * X + 1.6172
   LOGALPHA = C1 * (T ^ 2) + C2 * T + C3
   ALPHA = 10 ^ LOGALPHA
   Y = ALPHA * X / (1 + (ALPHA - 1) * X)
   T = T + 273.15              'Conversion from deg.C to Kelvin
   RETURN
'------------------------------------------------------------------------------------------------
```

APPENDIX 4: GENERAL INFORMATION AND SPECIFICATIONS FOR THE 6-CHANNEL AND 12-CHANNEL DATA RECORDERS

- 109-

2. GENERAL.

2-1. Description.

This manual describes the Model 4156 Recorder, a member of the μR100 series*. This six-point six-color dot-printing recorder provides analog type chart recording as well as digital printout, and digital display as well as analog (bargraph) display.

The μR100 series recorders support a wide range of inputs: DC voltage, nine types of thermocouples and RTD (resistance temperature detector), and converters for pressure, differential pressure, flow rate, dewpoint, humidity and pH.

Full-scale range, chart speed and alarms can be programmed via the side-panel keyboard. In addition to analog data writing (or printout), the μR100 also provides both digital and analog (bar graph) monitoring displays, and digital monitoring printout. The recorder is easy-to-use.

* The μR100 series also includes the one-, two- and three-pen models, which are covered in a separate manual.

2-2. Features.

(1) Programmable input types and full-scale ranges via side-panel keyboard.
Input types and full-scale ranges may be programmed for each point using the side-panel keyboard.

(2) Compact size – case depth is 230 mm (9-1/8").

(3) Versatile digital printout functions.
Periodical data, program listings and alarms can be printed out.

(4) Internal illumination (standard).
An internal fluorescent lamp is provided for quick chart reading even in low ambient light conditions.

(5) A wide range of input types – 9 types of TC's (types R, S, B, K, E, J, T, N, W), RTD (pt 100 ohms), or DC voltage inputs (span 5 mV to 50 V). These inputs may be selected and combined.

(6) Clear, distinct color traces.
Recording colors are

CH1: purple	CH2: red
CH3: green	CH4: blue
CH5: brown	CH6: black

The six-color ribbon cassette can be easily replaced without touching the ribbon with your fingers.

(7) Temperature difference (ΔT) recording, linear scaling functions.

(8) Versatile recorder with a wide range of standard and optional features.
Other standard features include channel skip, battery-backup memory and bar graph analog display.

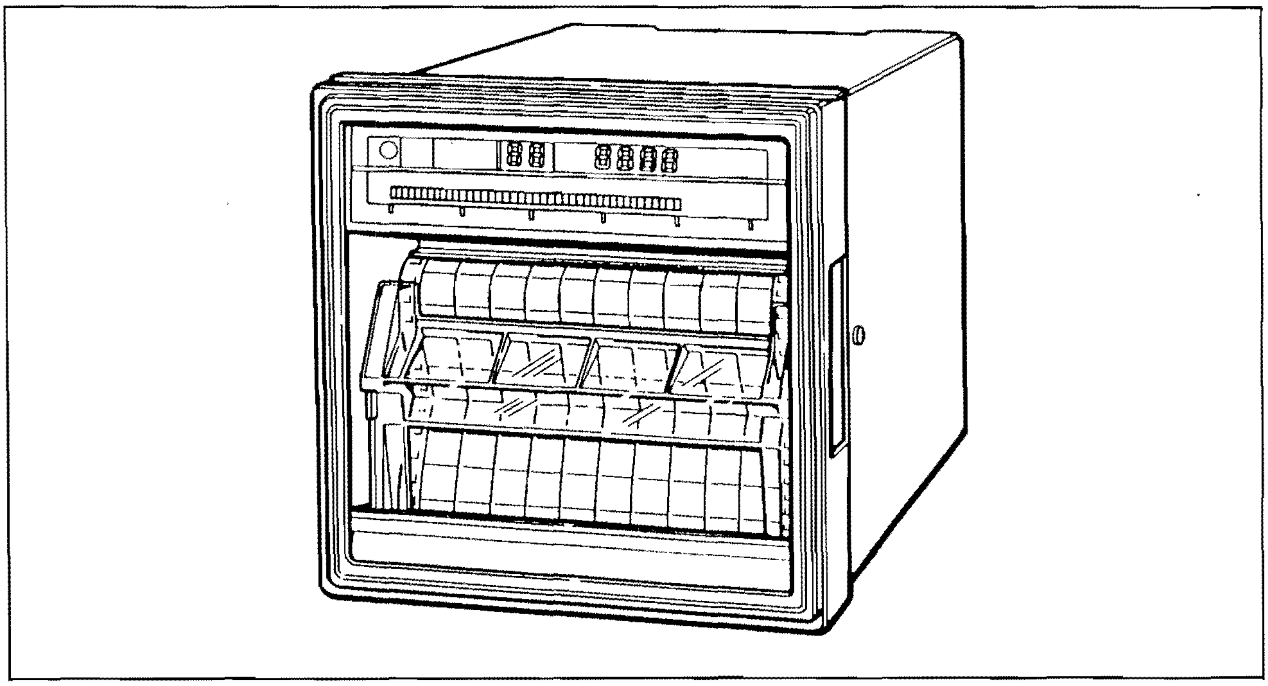


Figure 2-1. External View.

3. NAMES AND FUNCTIONS OF COMPONENTS.

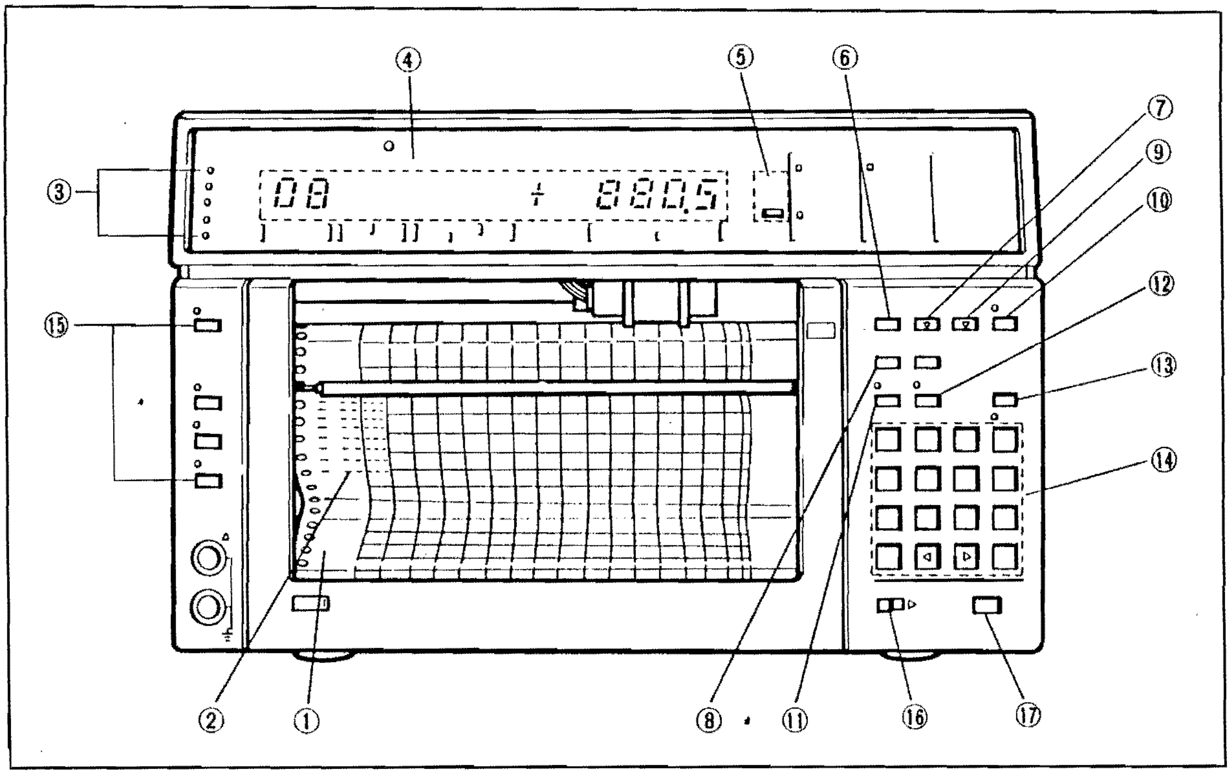


Figure 3-1. Names and Functions of Components (1).

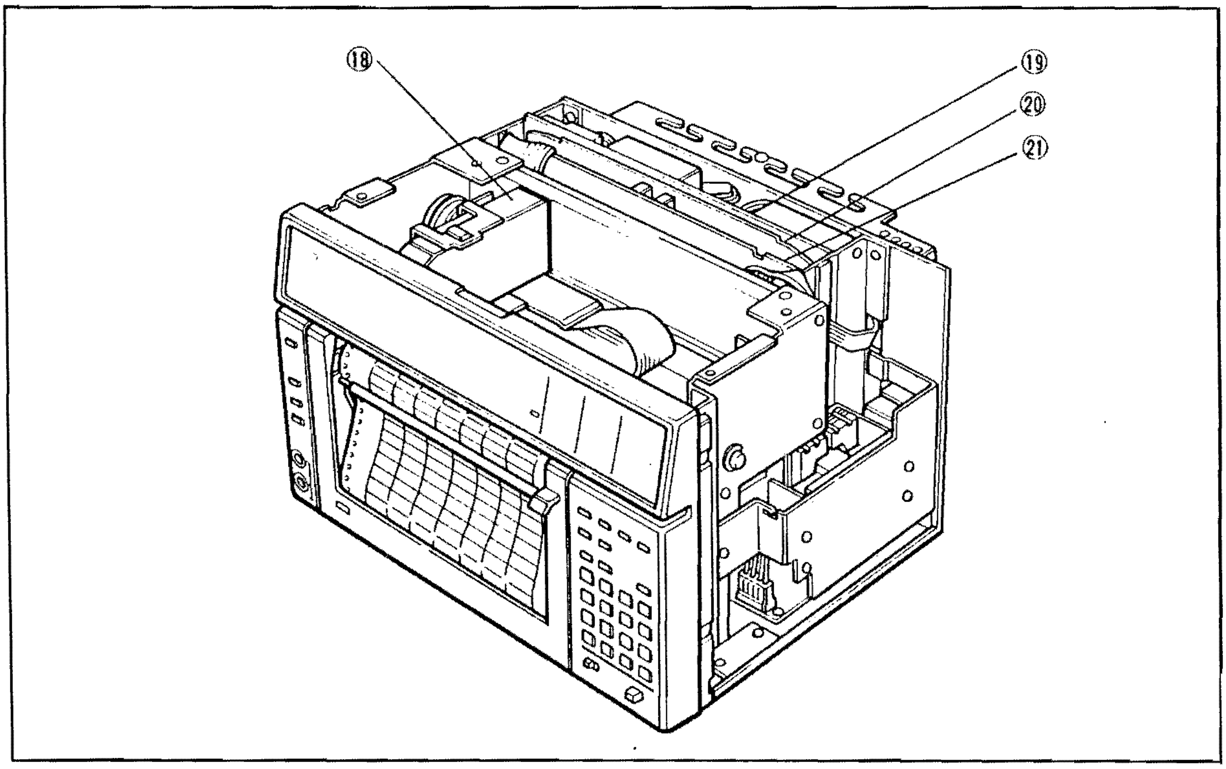


Figure 3-2. Names and Functions of Components (2).

① Chart

Z-fold chart (total width 210 mm, analog recording width 150 mm, digital printing approx. 20 mm in the left margin of the chart, total chart length 16 m) 100 uniform divisions.

② Digital measurement data printout

Measurement data are also digitally printed in the left margin of the chart. Such digital printing is executed automatically at fixed time intervals e.g. hourly (depends on the selected chart speed).

Relationships between Chart Speeds and Printouts.

Chart speed (mm/h)	CH No.	Date, Chart speed, Measurement data	Alarm Setpoint
1 to 9	printable	unprintable	printable
10 to 500	printable	printable	printable
501 to 1200	unprintable	unprintable	unprintable

Digital Measurement Data Printing Interval

Chart speed (mm/h)	Digital measurement data printing interval (h)
10 to 24	12
25 to 49	4
50 to 99	2
100 to 500	1

③ LED indicators

(1) ALARM: When any of the preset alarm conditions occurs, the red "ALARM" LED indicator lights.

(2) FAIL: The red "FAIL" LED indicator lights if the recorder function is abnormality.

(3) BATTERY: When the batteries for memory back-up are exhausted, the red "BATTERY" LED indicator flashes (batteries back up the memory for approx. three months).

(4) CHART: The red "CHART" LED indicator lights when chart end is sensed. Recording stops when the chart is fed 60 mm after this indicator lights.
When the CHART FEED key is pressed after this indicator lights, recording stops immediately. However, after the RENEW CHART mark on the chart paper, the LED becomes possible to operate occasionally ON/OFF.

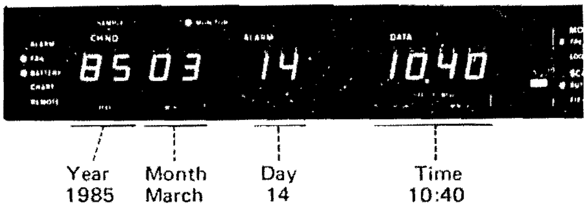
(5) REMOTE: The green "REMOTE" LED indicator lights when remote control is executed via the GP-IB interface bus (optional).

④ Displays

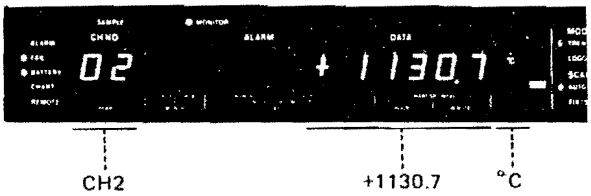
Year/month/day, time, measured data, chart speeds and various settings are displayed (LED 13 digits).

Examples:

(1) Year/month/day and time display
10:40 AM. March 14, 1985



(2) Data display Channel No. 2, 1130.7°C



⑤ Engineering Unit Display

Any one of the following engineering units lights according to the measuring range. However, when time, chart speed or scanning interval is displayed, engineering unit does not light.

mV	V
°C	°F
Ω	kΩ
MΩ	■

Lights when "scaling" set in performed.

Figure 3-3. Engineering Unit Display.

⑥ Mode Selector Key (MODE)

(1) TREND:
When MODE key is pressed and "TREND" LED indicator lights, the TREND mode is set.
When the TREND mode is set, analog printing and analog/digital printing can be executed.

(2) LOGGING:
When MODE key is pressed and "LOGGING" LED indicator lights, the LOGGING mode is set.
When the LOGGING mode is set, digital printing can be executed at fixed intervals.

⑦ Display Selector Key (DISPLAY)

Pressing DISPLAY key, you can select display any of DATA (AUTO), DATA (MAN) and CLOCK.

(1) DATA (AUTO): Displays CH No. and measurement data in order at 3 second intervals.

(2) DATA (MAN): Displays data only for the CH currently designated by the CH key. Pressing the CH key allows CH Nos. to be processively incremented, and the desired CH is called.

(3) CLOCK: Displays the year, month, day and time.

⑧ Scanning Interval Selector Key (SCAN)

By pressing SCAN key, either AUTO or FIX (5S) mode can be selected.

(1) AUTO: In TREND mode, the scanning period varies with the chart speed. Recording chart is fed 0.25 mm each scan. In LOGGING mode, input scanning is performed every scanning interval.

(2) FIX (5S): Keeps the scanning period constant (5 seconds) regardless of the chart speed selected.

⑨ **Data Set Selector Key (SET)**

By pressing SET key, any of RANGE, ALARM CLOCK, CHART SP/INTVL and PRINT TIME setting can be selected.

(1) RANGE: Measuring input range can be selected.

(2) ALARM: Alarm setting can be performed.

(3) CLOCK: Year, month, day and time may be set.

(4) CHART SP/INTVL: In TREND mode, chart speeds (at any point between 1 and 1200 mm/h) can be selected.
In LOGGING mode, intervals to print out measurement data (digital) on the chart can be set (for 1 min to 24h: in min unit).

(5) PRINT TIME: In TREND mode, the digital printout time can be set in minutes at any time. The digital printout interval complies with Item (2) above.

⑩ **LIST Key (LIST)**

The LIST key permits measuring range, alarm setting of each channel, chart speed, date and time, to be printed out on the chart paper.

⑪ **PRINT Key (PRINT)**

The PRINT key permits, analog/digital or digital printing. Printing operation (both in TREND and LOGGING modes) is possible only when the LED indicator lights. By pressing this key, input scanning is performed once.

⑫ **MAN PRINT Key (MAN PRINT)**

Digitally prints measurement data of all channel (except for SKIP CH.).

⑬ **CHART FEED Key (CHART FEED)**

The CHART FEED key permits chart feeding.

⑭ **Data Set Keys**

(1) SHIFT Key (SHIFT): When the LED above the SHIFT key lights, the characters and mark above the numeral keys are effective.

(2) Numeral Keys (0 to 9): Numeric characters (0 to 9) can be set. In addition, these keys allow alphabetic characters A to F, H, L, and P to be set with the SHIFT key pressed.

(3) Sign Key (+/−): Sign key to change sign + or −.

(4) Brightly Lit Position Shift Keys (◀, ▶): When the set data currently displayed are to be changed, these keys are used to shift brightly lit positions so that characters or numerals to be changed are brightly lit.

(5) Entry Key (ENT): Enters RANGE, ALARM, CLOCK, CHART SP/INTVL and PRINT TIME settings when pressed at the end of the entry.

(6) OFF Key (OFF/(−)): Designates channel skip (in RANGE setting) and alarm OFF.

(7) ⊢ / ⊣ Key: When the RANGE set data are displayed, this key is used to switch the LEFT END value to the RIGHT END value or vice versa. Pressing this key highlights the LEFT END value mark (⊢) or RIGHT END value mark (⊣) displayed and switching is completed by pressing SHIFT key and 0 (zero) key sbusequently to display the other end value.

⑮ **DMM Operation Keys**

(1) DMM Operation Keys (DMM): Displays measured data of DCV, ACV or OHM (Ω) applied to terminals H and L on the recorder front panel.

(2) DCV, ACV and Ω Keys (DC, AC, Ω): When the DMM key is turned on, these keys are operated to select the type of input to be measured.

(3) Terminals H and L: Input terminals on the front panel. (Use the measurement lead supplied with the recorder).

⑯ **Key Lock Switch:** When this switch is slid to KEY LOCK position, the keys other than DISPLAY key will be disabled.

⑰ **POWER Switch:** Turns the instrument ON/OFF.

⑱ **Ink Ribbon Cassette**

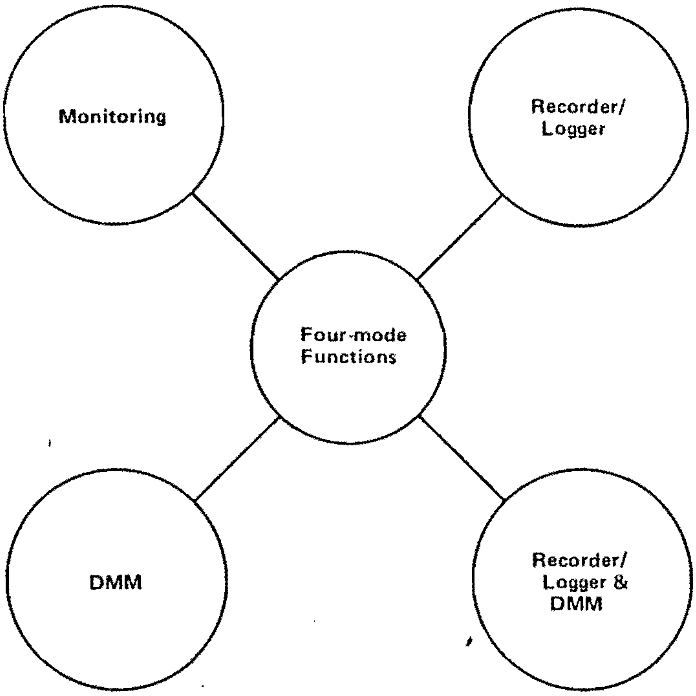
⑲ **A/D Card**

⑳ **MAIN CPU Card**

㉑ **SUB CPU Card**

4. FUNCTIONS.

4-1. Four Modes.



MODE	PRINT KEY	DMM KEY	FUNCTION
Monitoring	● PRINT ☐	● DMM ☐	Monitor Function . . . . . . CH1 to 12 (rear panel), CH13 (front panel) measurement and display Alarm Monitor . . . . Display, relay output GP-IB interface (optional)
Recorder/Logger	✿ PRINT ☐	● DMM ☐	Recorder Function . . . . . . CH1 to 12 and CH13 measurement, display, printout (analog trend or analog trend + digital printing) Logger Function . . . . CH1 to 12 and CH13 measurement, display, printout (digital logging) Alarm Monitor . . . . Display, print, relay output GP-IB interface (optional)
DMM	● PRINT ☐	✿ DMM ☐	DMM Function . . . . CH13 (front panel) measurement, display GP-IB interface (optional)
Recorder/Logger & DMM	✿ PRINT ☐	✿ DMM ☐	Recorder/Logger + DMM function CH13 is sampled in DMM mode except when the instrument is scanning for CH1 to 12. GP-IB interface (optional)

✿ . . . . KEY ON. ● . . . . KEY OFF.

4-2. Specifications.

Measuring range, number of display digits

Rear-panel inputs (CH1 to CH12):

(1) JIS, ANSI Model

Input type	Range code	Measuring range	Engineering unit	Number of digits	Description
DC V	00	−20 to +20 mV	mV	□□.□□□	
	01	−200 to +200 mV		□□□.□□	
	02	−2 to +2 V	V	□.□□□□	
	03	−20 to +20 V		□□.□□□	
	04	−50 to +50 V		□□.□□	
	05	1 to 5 V	Blank	□□□□.□	Scaling Refer to Note 1
	06	0 to 10 mV			
	07	0 to 10 V			
Thermocouple	10	Type R 0 to 1600°C 32 to 2912°F	°C °F	□□□□.□ □□□□	
	11	Type S 0 to 1600°C 32 to 2912°F	°C °F	□□□□.□ □□□□	
	12	Type B 400 to 1700°C 752 to 3092°F	°C °F	□□□□.□ □□□□	
	13	Type K −200 to 1350°C −328 to 2462°F	°C °F	□□□□.□ □□□□	
	14	Type E −200 to 800°C −328 to 1472°F	°C °F	□□□.□ □□□□.□	
	15	Type J −200 to 900°C −328 to 1652°F	°C °F	□□□.□ □□□□.□	
	16	Type T −200 to 400°C −328 to 752°F	°C °F	□□□.□ □□□.□	
	17	Type N −200 to 1300°C −328 to 2372°F	°C °F	□□□□.□ □□□□	
	18	Type W 0 to 1600°C 32 to 2912°F	°C °F	□□□□.□ □□□□	
Resistance temperature sensor	20	JPt 100Ω −200 to 550°C −328 to 1022°F	°C °F	□□□.□ □□□□.□	Measured current 1 mA
	21	JPt 100Ω −200 to 250°C −328 to 482°F	°C °F	□□□.□ □□□.□	Measured current 2 mA
	22	Pt 50Ω −200 to 550°C −328 to 1022°F	°C °F	□□□.□ □□□□.□	Measured current 2 mA

Notes 1. Range codes 05 to 07 are fixed ranges, which can be arbitrarily set on conditions that range is within −2000.0 to +2000.0 and that the span is ≦ 2000.0.

2. Only negative signs are displayed in the table (positive signs are omitted).

Pt 100 : JIS C 1604-1989, JIS C 1606-1989
DIN IEC 751, IEC 751
JPt 100: JIS C 1604-1989, JIS C 1606-1989
Pt 50 : JIS C 1604-1981, JIS C 1606-1986

2-3. Specifications. (6-channel)

Model: 6-point 100mm "Micro Recorder."

Input

Number of Inputs: 6

Scan Cycle Time (or Rate): 5s/6 points.

Input Signal Levels: DC V...5 mV span to 50V, TC...more than 100°C span (and 3 mV), RTD...more than 50°C span (Pt 100Ω).

Full-Scale Range Setting: Programmable via keyboard. (Using Range Code)

Measuring Range: ANSI, JIS (°C) model...

Input type	Range code	Range	Measuring range	Remarks
DCV	00		−20.00 to 20.00mV	
	01		−200.0 to 200.0mV	
	02		−2.000 to 2.000V	
	03		−6.000 to 6.000V	
	04		−20.00 to 20.00V	
	05		−50.00 to 50.00V	
TC (JIS ANSI)	10	Type R	0 to 1760°C	
	11	Type S	0 to 1760°C	
	12	Type B	400 to 1820°C	
	13	Type K	−200 to 1370°C	Former CA
	14	Type E	−200.0 to 800.0°C	Former CRC
	15	Type J	−200.0 to 1100°C	Former IC
	16	Type T	−200.0 to 400.0°C	Former CC
	17	**Type N	0 to 1300°C	NBS
	18	**Type W	0 to 2315°C	OMEGA
RTD	20	JPt100 Pt 100	−200.0 to 550.0°C	Measuring current 1mA
DCV (linear scaling) *mA	30		−20.00 to 20.00mV	
	31		−200.0 to 200.0mV	
	32		−2.000 to 2.000V	
	33		−6.000 to 6.000V	
	34		−20.00 to 20.00V	
	35		−50.00 to 50.00V	
DC (square rooting) *mA	40		−20.00 to 20.00mV	
	41		−200.0 to 200.0mV	
	42		−2.000 to 2.000V	
	43		−6.000 to 6.000V	
	44		−20.000 to 20.00V	
	45		−50.00 to 50.00V	

* μR100 can accept a current input when a current shunt is used.

** Type N (Nicrosil-Nisil), Type W (W5%Re-W26%Re) ..... not included in ANSI, DIN and JIS.

ANSI, DIN (°F) model

Input type	Range code	Range	Measuring range	Remarks
TC (ANSI)	10	Type R	32 to 3200°F	
	11	Type S	32 to 3200°F	
	12	Type B	752 to 3308°F	
	13	Type K	−328 to 2498°F	
	14	Type E	−328 to 1472°F	
	15	Type J	−328 to 2012°F	
	16	Type T	−328 to 752°F	
	17	Type N	32 to 2372°F	NBS
	18	Type W	32 to 4200°F	OMEGA
RTD	20	Pt 100	−328 to 1022°F	Measuring current 1mA

Other ranges correspond to the ANSI, JIS (°C) model.

DIN (°C) model

Input type	Range code	Range	Measuring range	Remarks
TC (DIN)	10	Type R (Pt13Rh-Pt)	0.0 to 1760.0°C	DIN IEC 584-1
	11	Type S (Pt10Rh-Pt)	0.0 to 1760.0°C	
	12	Type B (Pt30Rh-Pt6Rh)	400.0 to 1820.0°C	
	13	Type K (NiCr-Ni)	−200.0 to 170.0°C	
	14	Type E (NiCr-CuNi)	−200.0 to 800.0°C	
	15	Type L (Fe-CuNi)	−200.0 to 900.0°C	DIN 43710
	16	Type U (Cu-CuNi)	−200.0 to 400.0°C	DIN 43710
	17	Type N	0.0 to 1300.0°C	NBS
	18	Type W	0.0 to 2315.0°C	OMEGA
RTD	20	Pt 100	−200.0 to 550.0°C	Measuring current 1mA

Other ranges correspond to the ANSI, JIS (°C) model.

JPt 100: JIS C 1604-1989, JIS C 1606-1989
Pt 100 : JIS C 1604-1989, JIS C 1606-1989
DIN IEC 751, IEC 751

Maximum Allowable Input Voltage (Continuous):

±10V DC for ranges of less than 2V DC (range codes: 00, 01, 02, 30, 31, 32, 10 to 18 and 20).

±100V DC for ranges of 6 to 50V DC (range codes: 03, 04, 05, 33, 34 and 35).

Recording

Wiring System: wire-dot printer (using six-color ribbon cassette).

Recording Colors:

CH.1 (purple)	CH.2 (red)
CH.3 (green)	CH.4 (blue)
CH.5 (brown)	CH.6 (black)

Effective Recording Span: 100 mm (analog data).

Chart: Z-fold chart (16 m) with a calibrated width of 100 mm.

Chart Feed Speed: Arbitrarily settable within range of 1 to 1,500 mm/h in 1 mm/h steps.

Chart Feed Speed Setting: Set via keyboard (see paragraph 5-4-5 Chart Feed Speed Setting).

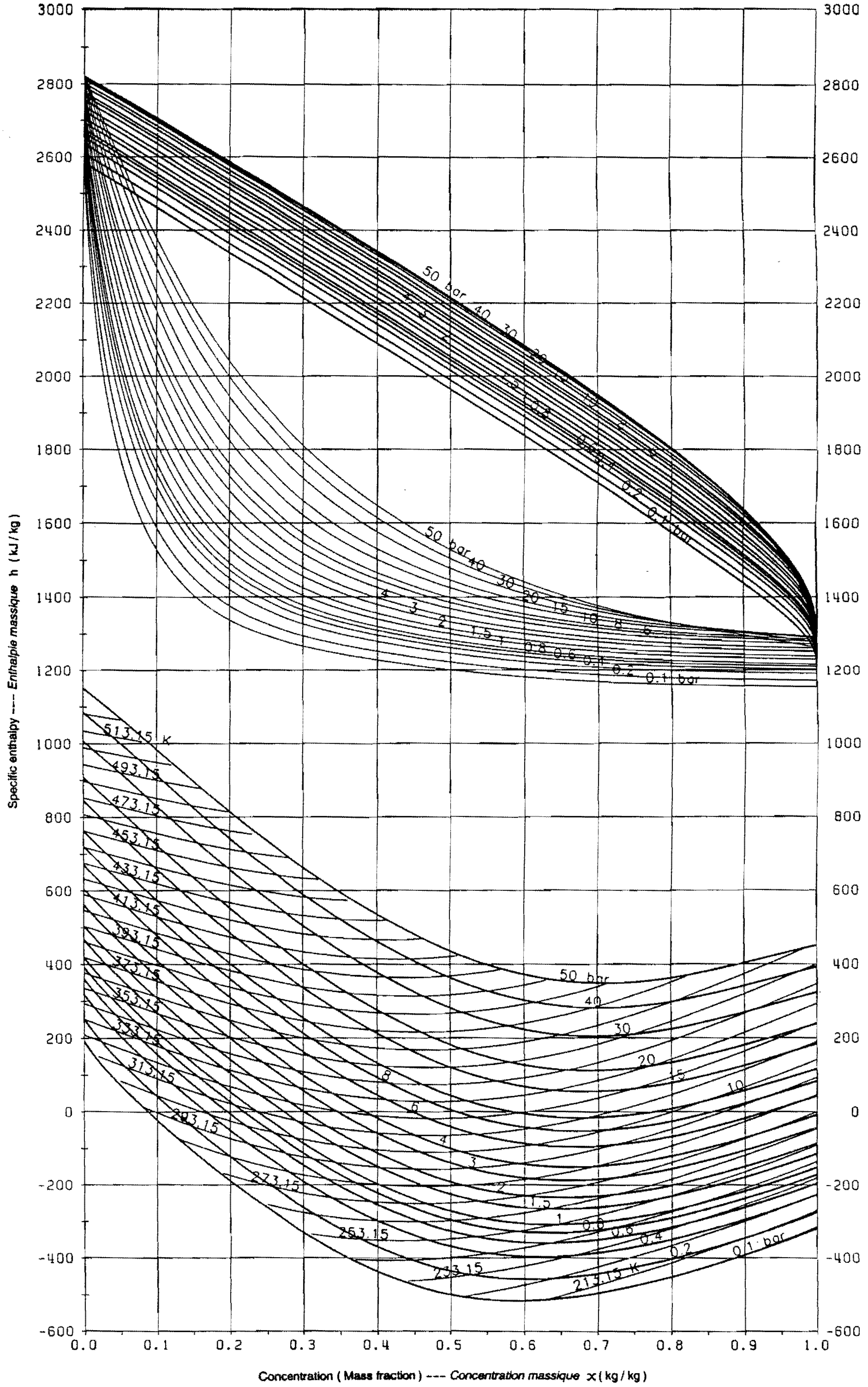
APPENDIX 5: ENTHALPY-CONCENTRATION DIAGRAM FOR AMMONIA-WATER MIXTURES

Ziegler B, Trepp Ch. [24]

Enthalpy-Concentration (Mass fraction) --- *Enthalpie-Concentration massique*

Ammonia-Water --- *Ammoniac-Eau*

(According to the equations of Ziegler --- D'après l'équation de Ziegler)



Institut International du Froid
International Institute of Refrigeration
177, Boulevard Malesherbes
75017 PARIS - FRANCE

Établi pour l'Institut International du Froid par
M. R. KRAUSS et K. STEPHAN, Institut für
Technische Thermodynamik und Thermische
Verfahrenstechnik, Universität Stuttgart, Allemagne, 1991