THE EFFECT OF THE CONDENSATE WATER TEMPERATURE ON THE PERFORMANCE OF THE VEHICLE AIR CONDITIONING SYSTEM



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE EFFECT OF THE CONDENSATE WATER TEMPERATURE ON THE PERFORMANCE OF THE VEHICLE AIR CONDITIONING SYSTEM

MUHAMMAD AIMAN BIN WAHID



Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DECLARATION

I declare that this project report entitled "The Effect of The Condensate Water Temperature on The Performance of The Vehicle Air Conditioning System" is the result of my own work except as cited in the references.



APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.



DEDICATION

To my beloved Umi and Ayah.



ABSTRACT

This study experimentally investigates the effect of condensate water temperature on the performance of automotive air conditioning (AAC) systems. The experimental test rig consists of the actual components of the AAC system from the Proton Wira passenger car. The experimental test rig has been modified by adding a spraying compartment to manipulate the temperature of the condenser. In the experimental work, the temperature of the condensed water was manipulated at $8 \pm 3^{\circ}$ C and $27 \pm 3^{\circ}$ C. The results were compared with the baseline conditions of the condenser with no condensate water sprayed. The other parameters such as the speed of compressor, volume flow rate of condenser, and the air inlet evaporator temperature were fixed at 1550 rpm, 450 ml/min and $30 \pm 3^{\circ}$ C, respectively. The study showed that the coefficient of performance (COP) of the AAC system increases at lower temperature of condensate water sprayed. It was due to a significant decrease in compressor work from both conditions as compared to the baseline state, and an increase in cooling capacity. In addition, the highest COP is at 4.81, increase 16.6% as compared to baseline condition, and this increment occurred at condensate water sprayed at 8.01°C. This is followed by condensate water sprayed at 27.2°C (15.5%), as compared to baseline condition.

ABSTRAK

Kajian ini meneliti secara eksperimental pengaruh suhu air tersejat terhadap prestasi sistem penyaman udara automotif (AAC). Rig ujian bagi tujuan eksperimen terdiri daripada komponen sebenar sistem AAC kereta penumpang Proton Wira. Sistem ini telahpun diubahsuai dengan penambahan peralatan penyembur air bagi memanipulasi suhu kondenser. Dalam kajian eksperimental ini, suhu air yang tersejat telah dimanipulasi pada kadar 8.01 dan 27.2°C. Manakala keputusan kajian telah dibandingkan dengan keadaan biasa kondenser tanpa sebarang penyemburan air tersejat dilakukan. Parameter lain seperti kelajuan awal pusingan pemampat penyejuk, kadar aliran isipadu kondenser dan suhu udara masuk penyejat telah ditetapkan pada 1550 ppm, 450 ml / min dan $30 \pm 3^{\circ}C$. Kajian telah menunjukkan bahawa pekali prestasi (COP) bagi sistem AAC meningkat apabila air tersejat disembur pada suhu yang menurun. Hal ini disebabkan oleh kadar kerja pemampat yang menunjukkan penurunan yang signifikan jika dibandingkan dengan keadaan dasar kondenser, dan kenaikan kadar penyejukan. Tambahan pula, COP tertinggi telah direkodkan pada 4.81 meningkat sebayak 16.61% jika dibandingkan dengan keadaan dasar, dan peningkatan ini berlaku ketika air penyemburan di suhu 8.01°C. Peratusan peningkatan COP ini juga diikuti oleh air tersejat yang disembur pada suhu 27.2°C (15.5%) dan situasi ini juga dibandingkan dengan keadaan dasar kondenser.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this study. Special appreciation goes to my supervisor, Dr. Mohamad Firdaus bin Sukri for giving me the opportunity to complete the final year project under his essential supervision and guidance. I am thankful for his support and tolerance while leading me in this project.

Secondly, I also would like to express my sincere thanks to assistant engineer, En. Asjufri bin Muhajir for devoting his time to guiding me. He would share his understanding of air conditioning system with me throughout experiments. His generosity in advising me on the best time to employ laboratory equipment for his activity saved me a lot of time.

Lastly, my deepest gratitude goes to my parents and housemates for their moral support, patience, and encouragement in realization of this project especially during this pandemic COVID-19 period.

TABLE OF CONTENT

	DECLARATION	PAGE
	DEDICATION	i
	ABSTRACT	ii
	ABSTRAK	iii
	ACKNOWLEDGEMENTS	iv
	TABLE OF CONTENTS	v
	LIST OF TABLES	vii
	LIST OF FIGURES	viii
	LIST OF ABBREVIATIONS	X
СН	APTER	
1.	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objective	4
	1.4 Scope of Project	4
2.	LITERATURE REVIEW	5
	2.1 History of AAC system and refrigerants	5
	2.1.1 AAC system	5
	2.1.2 Refrigerants	7
	2.2 Present-day conventional AAC systems	8
	2.3 Research on performance improvements made to AAC system	12
	2.4 Condensate water as AAC system performance enhancer	13
	2.5 Summary UNIVERSITI TEKNIKAL MALAYSIA MELAKA	17
3.	METHODOLOGY	18
	3.1 Overview and Flow chart	18
	3.2 Flow chart Explanation	20
	3.2.1 Experimental work	20
	3.2.1.1 Schematic diagram and model setup	20
	3.2.1.2 Temperature of condensate water sprayed	23
	3.2.1.3Test rig operation	24
	3.2.2 Data accuracy check	24
	3.2.3 Data analysis	25

4.	RESULTS AND ANALYSIS	26
	4.1 Overview	26
	4.1.1 Results on the baseline condenser condition	27
	4.1.2 Results on only condensate water is sprayed to condenser condition	29
	4.1.3 Results on the condensate water with ice sprayed to condenser condition	31
	4.2 Discussion	33
	4.2.1 Average gauge pressure	33
	4.2.2 Average temperature of refrigerant at main inlet components	35
	4.2.3 <i>P-h</i> diagram	36
	4.2.4 Compressor work	37
	4.2.5 Rate of heat removal	38
	4.2.6 Cooling capacity	39
	4.2.7 Coefficient of Performance (COP)	40
5.	CONCLUSION AND RECOMMENDATION	41
	5.1 Conclusion	41
	5.2 Recommendations	42
RE	FERENCES	43
API	PENDICES	47
	اونيۆم سيتي تيڪنيڪل مليسيا ملاك	
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Experimental studies on the methods of condensate water	14
	assisting the improvement of air-conditioning performance	
3.1	Temperature description	21
3.2	Gauge pressure description	21
3.3	Instrument specification	22
4.1	Operating condition of AAC system	28
4.2	Table of gauge pressure during baseline condition of condenser	29
4.3	Table of temperature during baseline condition	30
4.4	Table of gauge pressure after condensate water sprayed at	31
	27.2°C to the condenser	
4.5	Table of temperature after condensate water sprayed at 27.2°C	32
	to the condenser	
4.6	Table of gauge pressure after condensate water at 8.01°C	33
	sprayed to the condenser	
4.7	Table of temperature after condensate water at 8.01°C ice	34
	sprayed to the condenser	
4.8	Results of analysis	35

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	CO2 emissions patterns from energy sub-sectors in Malaysia	3
2.1	Complete system by Packard Motor Car company	5
2.2	A/C system disposition in the under hood by Harrison	7
23	Radiator Division of General Motors in 1953	Q
2.3	OT-AD system	10
2.5	Vapour compression cycle	11
2.6	T-s diagram	11
2.7	Categories of sub-cooling methods	13
2.8 (a)	AAC test rig schematic diagram	16
2.8 (b)	Actual experimental setup of AAC experimental facility	16
2.9	Utilization of condensate water as surface condenser coolant	17
3.1	Flow chart of methodology	19
3.2	Modified AAC test rig schematic diagram	20
3.3	Facility setup for the experimental work	22

LIST OF FIGURES

FIGURE	TITLE	PAGE
4.1	The effect of sprayed condensate water temperature on	36
	average gauge pressure of component	
4.2	The effect of sprayed condensate water temperature on	37
	average temperature of refrigerant at inlet components	
4.3	Effect of sprayed condensate water temperature to condenser	38
	on <i>p-h</i> diagram	
4.4	The effect of sprayed condensate water temperature on	39
	le ver, muis, incompressor work	
4.5	The effect of sprayed condensate water temperature to rate of	40
	heat removal III I EKNIKAL MALAY SIA MELAKA	
4.6	The effect of sprayed condensate water temperature to	41
	cooling capacity	
4.7	The effect of sprayed condensate water temperature to	42
	Coefficient of Performance	

LIST OF ABBEREVETIONS

AAC	Automotive Air Conditioning
VCRC	Vapor Compression Refrigeration System
СОР	Coefficient of Performance
CO_2	Carbon Dioxide
R12	Dichlorofluoromethane
A/C	Air-conditioning
CFC	Chlorofluorocarbon
HVAC	Heating, Ventilating and Air Conditioning
TXV-RD	Receiver drier and Thermostatic expansion valve
OT-AD	UNIVE Accumulator-drier and Orifice tube SIA MELAKA
TXV	Thermal expansion valve
RD	Receiver drier
OT	Orifice tube
AD	Accumulator drier
Qн	Rate of heat removal (kW)
Q_L	Rate of heat rejection (kW)
Qe	Cooling capacity (kW)

LIST OF ABBEREVETIONS

Win	Work of compressor (kW)
р	Absolute pressure (kPa)
Р	Gauge pressure (bar)
'n	Mass flow rate of refrigerants (kg/s)
h 1	Compressor refrigerant enthalpy (kJ/kg)
h2	Evaporator refrigerant enthalpy (kJ/kg)
<i>T</i> 1	Temperature refrigerant at inlet compressor (°C)
<i>T</i> 2	UNIVE Temperature refrigerant at inlet condenser (°C) AKA
Тз	Temperature refrigerant at inlet expansion valve (°C)
T_4	Temperature refrigerant at inlet evaporator (°C)
T 5	Temperature air inlet evaporator (°C)
Τ6	Temperature air outlet evaporator (°C)
<i>T</i> 7	Temperature water storage (°C)
Тв	Ambient temperature (°C)

LIST OF ABBEREVETIONS

<i>P</i> ₁	Pressure of refrigerant at inlet compressor (Bar)		
<i>P</i> 2	Pressure of refrigerant at inlet condenser (Bar)		
Рз	Pressure of refrigerant at inlet expansion valve (Bar)		
<i>P</i> ₄	Pressure of refrigerant at inlet evaporator (Bar)		
	اونيۈم سيتي تيڪنيڪل مليسيا ملاك		
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA		

CHAPTER 1

INTRODUCTION

1.1 Background

The improvement of living society demanding for the comfortable environment of the car interior including the performance of the automotive air conditioning (AAC) system. Furthermore, driver fatigue reduces as road safety and pleasant environment improve accordingly to the driver contentment (Sukri et al., 2020). Usage of the air conditioning system is considerably relates to some factors such as weather, time of day, season, type of vehicle, automotive paint, parking lot, driver apparel, active intensity of the driver, distance to destination, vehicle overtaking, and personal preference (Farrington & Rugh, 2000). Thus, it is necessary to improve the performance of the AAC system as the usage is reportedly higher in Malaysia climates.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

AAC system normally manufactured based on the Vapor Compression Refrigeration System (VCRC) which refers to the air treatment that results in temperature control, humidity, purity, scent, and flow, as needed by the users in a circumstance (Sukri et al., 2020). Due to the operation of AAC system, condensate water is formed through the air condensation on the evaporator surface. The temperature of the condensate water formed is slightly higher than the evaporator temperature which approximately at 5-7°C (Sumeru et al., 2019). Numerous of studies have proven that the improvement of air conditioning performance can be made by the wasted condensate water. The result of the experimental investigation showed that 6.1% of power consumption of compressor was reduced, while refrigeration capacity and coefficient of performance (COP) showed an increment by 20.5% and 21.4% respectively (Ibrahim et al., 2017). Apparently, the temperature difference between the cooling medium and the product relates to the cooling rate (Thompson, 1992). It is believed that differences happen on temperature of wasted condensate water produced to assist the sub-cooling process, and the effect is yet to be investigated.

1.2 Problem Statement

The contribution of the road transportation sector to emissions of air pollutants and greenhouse gases is a growing concern in developing countries (Thambiran & Diab, 2010) such as Malaysia. The increasing unit of car usage as a part of road transportation have resulting in a significant of air pollution and greenhouse effect. As shown in Figure 1, the emissivity of carbon dioxide (CO_2) by transportation ranked second after the power generation, as the CO_2 emission contributor in Malaysia. The annual growth increases by 6.4%, 4.4%, 3.6% and 13.9% in the respective sectors, power generation, transport, manufacturing, and other industries contributed 46%, 22%, 19% and 13% of total CO_2 emissions in 2013 (IEA,2014). These effects have resulted in the increment in the atmospheric concentrations of greenhouse gases which produces hot weather.



Figure 1.1: CO₂ emissions patterns from energy sub-sectors in Malaysia (1990-2013)

(IEA,2014)

Hot and humid climates in certain countries have led to an innovation to improve the efficiency of AAC system especially to a private transportation such as car. AAC system is found to be improved in performance due to the decrement of compressor discharged temperature. The used of unwanted condensate water discharged sprayed to the condenser has increased the cooling capacity of AAC system. In addition, the effect of water-injection of condensate water temperature also influenced the power consumption of the condenser. The COP of the AAC system will be compared in this study, as the manipulation of unwanted condensate temperature is made.

1.3 Objective

The objectives of this project are as follows:

- 1. To investigate the system pressure and temperature of the proposed system as compared to conventional system.
- 2. To determine the COP of AAC system assisted by different condensate water temperature.

1.4 Scope of Project

The scopes of the project will be covered in three dimensions, which are method of the project of the project, variables covered and validity of results. The scopes are prepared as shown below:

- 1. Only the result involving the experimental method are presented in this report.
- 2. Condensate water temperature are varied at 8 ±3°C and 27 ±3°C in comparison to conventional system as baseline condition, but compressor speed and condensate water speed are maintained. Other than that, humidity of air, air velocity and wet temperature are to be ignored during the experimental studies.
- Validity of the result is determined by the highest COP produced in the limitation of the compressor speed and condenser water speed are fixed at 1550 rpm and 450 ml/min, respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 History of AAC system and refrigerants

2.1.1 AAC system

The development of AAC system was began in the end of 1920s by General Motors (GM) researchers with the development of dichlorofluoromethane (R12) or Freon 12, a type of refrigerants that had been utilized in the refrigeration cycle in the early days. The research on the AAC system had reached its climax with the development of prototype self- contained unit mounted in the trunk of a 1939 Cadillac by the following years. In 1939, a complete air-conditioning (A/C) system for summer conditioning and winter warming was offered at \$274 by Packard Motor Car Company.



Figure 2.1: Complete system by Packard Motor Car company (Bhatti, 1999)

The initial studies were conducted in 1934 by a collaboration of Houde Engineering of Buffalo, N.Y. and Carrier Engineering of Newark, N.J. to create first bus accommodated with A/C system by implementation of the ideas on a Ford V8 five – passenger car. The system implemented to the car was compact, with the condenser was installed on the roof and least power equipped by the bus engine. Starting 1940s, A/C system were made available on the closed body models luxury cars. However, numerous problems were complained by the consumers during the earliest designs of the A/C system as well as World War II had stuttering the progress of the innovation.

It was until 1953 model launched, automotive air conditioning had made a revival and thrived to be an actual demand for more common cars owner. This was associated with measures taken by General Motor, Chrysler, and Packard introduced a practical A/C system, in which resolving previous major problems. The revolutionary air – conditioner model could be spaced in the under hood in the engine section was introduced by Harrison Radiator Division of General Motors in 1953. Throughout 1950s until 1960s, the utilization of air conditioning units became the feature element mounted by all the car makers including Ford, which had set A/C unit price at \$232, almost half of the average price due to its popularity.



Figure 2.2: A/C system disposition in the under hood by Harrison Radiator Division of

General Motors in 1953 (Bhatti, 1999)

2.1.2 Refrigerants

In 1974, Molina and Rowland the winner of 1995 Nobel Prize in Chemistry, revealed that the extensive use of the Chlorofluorocarbon (CFC) has depleted the ozone layer in stratosphere. CFC was widely use in the Heating, Ventilating and Air Conditioning (HVAC) instrument, as a food processing substance, foam blowing agent, sterile gas diluent, and aerosol oxidizer (Brown, 2012). R12 is considered as CFC as its molecular structure consists of chlorine and fluorine.

In 1976, Harrison Radiator did the chlorine elimination to produce R134a as the substitute for R12. Although the sustainability of R134a was proven by Harrison through wind tunnel test on a car model, the production of A/C system with R134a was halted due to the lack of R134a production. The commercial used of the R134a began by having chlorine replacement with fluorine in the refrigerant composition, and the production initially started by Du Pont De Nemours and Company (Dupont) and Imperial Chemical Industries (ICI) in 1990. The conversion to R134a as A/C system refrigerant took place in USA, Japan, and European country during 1991 to 1994, followed by the rest of the world during late1990s and beginning of 2000s.

2.2 Present-day conventional AAC systems

There are two types of conventional A/C system are installed in the car: system with receiver drier and thermostatic expansion valve (TXV-RD) and system with accumulatordrier and orifice tube (OT-AD). The arrangement of both TXV-RD and OT-AD are shown in Figure 2.3 and Figure 2.4, respectively. Both systems are lining up almost the same essential components such as compressor, condenser, and evaporator.

The basic operation of both systems start with the compressor compresses the cool gaseous state of the refrigerant from evaporator and pressurizes it in high pressure and temperature to the condenser. In the condenser, the refrigerant is then liquidized into lower temperature small pressure droplets after the refrigerant experiencing cooling phases, as cool air flow is provided by the condenser fan. The subcooled liquid refrigerant will then flow into receiver drier (RD) in TXV-RD system. In OT-AD system, the liquid will direct into fixed diameter orifice tube (OT).



Figure 2.3: TXV-RD system (Shah, 2006)

In TXV-RD system, RD improves the refrigerant subcooling temperature and works as moisture removal, as the refrigerant passes through the desiccant bag inside RD. The warm refrigerant from RD is then will be channelled to the thermal expansion valve (TXV), that can be varied in diameter. TXV works as flow regulator and giving a better cooling rate. It also plays a major role to control desired refrigerant superheat after the evaporator.



In OT-AD system, accumulator drier (AD) plays the same role as RD. However, AD placement is after the evaporator in OT-AD system. Meanwhile, OT has the identical functionality as TXV, but has lower cooling rate due to its fixed diameter and cannot control enter and exit condition from respective condenser or evaporator.

The substantial decrease in pressure and temperature happened to the pressurized liquid that moves through the expansion unit. In the HVAC panel under the dashboard, the mixture of cold liquid/vapor refrigerant from the expansion unit is pumped to the evaporator to produce cool warm fresh air circulation in the car interior. As the air on one fluid side is cooled in the evaporator, the other fluid side warming the liquid/vapor mixture of refrigerant and evaporates. The evaporated gas is then proceeding to the suction point of the compressor through the suction hose to restart this entire process again.

Ideally, these two systems can be summarized into thermodynamics process which is simple compression vapour cycle. Figure 2.5 shows the illustration of schematic diagram of the flow of the cycle and T-s diagram in Figure 2.6.



Figure 2.6: *T-s* diagram (Kerkeni et al., 2016)

Where:

$$Q_{L} = \dot{m} (h_{1} - h_{4}) \quad (2.1)$$

$$Q_{H} = \dot{m} (h_{2} - h_{3}) \quad (2.2)$$

$$W_{in} = \dot{m} (h_{2} - h_{1}) \quad (2.3)$$

2.3 Research on performance improvements made to AAC system

For the past few years, previous studies had shown that the performance of conventional A/C system is anticipated to grow at the expeditious pace. The advancement of the technologies and capabilities of various industries have stepped up the demands of AAC system improvement in the most efficient way. For instance, the used of microchannel heat exchanger to supply more cooling capacity to car compartment (Qi et al., 2010). Sharif et al. had also implemented nanofluid technology by using nano lubricants inside compressor (Sharif et al., 2017).

In term of computer simulation, performance of AAC system were analysed by the effects of different refrigerants applied to the system. For example, the recent studied on the artificial neural networks for AAC systems using simulation (Kamar et al., 2013). Further, an evaluation of R12 impact on the AAC systems (Jung et al., 1999). Also, the simulation was made on the usage of the alternative refrigerants on AAC systems (Joudi et al., 2003).

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيوم سيتي تيكنيكل مليسيا ملاك

2.4 Condensate water as AAC system performance enhancer

Until recently, sub-cooling control system had drawn more attention due to its simplicity in term of technologies but proved to deliver substantial energy savings. Figure 2.7 shown the method classification, which can be divided into 4 categories (Sumeru et al., 2019).



enhance the of AAC system performance. Table 2.1 shows the previous findings of UNIVERSITI TEKNIKAL MALAYSIA MELAKA improvement of AAC system efficiency by the used of condensate water from different

researchers until the present.

Table 2.1: Experimental studies on the methods of condensate water assisting the

improvement of air-conditioning performance

Author	Objective	Variables consider / range	Findings (Relationships)
Sawant et al.,	Reduce the temperature	Presence of	Energy
(2012)	of air that enters the	condensate as	consumption
	condenser of home air	condenser cooling	decreased by 13%
	conditioner.	agent.	and COP increment
			by 18%.
Sawant et al.,	Conduct experimental	Ambient	Reduction of energy
(2012)	process to assess the	conditions in	consumption by 5%
TEK	efficiency of the	months in Beirut	and 4.5% in
FISC	evaporative cooling for	City.	respective June and
الح	air condenser of a split air conditioner under	رسيتي تيڪن	August.
UN	varying atmospheric KA	_ MALAYSIA ME	LAKA
	conditions.		
Ibrahim et	to increase the efficiency	Temperature of	Increment of COP
al., (2017)	of an air-cooled vapour	pre-cooling air to	and its efficiency by
	compression device by	control the	21.4% and 20.5%
	pre-cooling air into the	discharge pressure	respectively.
	condenser by using		
	condensate.		

Ardita &	Experimental study on	Presence of water	The COP increase
Subagia.,	the use of condensate	condensate as	by 7%, while 3%
(2018)	water as an extra cooling	additional coolant	decrement of power
	agent of the condenser.	on split air	consumption.
		conditioner.	
Sumeru et al.,	Study the effect of	Controlled indoor	The cooling capacity
(2019)	condensate water	and outdoor	and the COP
	discharged to improve	temperature at 20°C	increased by 12.1%
	performance of	and 33°C	and 21.7%
	residential air	respectively.	respectively.
LEKHIKA	conditioning system.		
Sukri et al.,	Study the performance of	Volume flow rate	The highest COP
(2020)	AAC system by	manipulated at 0,	recorded at 3.66
12	implementing the	140, and 340	which occurred at
LIN	condensate water under	ml/min. While air	32°C and volume
011	temperature difference of	inlet temperature	condensate water
	evaporator air inlet.	varied at 28, 32,	flow rate at 140
		and 36°C.	ml/min

The experimental test rig for this study is conducted based on the project made by Sukri et al., (2020). The major difference between these studies is the manipulated variable in which in this investigation the temperature condensate water sprayed are vary. Figures 2.8(a) and 2.8(b) show the schematic diagram and actual setup for the experiment, respectively.



Figure 2.8 (b): Actual experimental setup of AAC experimental facility (Sukri et al., 2020)

2.5 Summary

The other option of condensate-assisted sub-cooling process is by cooling the compressor discharged to improve the cooling capacity of AAC system. As far, the effect of condensate water in different temperature assisting sub-cooling process of condenser surface are yet to be investigated. The schematic diagram on Figure 2.9 below shows the process of the cooling method by flowing the wasted condensate water from evaporator to the condenser surface.



Figure 2.9: Utilization of condensate water as surface condenser coolant (Sukri et al., UNIVERSITI TEKNIK 2020) ALAYSIA MELAKA

When the temperature of condensate water sprayed is lower than the condenser ambient, it will increase the effectiveness of the condenser to remove heat efficiently. This effect is caused by the temperature difference between the surrounding and the condenser body are relatively higher compared to temperature difference between the surrounding and the condenser surface before the water sprayed. As a result, the higher the heat transfer can be rejected to the air. By that reason, this title is proposed to the study the effect of the temperature difference of the condensate water sprayed to the condenser to the overall performance of the AAC system.

CHAPTER 3

METHODOLOGY

3.1 Overview and Flow chart

This subtopic discusses the experimental setup and the procedures for this research. The project starts with the redesign the schematic diagram for the AAC system test rig based on the previous study by Sukri et al. to describe the path of the experiment and make some modifications for the current investigation. Then, the data accuracy is checked by taking the measurement for three times and the average of every data taken will be the final value. The uncertainty of every data taken lead to the restart of the experimental works. Next, data analysis will be made after consistent measurements is obtained to indicate COP of the whole system.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Figure 3.1: Flow chart of methodology

3.2 Flow chart Explanation

3.2.1 Experimental work

3.2.1.1 Schematic diagram and model setup

The test rig is based on the AAC system used in Proton Wira which has been modified in accordance with experimental study and facilities of *heating*, *ventilation*, *and air conditioning* (*HVAC*) *lab in* Faculty of Mechanical Engineering, UTeM. Figure 3.2 shows the modified schematic diagram of AAC system test rig. The setup of the experiment is shown in Figure 3.3.



Figure 3.2: Modified AAC test rig schematic diagram
Table 3.1: Temperature	description
------------------------	-------------

Τ1	Temperature refrigerant at inlet compressor	T5	Temperature air inlet evaporator
<i>T2</i>	Temperature refrigerant at inlet condenser	Τ6	Temperature air outlet evaporator
Тз	Temperature refrigerant at inlet expansion valve	Τ7	Temperature water storage
T4	Temperature refrigerant at inlet evaporator	Тв	Ambient temperature

	Table 3.2: Gauge	pressure	e description
P1	Pressure of refrigerant at inlet	Рз	Pressure of refrigerant at inlet expansion valve
<i>P</i> 2	Pressure of refrigerant at inlet condenser	. P4	Pressure of refrigerant at inlet evaporator
	UNIVERSITI TEKNIKAI	L MAI	LAYSIA MELAKA



Figure 3.3: Facility setup for the experimental work

W	ALAYSIA		
TEKING	Table 3.3: Instru	iment specification	
Instrument	Model	Range of	System
201	Wn .	measurement	uncertainty
Thermocouple	K-Type with TC-08 USB Pico Data ERSITTEKNIKA Logger	رسيني کې2 <u>00:350</u> °C L MALAYSIA ME	±0.75%
Pressure gauge	-	-100:3800/5300 kPa	-
Mass flow meter	Platton/NGX	4:56 g/s	±1.25% FSD
Digital tachometer	Ono Sokki/HT-4100	30:24999 rpm	±1 rpm

The compressor is driven by 3 kW electric motor with 415 V electrical supply controlled by a frequency inverter. The 6 bulbs control the evaporator returned air using switch manually. The electrical power used by each bulb is 100 W. A tachometer is used to control the speed of the compressor at 1550 rpm. The condensate is pumped and sprayed on the body of the condenser through a high-pressure electric pump and a nozzle.

Determination of the refrigerant pressure and inlet or outlet temperature of each main part are made by using respective four pressure gauges and a TC-08 USB temperature data logger with a K-type thermocouple. Plus, the inlet temperature of the condenser air, the temperature of the condensate water, and the return temperature of the evaporator air are also be calculated and monitored using the TC-08 USB K-type thermocouple temperature data logger. A refrigerant mass flow meter placed in between the condenser and the expansion valve.

3.2.1.2 Temperature of condensate water sprayed

The baseline temperature of the condenser was set by not spraying any condensate to the condenser, acting as current conventional system. In term of temperature condensate water sprayed, the temperature was set at $27 \pm 3^{\circ}$ C and $8 \pm 3^{\circ}$ C. The condition $27 \pm 3^{\circ}$ C was achieved by spraying the only water filled in the box. Meanwhile, the condition of $8 \pm 3^{\circ}$ C was attained by placing the water in polystyrene box with ice. The amount of ice will be depending on the calibration of water storage tank temperature using thermocouples.

3.2.1.3 Test rig operation

This experiment was conducted between 10.30 am to 12.00 pm to attain ambient temperature and air inlet condenser temperature at $32 \pm 3^{\circ}$ C. The test rig was operated for 10 minutes with a 20 second time of intervals for each data collection in the last 5 minutes. Data collection for each experimental setup was repeated for 3 times to get the reliable results. Detail procedure for baseline and other setting parameter can be referred in Appendix A.

3.2.2 Data accuracy check

For this experiment, accuracy of data was influenced by thermal equilibrium process and variation of temperatures taken. Thermal equilibrium is a state of transitivity between two bodies in different temperatures contacted, which in the end both will have no net flow of thermal energy. In this study, the water condensate which is low temperature is in contacted with the high temperature condenser.

After a period of steady flow water condensate sprayed, the condenser temperature has lowered into expected degrees. However, in many times the temperature was higher or lower than the predicted outcome. This scenario happened due to the environmental factor which differs every day. For instance, the experimental works were done for three days under same weathers but different in light intensity. Thus, it is important to be aware of climate change to avoid this error.

Temperature variation indicated by the instability of tolerance values chosen during the experimental work. Uncertainty of values recorded may result to systematic error which effect the final values. Therefore, the measurement of the temperature taken have been expressed in uniform tolerance values at $\pm 3^{\circ}$ C. These errors should be avoided, otherwise, the experimental works must be back to square one.

3.2.3 Data analysis

The COP refer to the ratio of cooling capacity to work input. From equation (2.1) to (2.3), the COP of air conditioning for vehicles can be expressed as equation (3.1). Determination of enthalpy are based on the determination of absolute pressure following equation (3.5).

$$COP = Q_e / W_{in} = (h_2 - h_3) / (h_1 - h_4)$$
(3.1)

$$Q_e = Q_L = \dot{m} (h_1 - h_4)$$
 (3.2)

$$W_{in} = \dot{m} (h_2 - h_1)$$
 (3.3)

$$Q_{H} = \dot{m} (h_{2} - h_{3})$$
(3.4)
$$p = (P \times 100 \ kPa) + 101.325 \ kPa$$
(3.5)

1. 1. 2. 1. 1. 1.

Where: $Q_e = \text{cooling capacity (kW)}$, $Q_L = \text{Rate of heat rejection (kW)}$, $Q_H = \text{Rate of heat}$ removal (kW), $W_{in} = \text{work of compressor (kW)}$, $\dot{m} = \text{Mass flow rate of refrigerants (kg/s)}$, $h_1 = \text{Compressor refrigerant enthalpy (kJ/kg)}$, $h_2 = \text{Evaporator refrigerant enthalpy (kJ/kg)}$, p = absolute pressure (kPa), P = gauge pressure (bar)

There are two assumptions that must be taken in line with simple vapour compression cycle based on Figure 4.3, which are:

- 1. Refrigerant is at saturated vapour state at the compressor inlet (point 1)
- 2. Process of isentropic expansion occur in the expansion valve (point 3 to point 4 process)

The enthalpy of refrigerant is calculated using Refrop Mini software (Nist, 2013). For this study, average readings are considered as final readings.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Overview

The experiment is carried out following the procedure as working guidelines. Table 4.1 below shows the operating condition of the test rig along the experimental period.



Table 4.1: Operating condition of AAC system

4.1.1 Results on the baseline condenser condition

Table 4.2 represents the average gauge pressure of P_1 , P_2 , P_3 . and P_4 for each trial of baseline condition of condenser. Table 4.3 shows the average temperature T_1 until T_8 representing each test rig component during the same condition. Details on data are represented in Appendix B (i) and (ii), respectively.

Trial	Pressure 1, <i>P</i> ₁	Pressure 2, P2	Pressure 3, P3	Pressure 4, P4
	(Bar)	(Bar)	(Bar)	(Bar)
1 5	1.50	11.0	11.0	2.0
KI	KA			
2	1.25	11.0	10.5	2.0
E.				
3	1.25	11.0	11.0	2.0
ch.l			· · ·	•
Average	1.33	11.0	و 10.8 ي 1	2.0
LININ			AVCIA MELA	12.0
UNIN	EKOILLEN	NIKAL MAL	AT SIA WELA	INA .

Table 4.2: Table of gauge pressure during baseline condition of condenser

Mass flow rate of refrigerant (kg/s), *m*: 0.039

Trial	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature
	1, <i>T</i> ₁ (°C)	2, <i>T</i> 2(°C)	3, <i>T</i> 3(°C)	4, <i>T</i> 4(°C)	5, <i>T5</i> (°C)	6, <i>T</i> 6 (°C)	8, <i>Ts</i> (°C)
1	32.49	62.55	41.14	35.06	31.41	22.10	32.42
2	33.13 -	67.56	42.46	34.31	31.11	21.26	34.52
3	31.49	60.72	40.15	34.61	30.84	22.55	30.83
Average	32.38	64.35	41.36	34.66	31.12	21.97	32.59
		44 44	0	a.0	. O. V	1.1	

Table 4.3: Table of temperature during baseline condition

Final speed of compressor (rpm): 1565

4.1.2 Results on only condensate water is sprayed to condenser condition

Table 4.4 represents the average gauge pressure of P_1 , P_2 , P_3 . and P_4 for each trial of condensate water sprayed on the condenser. Table 4.5 shows the shows the average temperature T_1 until T_8 representing each test rig component in the same condition. Details on data are represented in Appendix C (i) and (ii), respectively.

Initial temperature of condensate water sprayed (°C): 27.2

Table 4.4: Table of gauge pressure after condensate water sprayed at 27.2°C to the

	MALAYSIA			
Trial	Pressure 1, P1	Pressure 2, P2	Pressure 3, P3	Pressure 4, P4
TEKN	(Bar)	(Bar)	(Bar)	(Bar)
1	1.0	8.0	8.0	1.5
2	ىل مليسيا ملا	8.0	بوہر سیتی تی	1.5
3 <u>UN</u>	1.0 IVERSITI TEK	8.0 NIKAL MAL/	* 8.0 AYSIA MELA	3.0 KA
Average	1.0	8.0	8.0	2.0

condenser

Mass flow rate of refrigerant (kg/s), *m*: 0.032

Trial	Temperature	Temperature 2,	Temperature 3,	Temperature	Temperature	Temperature	Temperature	Temperature
	1, <i>T1</i> (°C)	<i>T2</i> (°C)	<i>T3</i> (°C)	4, <i>T</i> 4 (°C)	5, <i>T</i> 5 (°C)	6, <i>T</i> 6 (°C)	7, <i>T</i> 7(°C)	8, <i>Ts</i> (°C)
1	29.90	57.71	33.04	30.66	29.72	22,22	26.08	33.59
2	30.02	58.54	33.07	30.97	29.97	22.71	26.83	32.90
3	29.94	61,39	34.64	32.29	31.57	23.32	29.34	38.23
Average	29.95	59.21	33.58	31.30	30.71	22.75	27.41	34.90
			0		. Ģ.	· · · · · ·		

Table 4.5: Table of temperature after condensate water sprayed at 27.2°C to the condenser

Final speed of compressor (rpm): 1535ERSITI TEKNIKAL MALAYSIA MELAKA

4.1.3 Results on the condensate water with ice sprayed to condenser condition

Table 4.6 represents the average gauge pressure of P_1 , P_2 , P_3 . and P_4 for each trial of condensate water sprayed with ice on the condenser. Table 4.7 shows the average temperature T_1 until T_8 representing each test rig component in the same condition. Details on data are represented in Appendix D (i) and (ii), respectively.

Initial temperature of condensate water sprayed (°C): 8.01

Table 4.6: Table of gauge pressure after condensate water at 8.01°C sprayed to the

	MALAYSIA			
Trial	Pressure 1, P1	Pressure 2, P2	Pressure 3, P3	Pressure 4, P4
TEKN	(Bar)	(Bar)	(Bar)	(Bar)
1 5	0.75	7.0	7.0	1.25
2	ىل مليسيا ملا	7.0	وتر سيتي ت <u>م</u>	1.25 اون
3	0.75 IIVERSITI TEK	7.0 NIKAL MAL	7.25 AYSIA MELA	1.25
Average	0.75	7.0	7.083	1.25

condenser

Mass flow rate of refrigerant (kg/s), m: 0.0315

Trial	Temperature 1,	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature	Temperature
	<i>T1</i> (°C)	2, <i>T</i> ₂ (°C)	3, <i>T</i> 3 (°C)	4, <i>T</i> 4 (°C)	5, <i>T</i> 5 (°C)	6, <i>T</i> 6(°C)	7, <i>T</i> 7(°C)	8, <i>Ts</i> (°C)
1	29.62	59.26	30.63	30.49	30.12	24.98	9.09	31.63
2	30.17	58.74	31.11	29.95	31.11	25.77	7.57	32.94
3	30.54	59.11	31.58	30.86	30.62	25.54	9.4	33.88
Average	30.11	59.04	31.11	30.43	30.62	25.43	8.68	32.66
			0	a9	- <u> </u>	· / / ·		

Table 4.7: Table of temperature after condensate water at 8.01°C ice sprayed to the condenser

Final speed of compressor (rpm): 1555 ERSITI TEKNIKAL MALAYSIA MELAKA

4.2 Discussion

Table 4.8 shows the overall results comparison of different condition of condenser under the implementation of condensate water sprayed comprising rate of heat removal, Q_{H} , cooling capacity, Q_e , compressor work, W_c , and COP

Temperature of	Rate of heat	Cooling	Compressor	Coefficient of
condensate water	removal, <i>Q</i> H	capacity, <i>Qe</i>	work, Wc	Performance
sprayed (°C)	(kW)	(kW)	(k W)	(COP)
Baseline	7.97	6.37	1.59	4.01
27.2	6.87	5.67	1.2	4.73
8.01	6.98	5.77	1.2	4.81
LIN		UI	EIV	

Table 4.8: Results of analysis

4.2.1 Average gauge pressure

Figure 4.1 shows the refrigerant pressure difference after the changes made to the condition of the condenser by spraying condensate water at different temperature. In general, every component of the test rig during baseline condition have recorded the highest pressure of refrigerant especially at P_2 (11 bar) situated at the condenser. As comparison, the system recorded lower pressure at P_2 which are 8 bar and 7 bar during respective water condensate sprayed to the condenser condition and water condensate with ice sprayed to the condenser condition.

The lowest pressure of refrigerant is recorded at P_1 during water condensate at 8.01°C sprayed to the condenser condition (0.75 bar) compared to baseline condition of condenser and water condensate at 27.2°C sprayed to the condenser condition at 1.33 bar and 1 bar, respectively.

 P_3 which situated at the expansion valve set the highest value at 10.83 bar during the baseline condition while it recorded 8 bar and 7.083 bar during respective water condensate sprayed to the condenser condition and water condensate with ice sprayed to the condenser condition. The marginal decline of P_3 from P_2 recorded is because expansion valve allows the expansion of the liquid refrigerant from the condenser to start vaporising as it is entering the evaporator.

Meanwhile, P_4 during the system in baseline state of condenser and water condensate sprayed to the condenser state are showing the same pressure at 2 bar, and it slightly lower at 1.25 bar during water condensate with ice sprayed condition.



Figure 4.1: The effect of sprayed condensate water temperature on average pressure of

component

4.2.2 Average temperature of refrigerant at main inlet components

Figure 4.2 shows the comparison of average temperature for each AAC component as the resulting of sprayed condensate water temperature to the condenser. Generally, highest temperature of refrigerant at each component of AAC system happened at baseline condition, followed by condition of water condensate at 27.2°C sprayed to the condenser and during water condensate at 8.01°C sprayed to the condenser. This phenomenon pictures the effectiveness of the usage water condensate in lower temperature as condenser surface coolant and thus, it shows the increment efficiency of working compressor through this method.



Figure 4.2: The effect of sprayed condensate water temperature on average temperature of

refrigerant at inlet components

4.2.3 *P-h* diagram

Figure 4.3 depicts the AAC system in p-h diagram in which, consists of 4 phases representing absolute pressure of 4 main components of the system. Phase 1 denotes as the compressor, phase 2 is the condenser, phase 3 is the expansion valve and phase 4 is the evaporator. The length between phases determines future value of the COP, especially for the vast length differences between phase 1 and phase 2 at each condition which indicates the compressor work. The longer the length difference between phase 1 and phase 2, the bigger the compressor work. This by means shown that the highest compressor work denotes by the baseline condition.

The horizontal length of phase 1 and phase 4 indicates the cooling capacity of AAC system. Applying condensate water as surface coolant of condenser results in the pressure dropped of the whole system and increment of the system efficiency. This result is shown in both conditions of condenser after sprayed by condensate water. If longer length difference between phase 1 and phase 4 (the higher cooling capacity) working with the shorter difference length between phase 1 and phase 2 (the lower compressor work), it will result in an increment of the COP and refrigerating capacity of the AAC system.



Figure 4.3: Effect of sprayed condensate water temperature to condenser on *p*-*h* diagram

4.2.4 Compressor work

Figure 4.4 shows the effect of different condensate water sprayed to the condenser on compressor work. The baseline condition shows the highest compressor work at 1.6 kW due to higher mass flow rate of refrigerant as compared to the other conditions. As the compressor work increases, the higher mass flow of refrigerant may be the reason for the increase in heat transfer rate (Datta et al., 2016). Hence, the mass flow rate of refrigerant is high because of the needs in the increment of the rate of heat transfer. This process also results to the increment rate of heat removal and cooling capacity of the system in the baseline condition.

Nevertheless, the compressor work decreases extensively after the water condensate at 27.2°C sprayed to the condenser to 1.2 kW, and it remains unchanged even the temperature of water condensate sprayed reduced to 8.01°C. Following Figure 4.3, the reduction of the compressor work is caused by decreasing temperature and pressure on the compressor discharge at point 2. Therefore, as the compressor work decrease, it will reduce the power consumption and will increase the longevity of life expectancy of the compressor.



Figure 4.4: The effect of sprayed condensate water temperature on compressor work

4.2.5 Rate of heat removal

Figure 4.5 portrays the rate of heat removal by the system working at different condition of condenser. It shows that the system with baseline condition is the highest in term of heat removal at 7.97 kW as compared to the condenser of system with the water condensate sprayed at 27.2°C recorded 6.87 kW and water condensate at 8.01°C sprayed at 6.98 kW. This situation relates to the amount of the of the refrigerant specific enthalpy entering the expansion valve, in which the system with baseline condition of condenser recorded the highest specific enthalpy (phase 3), as shown in *p*-*h* diagram in Figure 4.3.



Figure 4.5: The effect of sprayed condensate water temperature to rate of heat removal

4.2.6 Cooling capacity

Figure 4.6 illustrates the cooling capacity of AAC system in three different conditions of condenser. Generally, a decrement of cooling capacity by 0.7 kW has been recorded by the system as water condensate at 27.2°C is sprayed to the condenser from baseline condition of condenser and slightly rose by 0.1 kW after condenser was sprayed using condensate water at 8.01°C. This figure also shows that reduction rate of cooling capacity in comparison to baseline condition of system, in which system working with condensate water sprayed at 27.2°C to the condenser recorded the highest reduction by 11%. This is followed by the system working during 8.01°C of condensate sprayed to the condenser which has registered 0.45% of reduction.



Figure 4.6: The effect of sprayed condensate water temperature to cooling capacity

4.2. Coefficient of Performance (COP)

Following the results from the decrement of cooling capacity on Figure 4.6, and the reduction of compressor work on Figure 4.3 have led to an increment in COP of the AAC system. Based on the equation 3.4, COP will be higher as the ratio of cooling capacity against the compressor work is big. Even though the baseline condition has recorded the highest mass flow rate, due to high temperature and pressure of inlet refrigerant of compressor at point 2 in Figure 4.3, the system have set down the lowest COP at 4.01 as compared to condenser condition with condensate water sprayed.

Figure 4.7 depicts the result of the COP of the system in three different condenser conditions. The best operating condition appears when the condenser was sprayed with condensate water at 8.01°C, with the highest COP of 4.81. The percentage increment of COP is the highest occurred during this condition at 16.6%, as compared to the system using baseline condition of condenser. This is followed by the system working with condensate water at 27.2°C sprayed to the condenser at 15.2% of increment from the baseline condition.



Figure 4.7: The effect of sprayed condensate water temperature to Coefficient of

Performance

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The performance of the AAC system with the effect of waste condensate waste at different temperature has been experimentally studied and presented in this report. Based on this study, the reduction of the system pressure and temperature of the proposed system have led to the decrement of specific enthalpy at phase 2 and phase 3 in p-h diagram. As a result, the increment of the COP was recorded by both proposed systems as compared to the conventional system.

Furthermore, it is found that the COP of the AAC system is the highest during the condensate water at 8.01°C sprayed to the condenser (4.81) due to the system energy balance. The decrease in compressor work and the increment of cooling capacity through the reduction of condensing pressure and temperature have emerged the raise in the COP.

However, the COP is the lowest at the baseline condition (4.01) due to ratio of cooling capacity over compressor work is the smallest, even its cooling capacity and compressor work were recorded the highest as compared to the other system conditions. The highest COP improvement occurred during condensate water at 8.01°C sprayed to condenser (16.6%) followed by condensate water at 27.2°C sprayed to condenser (15.5%) in comparison to the baseline condition.

5.2 **Recommendations**

It is found that the cool air from evaporator is blow out to the surrounding which may results in unstable data collection for air inlet evaporator temperature, *T*₅. An enclosed channel to a specific space for air evaporator outlet is suggested to be built to make sure there is no return air circulation from the evaporator and only air from the surroundings is sucks into the evaporator return air channel.

Furthermore, in comparison to an actual condition, the volume flow rate of condensate water sprayed at 450 ml/min is unachievable. However, due to the limitation of water spray, the volume flow rate must be considered as constant variable. Therefore, a water suction for spray which can flow lower volume flow rate of condensate water is suggested to be installed in the test rig.

Lastly, the inverter motor can only last for 10 minutes for a single trial, and longer working operation may results in overheat and failure. The installation of higher specifications of motor is needed to prolong the experimental duration for the data to be taken and the imitation of real time AAC system working process is achievable.

REFERENCES

- Ardita, I. N., & Subagia, I. W. A. (2018). The application of condensate water as an additional cooling media intermittently in condenser of a split air conditioning. *Journal of Physics: Conference Series*, 953(1). https://doi.org/10.1088/1742-6596/953/1/012059
- Bhatti, M. S. (1999). Riding in comfort, Part II: Evolution of automotive air conditioning. *ASHRAE Journal*, 41(9).
- Brown, M. (2012). Discovery of a Lifetime F. Sherwood Rowland and the Ozone Layer. april, 1–20. https://www.lib.uci.edu/sites/all/docs/exhibits/checklist-rowland.pdf
- Datta, S. P., Das, P. K., & Mukhopadhyay, S. (2016). Effect of Refrigerant Charge, Compressor Speed and Air Flow through the Evaporator on the Performance of an Automotive Air Conditioning System. Renewable and Sustainable Energy Reviews, 80(2007), 1–10. http://docs.lib.purdue.edu/iracc/1470

Farrington, R., & Rugh, J. (2000). Impact of Vehicle Air-Conditioning on Fuel Economy, Tailpipe Emissions, and Electric Vehicle Range. *Earth Technologies Forum*, *September*, http://www.nrel.gov/docs/fy00osti/28960.pdf. http://www.smesfair.com/pdf/airconditioning/28960.pdf

Ibrahim, N. I., Al-Farayedhi, A. A., & Gandhidasan, P. (2017). Experimental investigation of a vapor compression system with condenser air pre-cooling by condensate. *Applied Thermal Engineering*, *110*, 1255–1263.
https://doi.org/10.1016/j.applthermaleng.2016.09.042

- Joudi, K. A., Mohammed, A. S. K., & Aljanabi, M. K. (2003). Experimental and computer performance study of an automotive air conditioning system with alternative refrigerants. *Energy Conversion and Management*, 44(18), 2959–2976. https://doi.org/10.1016/S0196-8904(03)00051-7
- Jung, D., Park, B., & Lee, H. (1999). Evaluation of supplementary/retrofit refrigerants for automobile air-conditioners charged with CFC12. *International Journal of Refrigeration*, 22(7), 558–568. https://doi.org/10.1016/S0140-7007(99)00022-5
- Kamar, H. M., Ahmad, R., Kamsah, N. B., & Mohamad Mustafa, A. F. (2013). Artificial neural networks for automotive air-conditioning systems performance prediction. *Applied Thermal Engineering*, 50(1), 63–70.

https://doi.org/10.1016/j.applthermaleng.2012.05.032

- Kerkeni, L., Ruano, P., Delgado, L. L., Picco, S., Villegas, L., Tonelli, F., Merlo, M.,
 Rigau, J., Diaz, D., & Masuelli, M. (2016). We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists TOP 1 %. *Intech, tourism*, 13. https://www.intechopen.com/books/advanced-biometric technologies/liveness-detection-in-biometrics
- Lemmon, E. W., Huber, M. L. & McLinden, M. O. NIST Standard Reference Database 23:
 Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 9.1.
 Gaithersburg: National Institute of Standards and Technology, Standard Reference
 Data Program, (2013).
- Qi, Z., Zhao, Y., & Chen, J. (2010). Performance enhancement study of mobile air conditioning system using microchannel heat exchangers. *International Journal of Refrigeration*, 33(2), 301–312. https://doi.org/10.1016/j.ijrefrig.2009.08.014

Sawant, R., Ghali, K., & Al-Hindi, M. (2012). Use of condensate drain to pre-cool the inlet air to the condensers: A technique to improve the performance of split airconditioning units. *HVAC and R Research*, *18*(3), 417–431. https://doi.org/10.1080/10789669.2012.619395

- Sawant, A. P., Agrawal, N., & Nanda, P. (2012). Performance assessment of an evaporative cooling-assisted window air conditioner. *International Journal of Low-Carbon Technologies*, 7(2), 128–136. https://doi.org/10.1093/ijlct/ctr029
- Shah, R. K. (2006). AUTOMOTIVE AIR-CONDITIONING SYSTEMS HISTORICAL DEVELOPMENTS, THE STATE OF TECHNOLOGY AND FUTURE TRENDS 2. Basic Operation of Current Automotive A / C Systems 3. Brief History of the Refrigerant and A / C System. December, 20–22.
- Sharif, M. Z., Azmi, W. H., Redhwan, A. A. M., Mamat, R., & Yusof, T. M. (2017). Analyse de la performance du nanolubrifiant SiO2/PAG dans un système de conditionnement d'air automobile. *International Journal of Refrigeration*, 75, 204–216. https://doi.org/10.1016/j.ijrefrig.2017.01.004
- Sukri, M. F., Lokman, R., Muhajir, A., Wasbari, F., Damanhuri, A. A. M., & Sumeru, K. (2020). The effect of condensate water on the performance of automotive air conditioning system under difference evaporator air inlet temperature. *International Journal of Nanoelectronics and Materials*, 13(Special Issue ISSTE2019), 85–94.
- Sumeru, K., Margana, A. S., & Hidayat, S. (2019). Condensate water as a compressor discharge cooler to generate subcooling on the residential air conditioning using R32 as refrigerant. *Journal of Physics: Conference Series*, 1295(1). https://doi.org/10.1088/1742-6596/1295/1/012044

Tailpipe Emissions, and Electric Vehicle Range. *Earth Technologies Forum, September*, http://www.nrel.gov/docs/fy00osti/28960.pdf. http://www.smesfair.com/pdf/airconditioning/28960.pdf

Thambiran, T., & Diab, R. D. (2010). Air Pollution and Climate Change Co-benefit Opportunities in the Road Transportation Sector in Durban, South Africa Author for correspondence: tthambiran@csir.co.za CSIR Natural Resources and the Environment, PO Box 17001, Congella 4013, South Africa. 1–21.

Thompson, J. F. (1992). Precooling and Storage Facilities.

UKEssays. (November 2018). Characteristics Of Vapour Compression Refrigeration Cycles Engineering Essay. Retrieved from

https://www.ukessays.com/essays/engineering/characteristics-of-vapourcompression-refrigeration-cycles-engineering-essay.php?vref=1

Youbi-Idrissi, M., Macchi-Tejeda, H., Fournaison, L., & Guilpart, J. (2007). Numerical model of sprayed air cooled condenser coupled to refrigerating system. *Energy Conversion and Management*, 48(7), 1943–1951.
 https://doi.org/10.1016/j.enconman.2007.01.025

APPENDICES

Appendix A

Procedure:

Baseline procedure:

- 1. Set up the TC-08 USB K-type thermocouple temperature data logger at every compartment of AAC system in the test rig.
- 2. Press the green start button, turn ON the expansion valve and condenser knob and the evaporator and compressor knob simultaneously.
- 3. Adjust the frequency of the inverter to achieve steady 1550 rpm of the compressor.
- 4. Check the compressor speed by using the tachometer.
- Turn ON the bulbs at the evaporator returned air channel to maintain adequate load at 30 ±3°C if needed. Turn OFF once it exceeds the load temperature.
- 6. Run the test rig for 10 minutes.
- 7. Record the temperature and pressure of AAC system compartment and mass flow rate of refrigerant during the running period in the last 5 minutes with 20 seconds of intervals.
- 8. Repeat the experiment for 3 times to attain the stable results.

Operating procedure with condensate water (with ice) spray:

- 1. Set up the TC-08 USB K-type thermocouple temperature data logger at every compartment of AAC system in the test rig.
- 2. Fill the polystyrene box with 5L of condensate water with an amount of ice and control the temperature by immerse one of the K-type thermocouples into the box.
- 3. Press the green start button. Turn ON the expansion valve and condenser knob, the evaporator and compressor knob, and jet pump knob simultaneously.
- 4. Set the nozzle to wide spray setting. Control the spray speed knob and measure the volume flow rate of the by spraying the condensate water into measuring jug to obtain the speed of 450 ml/min.
- 5. Adjust the frequency of the inverter to achieve steady 1550 rpm of the compressor.
- 6. Check the compressor speed by using the tachometer.
- 7. Turn ON the bulbs at the evaporator returned air channel to maintain adequate load at 30 ±3°C if needed. Turn OFF once it exceeds the load temperature.
- 8. Run the test rig for 10 minutes. Start the spraying process by pointing the spraying point to the middle of condenser.
- 9. Record the temperature and pressure of AAC system compartments and mass flow rate of refrigerant during the running period in the last 5 minutes with 20 seconds of intervals.
- 10. Repeat the experiment for 3 times to attain the stable results.

Appendix B (i)

Trial 1

Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> 3	<i>P</i> ₄
0:06:00	1.5	10.0	11.0	2.0
0:07:00	1.5	11.0	11.0	2.0
0:08:00	1.5	12.0	11.0	2.0
0:09:00	1.5	11.0	11.0	2.0
0:10:00	1.5	11.0	11.0	2.0

Trial 2

Time interval	<i>P</i> ₁	<i>P</i> ₂	Рз	<i>P</i> ₄
0:06:00	1.0	11.0	11.0	2.0
0:07:00	1.5	11.0	10.5	2.0
0:08:00	1.25AY 8/4	11.0	11.0	2.0
0:09:00	1.25	11.0	10.0	2.0
0:10:00	1.25 🚱	11.0	10.0	2.0
TER	· · · · · · · · · · · · · · · · · · ·			
Trial 3			GIV	

	44.			
Time interval	P1	P_2	<i>P</i> ₃	P_4
0:06:00	1.0	11.0	11.0	2.0
0:07:00	1.5	11.0	11.0	2.0
0:08:00	1.25 SITI TEK	11.0	11.0 MEL AL	2.0
0:09:00	1.25	11.0	11.0	2.0
0:10:00	1.25	11.0	11.0	2.0

Appendix B (ii)

Time								
interval	T_1	<i>T</i> 2	Тз	T_4	T5	<i>T</i> 6	<i>T</i> 7	Тв
0:00:00	30.095	49.512	39.071	33.181	31.924	20.896	-	32.164
0:00:20	30.258	51.37	39.763	33.791	30.981	21.87	-	31.314
0:00:40	30.396	52.795	39.876	33.961	31.03	21.94	-	31.254
0:01:00	30.475	52.941	39.784	34.15	31.32	22.45	-	30.95
0:01:20	30.577	53.093	40.17	34.322	31.2	22.181	-	30.9
0:01:40	30.72	53.842	40.26	34.49	31.329	22.145	-	30.812
0:02:00	30.913	54.41	40.307	34.547	31.429	22.265	-	30.92
0:02:20	31.162	55.331	40.318	34.57	31.996	22.356	-	31.525
0:02:40	31.389	56.288	40.484	34.608	32.131	22.539	-	31.641
0:03:00	31.597	57.37	40.697	34.744	32.13	22.685	-	31.919
0:03:20	31.822	58.298	40.781	34.805	31.466	22.537	-	31.171
0:03:40	32.095	58.999	40.854	35.01	30.921	22.305	-	31.338
0:04:00	32.355	59.776	41.136	35.275	30.657	21.996	-	31.13
0:04:20	32.547	60.582	41.443	35.498	30.091	21.854	-	30.945
0:04:40	32.615	61.146	41.491	35.514	31.212	21.566	1 -	31.253
0:05:00	32.549	61.293	41.325	35.349	31.735	22.092	-	32.079
0:05:20	32.526	61.258	41.212	35.238	31.162	22.105	-	31.754
0:05:40	32.53	61.3	41.23	35.331	31.201	22.235		30.991
0:06:00	32.527	60.978	41.093	35.387	31.662	22.527	Low	31.098
0:06:20	32.528	60.562	40.862	35.23	32.806	22.747	····	31.142
0:06:40	32.561	60.406	40.697	35.082	32.86	22.874	AKA	31.087
0:07:00	32.598	60.407	40.497	34.855	31.473	22.795		32.735
0:07:20	32.661	60.785	40.499	34.778	30.26	22.185	-	32.239
0:07:40	32.708	61.433	40.754	34.888	30.285	21.44	-	32.287
0:08:00	32.618	62.103	40.969	34.861	29.951	21.006	-	31.988
0:08:20	32.506	62.705	41.103	34.823	30.688	20.828	-	32.577
0:08:40	32.411	63.278	41.205	34.899	32.332	20.983	-	32.769
0:09:00	32.405	63.82	41.546	35.201	32.647	21.624	-	33.699
0:09:20	32.45	64.249	41.862	35.485	32.711	22.257	-	34.115
0:09:40	32.409	64.463	41.84	35.424	31.63	22.734	-	32.756
0:10:00	32.377	64.555	41.582	35.185	30.438	22.755	-	31.485
0:10:20	32.297	64.6	41.373	34.96	30.588	22.323	-	32.005

I mar 2

Time								
interval	<i>T</i> 1	T_2	Тз	T_4	<i>T</i> 5	<i>T</i> 6	<i>T</i> 7	Тв
0:00:00	30.305	65.604	40.23	31.987	29.613	21.03	-	31.785
0:00:20	30.521	65.743	40.418	31.254	29.347	21.032	-	32.21
0:00:40	30.765	65.84	40.513	31.344	29.982	21.112	-	33.754
0:01:00	30.98	66.042	40.579	31.421	29.35	21.036	-	33.035
0:01:20	31.401	66.107	40.684	31.598	29.377	21.821	-	33.239
0:01:40	31.49	66.176	41.076	31.65	29.654	21.359	-	33.972
0:02:00	31.551	66.214	41.29	31.854	29.791	21.547	-	33.187
0:02:20	31.601	66.298	41.375	31.987	29.831	21.311	-	33.145
0:02:40	31.655	66.354	41.445	32.023	29.903	21.358	-	33.014
0:03:00	31.889	66.39	41.497	32.356	30.112	21.433	-	32.514
0:03:20	31.907	66.412	41.531	32.984	30.213	21.698	-	32.546
0:03:40	31.98	66.451	41.586	33.077	29.951	21.571	-	33.213
0:04:00	32.05	66.498	41.603	33.206	30.356	21.651	_	32.387
0:04:20	32.36	66.521	41,664	33.298	30.279	21.987	-	32.51
0:04:40	32.335	66.587	41.701	33.354	30.4	22.63	-	33.287
0:05:00	32.4	66.621	41.732	33.487	30.431	22.497	-	33.326
0:05:20	32.489	66.684	41.8	33.521	30.476	22.318	-	33.612
0:05:40	32.558	66.708	41.845	33.624	30.582	22.549	-	33.67
0:06:00	32.69	66.759	41.981	33.89	30.61	21.004	+ +	34.189
0:06:20	33.74	67.114	41.8	33.904	30.577	21.587	او یہ	33.225
0:06:40	33.875	67.21	41.99	33.96	30.799	21.798	_	34.097
0:07:00	32.99	67.471	42.005	34.01	30.85	21.416	AKA	34.201
0:07:20	33.01	67.51	42.297	34.97	30.863	22.097	-	33.971
0:07:40	33.098	67.561	42.366	34.165	30.902	22.154	-	34.213
0:08:00	33.133	67.85	42.53	34.205	30.94	21.026	-	34.25
0:08:20	33.198	67.899	42.657	34.374	30.876	21.129	-	34.874
0:08:40	33.254	67.903	42.74	34.497	30.99	21.256	-	34.321
0:09:00	33.336	67.93	42.832	34.555	31.04	21.334	-	34.58
0:09:20	33.462	67.91	42.876	34.617	31.433	21.429	-	34.359
0:09:40	33.49	67.85	42.903	34.732	31.87	21.45	-	35.144
0:10:00	33.501	67.79	42.952	34.89	32.11	21.52	-	35.38
0:10:20	33.59	67.985	43.097	34.933	32.623	21.681	-	34.671

Trial	3
-------	---

Time								
interval	T_1	T_2	Тз	T_4	T_5	T_6	<i>T</i> 7	T8
0:00:00	29	48.945	38.355	33.472	29.038	21.032		29.354
0:00:20	29.145	49.75	38.762	33.629	29.497	21.127		29.623
0:00:40	29.253	49.218	38.954	33.863	29.567	21.191		30.11
0:01:00	29.304	49.704	39.014	33.079	29.615	21.346	-	29.375
0:01:20	29.559	50.548	39.154	33.293	30.171	21.571	-	30.218
0:01:40	29.789	51.357	39.296	33.515	30.451	21.863	-	30.807
0:02:00	29.971	52.058	39.278	33.604	29.654	22.164	-	31.499
0:02:20	30.162	52.718	39.265	33.708	29.234	21.552	-	29.932
0:02:40	30.253	53.282	39.192	33.619	29.065	21.047	-	29.297
0:03:00	30.319	53.747	39.181	33.612	29.913	21.165	-	29.934
0:03:20	30.392	54.398	39.39	33.87	30.232	21.809	-	30.257
0:03:40	30.516	55.247	39.743	34.124	30.076	22.105	-	29.915
0:04:00	30.664	56.043	40.059	34.291	30.09	22.276	_	29.94
0:04:20	30.803	56.668	40,237	34.366	30.277	22.267	-	29.597
0:04:40	30.916	57.017	40.329	34.411	30.4	22.424	-	30.148
0:05:00	31.053	56.98	40.327	34.675	30.041	22.574	-	29.983
0:05:20	31.173	57.099	40.288	34.895	30.638	22.677	-	31.364
0:05:40	31.292	57.506	40.562	35.032	30.042	22.648	-	31.131
0:06:00	31.343	57.962	40.685	34.92	29.64	22.246	• 1	32.243
0:06:20	31.313	58.368	40.482	34.616	30.494	22.042	او یہ	32.618
0:06:40	31.304	58.832	40.232	34.437	30.569	22.199	-	32.215
0:07:00	31.314	59.339	40.175	34.441	30.446	22.172	AKA	31.692
0:07:20	31.3	59.767	40.279	34.444	30.213	22.095	-	30.212
0:07:40	31.32	60.129	40.298	34.422	30.151	21.994	-	30.374
0:08:00	31.326	60.425	40.202	34.357	30.22	21.934	-	30.761
0:08:20	31.313	60.671	40.08	34.42	31	22.216	-	30.174
0:08:40	31.358	60.96	40.149	34.657	31.186	22.546	-	31.136
0:09:00	31.473	61.282	40.259	34.894	30.973	22.697	-	30.294
0:09:20	31.617	61.581	40.462	35.158	31.096	22.799	-	30.432
0:09:40	31.751	61.809	40.472	35.214	31.792	22.951	-	29.831
0:10:00	31.792	61.833	40.144	34.894	31.728	23.179	-	29.607
0:10:20	31.764	61.821	39.767	34.507	31.293	23.271	-	30.219

Appendix C (i)

Trial 1

Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> 3	<i>P</i> ₄
0:06:00	1.0	8.0	8.0	1.5
0:07:00	1.0	8.0	8.0	1.5
0:08:00	1.0	8.0	8.0	1.5
0:09:00	1.0	8.0	8.0	1.5
0:10:00	1.0	8.0	8.0	1.5

Trial 2

Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> 3	<i>P</i> ₄
0:06:00	1.0	8.0	8.0	1.5
0:07:00	1.0	8.0	8.0	1.5
0:08:00	1.0 AYSIA	8.0	8.0	1.5
0:09:00	1.0	8.0	8.0	1.5
0:10:00	1.0	8.0	8.0	1.5
TEP			AN	
Trial 3				

	4100			
Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> ₃	P_4
0:06:00	1.0	8.0	8.0	3.0
0:07:00	1.0	8.0	8.0	3.0
0:08:00		8.0	8.0	3.0
0:09:00	1.0	8.0	8.0	3.0
0:10:00	1.0	8.0	8.0	3.0

Appendix C (ii)

Time								
interval	T_1	T_2	Тз	T_4	T_5	T_6	<i>T</i> 7	T8
0:00:00	28.34	42.808	33.373	30.64	30.183	22.526	25.29	32.941
0:00:20	28.507	44.083	33.664	30.782	30.198	22.565	25.29	32.897
0:00:40	28.724	45.611	34.024	30.966	29.551	22.589	25.749	33.004
0:01:00	28.922	46.935	34.248	31.103	29.468	22.503	25.821	32.961
0:01:20	29.087	48.089	34.352	31.172	29.449	22.53	25.846	32.923
0:01:40	29.227	49.073	34.4	31.214	29.862	22.579	25.866	33.127
0:02:00	29.436	50.051	34.51	31.352	29.596	22.593	25.855	33.079
0:02:20	29.638	50.944	34.636	31.506	29.127	22.406	25.882	33.029
0:02:40	29.788	51.783	34.757	31.616	30.2	22.163	25.863	33.023
0:03:00	29.877	52.573	34.815	31.662	30.976	22.43	25.879	32.994
0:03:20	29.984	53.318	34.903	31.756	30.289	22.598	25.876	33.112
0:03:40	30.106	54.011	35.011	31.889	30.652	22.771	25.894	33.16
0:04:00	30.191	54.645	35.031	31.934	30.745	23.051	25.924	33.032
0:04:20	30.296	55.215	35.093	31.956	30.711	23.123	25.905	33.114
0:04:40	30.423	55.568	35.142	32.02	29.925	22.963	25.903	33.132
0:05:00	30.502	55.929	34.949	31.935	30.275	22.898	25.949	33.243
0:05:20	30.506	55.63	34.596	31.699	30.059	22.961	25.98	33.355
0:05:40	30.443	54.708	34.221	31.433	29.253	22.77	25.984	33.293
0:06:00	30.327	54.22	33.871	31.158	29.4	22.422	26.006	33.418
0:06:20	30.189	54.486	33.555	30.924	29.37	22.182	26.031	33.5
0:06:40	30.043	55.09	33.282	30.736	29.405	22.077	26.049	33.57
0:07:00	29.931	55.855	33.098	30.632	29.822	22.03	26.058	33.388
0:07:20	29.87	56.64	33.043	30.645	30.014	22.087	26.076	33.537
0:07:40	29.826	57.384	33.019	30.667	29.971	22.094	26.093	33.726
0:08:00	29.792	58.038	32.956	30.641	30.123	22.184	26.09	33.712
0:08:20	29.776	58.611	32.896	30.627	30.546	22.4	26.098	33.43
0:08:40	29.795	59.171	32.829	30.608	30.002	22.488	26.122	33.942
0:09:00	29.804	59.686	32.726	30.541	29.669	22.399	26.129	33.759
0:09:20	29.764	60.166	32.589	30.392	29.471	22.246	26.138	34.074
0:09:40	29.71	60.532	32.537	30.313	29.707	22.2	26.137	33.529
0:10:00	29.665	60.734	32.539	30.303	29.605	22.052	26.134	33.677
0:10:20	29.636	60.889	32.554	30.332	29.708	21.932	26.13	33.528

Time								
interval	T_1	T_2	Тз	T_4	T_5	T_6	<i>T</i> 7	T8
0:00:00	28.633	38.807	31.888	30.182	30.116	23.692	26.975	33.347
0:00:20	28.644	40.056	32.423	30.41	29.548	23.098	26.969	33.06
0:00:40	28.766	41.863	33.091	30.699	29.812	22.365	26.989	33.135
0:01:00	28.913	43.609	33.626	30.962	30.214	22.071	26.975	33.382
0:01:20	29.079	45.3	34.08	31.271	30.271	22.059	26.955	32.845
0:01:40	29.284	46.872	34.478	31.59	30.787	22.139	26.951	33.123
0:02:00	29.492	48.3	34.82	31.848	30.985	22.271	26.937	33.035
0:02:20	29.709	49.54	35.078	32.053	30.681	22.505	26.922	32.901
0:02:40	29.927	50.592	35.201	32.194	30.322	22.612	26.909	33.057
0:03:00	30.129	51.51	35.236	32.341	30.667	22.586	26.893	33.123
0:03:20	30.318	52.364	35.329	32.508	31.334	22.625	26.885	32.905
0:03:40	30.465	53.23	35.482	32.611	30.851	22.716	26.868	32.825
0:04:00	30.569	54.036	35.604	32.647	30.776	22.832	26.862	33.003
0:04:20	30.671	54.801	35,711	32.717	30.996	22.861	26.836	33.13
0:04:40	30.739	55.336	35.703	32.714	30.478	22.986	26.812	32.949
0:05:00	30.759	55.021	35.398	32.471	30.424	23.136	26.803	32.889
0:05:20	30.729	54.019	34.986	32.141	30.309	23.228	26.799	33.03
0:05:40	30.655	54.098	34.575	31.829	30.197	23.199	26.791	33.06
0:06:00	30.552	54.74	34.177	31.551	30.009	23.106	26.791	33.012
0:06:20	30.411	55.551	33.809	31.302	29.93	22.95	26.788	33.051
0:06:40	30.274	56.366	33.531	31.149	30.328	22.838	26.792	33.022
0:07:00	30.171	57.152	33.305	31.07	30.592	22.865	26.79 <mark>2</mark>	32.971
0:07:20	30.075	57.83	33.089	30.984	30.394	22.862	26.794	32.915
0:07:40	30.028	58.482	32.965	30.967	30.015	22.856	26.806	32.971
0:08:00	29.986	59.097	32.872	30.946	29.667	22.826	26.814	32.914
0:08:20	29.927	59.628	32.752	30.838	29.242	22.605	26.824	32.876
0:08:40	29.857	60.063	32.654	30.728	29.693	22.389	26.842	32.888
0:09:00	29.798	60.411	32.591	30.682	30.086	22.369	26.859	32.798
0:09:20	29.731	60.739	32.537	30.656	29.657	22.475	26.866	32.717
0:09:40	29.661	61.067	32.48	30.581	29.588	22.39	26.874	32.749
0:10:00	29.614	61.32	32.429	30.519	29.518	22.375	26.872	32.829
0:10:20	29.579	61.538	32.412	30.503	30.344	22.471	26.871	32.851

Trial	3

Time								
interval	T_1	T_2	Тз	T_4	T_5	T6	<i>T</i> 7	Тв
0:00:00	27.929	46.127	32.628	29.916	29.161	21.501	28.644	32.99
0:00:20	27.998	47.343	33.172	30.253	29.793	21.247	28.684	33.457
0:00:40	28.155	48.914	33.804	30.676	30.652	21.378	28.843	33.68
0:01:00	28.371	50.432	34.473	31.166	30.21	21.606	28.912	35.841
0:01:20	28.586	51.892	35.132	31.598	31.233	21.981	28.987	35.127
0:01:40	28.828	53.238	35.73	32	30.686	22.381	29.056	34.58
0:02:00	29.063	54.361	36.146	32.323	30.364	22.474	29.078	35.275
0:02:20	29.276	55.285	36.426	32.582	31.483	22.683	29.08	34.871
0:02:40	29.468	56.112	36.621	32.777	30.933	22.769	29.096	35.143
0:03:00	29.657	56.769	36.761	32.954	31.178	22.845	29.139	35.416
0:03:20	29.843	57.27	36.836	33.097	31.489	23.174	29.146	35.737
0:03:40	30.031	57.738	36.873	33.277	31.265	23.372	29.154	36.086
0:04:00	30.202	58.267	37.015	33.429	31.531	23.517	29.062	36.264
0:04:20	30.332	58.584	37.008	33.478	31.782	23.78	28.861	36.426
0:04:40	30.444	58.651	36.778	33.383	31.103	24.097	28.827	36.56
0:05:00	30.537	58.807	36.408	33.159	31.022	24.298	28.822	36.813
0:05:20	30.573	58.592	36.026	32.939	31.409	24.36	28.807	37.019
0:05:40	30.56	58.591	35.742	32.769	31.532	24.415	28.804	37.265
0:06:00	30.501	58.871	35.516	32.628	31.666	24.415	28.804	37.396
0:06:20	30.426	59.339	35.324	32.523	31.86	24.394	28.862	37.751
0:06:40	30.357	59.886	35.188	32.482	32.131	24.442	28.882	37.853
0:07:00	30.265	60.486	35.094	32.477	31.541	24.376	28.85 <mark>3</mark>	38.116
0:07:20	30.158	61.03	34.939	32.416	31.088	24.035	28.821	37.13
0:07:40	29.997	61.459	34.702	32.259	30.937	23.639	28.767	38.331
0:08:00	29.853	61.806	34.476	32.099	31.103	23.238	28.714	38.412
0:08:20	29.754	62.089	34.272	31.981	31.338	22.933	28.601	38.431
0:08:40	29.684	62.351	34.056	31.935	31.25	22.581	28.651	38.362
0:09:00	29.627	62.535	33.954	31.96	31.704	22.242	29.867	38.332
0:09:20	29.598	62.76	34.021	32.088	31.749	22.451	30.524	38.428
0:09:40	29.557	63.041	34.114	32.213	31.156	22.241	29.967	38.642
0:10:00	29.469	63.274	34.166	32.295	31.853	22.31	30.468	38.875
0:10:20	29.372	63.449	34.222	32.403	31.93	22.628	31.051	39.098
Appendix D (i)

Trial 1

Time interval	<i>P</i> ₁	<i>P</i> ₂	Рз	<i>P</i> ₄
0:06:00	0.75	7.0	7.0	1.25
0:07:00	0.75	7.0	7.0	1.25
0:08:00	0.75	7.0	7.0	1.25
0:09:00	0.75	7.0	7.0	1.25
0:10:00	0.75	7.0	7.0	1.25

Trial 2

Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> 3	<i>P</i> ₄
0:06:00	0.75	7.0	7.0	1.25
0:07:00	0.75	7.0	7.0	1.25
0:08:00	0.75AYS/4	7.0	7.0	1.25
0:09:00	0.75	7.0	7.0	1.25
0:10:00	0.75	7.0	7.0	1.25
1Ex	· · · · · · · · · · · · · · · · · · ·			
Trial 3			IEIV	

	11.			
Time interval	<i>P</i> ₁	<i>P</i> ₂	<i>P</i> ₃	P_4
0:06:00	0.75	7.0	7.5	1.25
0:07:00	0.75	7.0	7.25	1.25
0:08:00	0.75	7.0	7.25	1.25
0:09:00	0.75	7.0	7.25	1.25
0:10:00	0.75	7.0	7.0	1.25

Appendix D (ii)

Trial 1

Time								
interval	T_1	T_2	Тз	T_4	T_5	T6	T_7	Тв
0:00:00	28.431	45.845	30.728	29.279	28.918	24.807	6.607	30.44
0:00:20	28.569	47.07	30.951	29.473	29.244	24.691	6.614	30.459
0:00:40	28.691	48.267	31.167	29.623	28.949	24.547	6.61	30.47
0:01:00	28.792	49.38	31.345	29.721	29.254	24.441	6.618	30.382
0:01:20	28.868	50.466	31.519	29.812	29.089	24.399	6.634	30.552
0:01:40	28.942	51.496	31.65	29.922	29.794	24.43	6.66	30.602
0:02:00	29.032	52.463	31.841	30.086	29.874	24.577	6.687	30.521
0:02:20	29.128	53.411	32.056	30.238	30.174	24.711	6.688	30.496
0:02:40	29.249	54.277	32.258	30.41	30.371	24.842	6.695	30.552
0:03:00	29.382	55.069	32.458	30.564	30.323	25.052	6.715	30.589
0:03:20	29.525	55.815	32.614	30.671	29.882	25.099	6.747	30.529
0:03:40	29.643	56.456	32.698	30.712	29.551	24.988	6.781	30.223
0:04:00	29.711	57.007	32.71	30.681	28.959	24.77	6.815	30.661
0:04:20	2 9. 741	57.47	32.679	30.629	29.707	24.586	6.841	30.804
0:04:40	29 . 747	57.877	32.59	30.567	30.045	24.628	6.859	30.88
0:05:00	29.734	58.193	32.382	30.471	30.026	24.803	6.965	30.943
0:05:20	29.726	58.457	32.168	30.394	30.342	24.998	6.953	30.99
0:05:40	29.728	58.691	31.936	30.355	30.324	25.041	7.459	31.004
0:06:00	29.734	58.847	31.705	30.326	30.539	25.033	7.946	31.1
0:06:20	29.736	58.957	31.499	30.282	30.317	25.065	7.796	31.034
0:06:40	29.731	59.037	31.263	30.185	30.446	25.089	7.738	31.16
0:07:00	29.711	59.056	31.025	30.071	29.671	25.044	7.793	31.188
0:07:20	29.674	59.073	30.815	29.976	29.974	24.971	7.851	31.113
0:07:40	29.631	59.166	30.619	29.897	30.573	24.949	8.028	31.124
0:08:00	29.592	59.24	30.443	29.857	30.746	24.947	8.423	31.109
0:08:20	29.554	59.312	30.285	29.816	30.487	24.961	8.378	31.084
0:08:40	29.536	59.393	30.153	29.778	30.687	24.974	8.616	31.148
0:09:00	29.516	59.479	30.049	29.739	30.632	25.026	8.595	31.273
0:09:20	29.524	59.554	29.984	29.743	30.693	25.04	8.425	31.31
0:09:40	29.54	59.64	29.952	29.785	29.624	25.057	8.549	31.161
0:10:00	29.538	59.7	29.91	29.742	29.011	24.845	12.68	31.145
0:10:20	29.484	59.811	29.83	29.604	28.776	24.472	10.352	31.239

That Z	Tri	al	2
--------	-----	----	---

Time								
interval	T_1	<i>T</i> 2	Тз	T_4	T_5	T_6	<i>T</i> 7	T8
0:00:00	28.768	43.333	30.893	29.57	30.293	24.868	7.089	32.049
0:00:20	28.825	44.278	31.047	29.662	29.835	24.887	7.158	32.224
0:00:40	28.932	45.822	31.305	29.814	29.893	24.756	7.018	32.354
0:01:00	29.067	47.264	31.555	29.986	29.946	24.637	7.11	32.265
0:01:20	29.187	48.631	31.8	30.143	29.431	24.544	7.317	32.462
0:01:40	29.281	49.907	31.989	30.231	29.328	24.435	7.238	32.362
0:02:00	29.341	50.991	32.115	30.268	29.389	24.336	7.22	32.435
0:02:20	29.371	52.016	32.233	30.312	30.641	24.353	7.09	32.469
0:02:40	29.445	53.009	32.392	30.471	30.166	24.522	6.842	32.444
0:03:00	29.523	53.941	32.548	30.599	29.829	24.634	6.582	32.471
0:03:20	29.573	54.7	32.561	30.604	29.97	24.627	7.002	32.588
0:03:40	29.651	55.371	32.587	30.65	29.714	24.638	6.954	32.401
0:04:00	29.776	55.966	32.671	30.818	30.525	24.765	7.342	32.781
0:04:20	29.906	56.43	32.747	30.974	30.764	24.955	7.389	32.489
0:04:40	30.045	56.923	32.799	31.107	30.919	25.128	7.369	32.627
0:05:00	30.149	57.327	32.68	31.164	30.767	25.324	7.762	32.69
0:05:20	30.212	57.702	32.51	31.137	31.172	25.497	7.677	32.317
0:05:40	30.243	58.01	32.344	31.071	31.188	25.682	7.637	32.693
0:06:00	30.268	58.278	32.148	30.985	31.034	25.831	7.679	32.748
0:06:20	30.283	58.481	31.894	30.866	30.745	25.882	7.554	33.04
0:06:40	30.265	58.54	31.611	30.715	30.947	25.876	7.521	33.018
0:07:00	30.24	58.573	-31.39	30.607	31.099	25.895	7.503	33.235
0:07:20	30.211	58.633	31.216	30.544	31.167	25.905	7.59	32.702
0:07:40	30.192	58.708	31.07	30.497	30.922	25.868	7.598	33.277
0:08:00	30.171	58.738	30.924	30.425	30.65	25.785	7.558	33.024
0:08:20	30.159	58.765	30.807	30.353	30.836	25.713	7.53	32.993
0:08:40	30.14	58.801	30.705	30.305	30.691	25.717	7.539	32.965
0:09:00	30.12	58.862	30.632	30.257	30.641	25.703	7.549	32.704
0:09:20	30.095	58.949	30.561	30.216	30.764	25.693	7.567	32.886
0:09:40	30.069	59.099	30.505	30.199	30.538	25.671	7.579	32.793
0:10:00	30.046	59.23	30.449	30.173	30.426	25.616	7.549	32.996
0:10:20	30.01	59.329	30.401	30.142	30.49	25.549	7.57	32.801

Trial	3
-------	---

Time								
interval	T_1	T_2	Тз	T_4	T_5	T_{6}	<i>T</i> 7	T8
0:00:00	29.173	42.851	31.756	30.737	31.002	25.157	8.145	33.555
0:00:20	29.313	44.123	31.974	30.901	31.181	25.116	8.168	33.387
0:00:40	29.511	45.6	32.224	31.09	31.329	25.105	8.196	33.652
0:01:00	29.715	46.985	32.469	31.249	31.494	25.118	8.216	33.431
0:01:20	29.916	48.287	32.741	31.42	31.326	25.102	8.236	33.638
0:01:40	30.089	49.454	32.97	31.55	31.084	25.117	8.252	33.56
0:02:00	30.227	50.501	33.117	31.617	31.233	25.143	8.266	33.598
0:02:20	30.341	51.495	33.237	31.669	30.653	25.143	8.285	33.519
0:02:40	30.434	52.489	33.347	31.723	30.306	25.033	8.301	33.556
0:03:00	30.498	53.423	33.388	31.7	29.695	24.784	8.31	33.589
0:03:20	30.535	54.277	33.356	31.672	31.092	24.649	8.317	33.331
0:03:40	30.593	55.041	33.366	31.746	30.769	24.847	8.327	33.678
0:04:00	30.671	55.638	33.381	31.827	31.141	24.986	8.346	33.727
0:04:20	30.753	56.224	33.436	31.928	31.14	25.077	8.354	34.014
0:04:40	30.838	56.805	33 <mark>.5</mark> 01	32.028	31.172	25.156	8.357	33.452
0:05:00	30.917	57.355	33.57	32.128	31.376	25.251	8.353	33.698
0:05:20	30.968	57.785	33.514	32.121	31.077	25.424	8.782	33.501
0:05:40	30.984	58.015	33.283	31.941	30.813	25.59	9.928	34.021
0:06:00	30.947	58.166	32.963	31.677	30.892	25.669	9.614	33.81
0:06:20	30.885	58.246	32.607	31.411	30.584	25.733	9.247	33.802
0:06:40	30.821	58.289	32.233	31.146	30.729	25.77	9.148	33.551
0:07:00	30.757	58.431	31.911	30.956	30.717	25.781	9.124	33.55
0:07:20	30.685	58.632	31.64	30.825	30.717	25.69	9.141	33.829
0:07:40	30.603	58.874	31.415	30.713	30.704	25.586	9.145	33.903
0:08:00	30.534	59.082	31.251	30.63	29.95	25.52	9.156	34.216
0:08:20	30.445	59.286	31.112	30.531	29.958	25.284	9.197	33.807
0:08:40	30.356	59.479	30.975	30.442	30.614	25.141	9.315	33.766
0:09:00	30.271	59.616	30.868	30.418	30.742	25.186	9.361	33.908
0:09:20	30.214	59.79	30.842	30.46	30.986	25.335	9.343	33.896
0:09:40	30.172	60.043	30.844	30.529	31.54	25.436	9.558	33.825
0:10:00	30.169	60.257	30.889	30.641	30.79	25.522	9.731	33.924
0:10:20	30.19	60.467	30.933	30.722	31.15	25.435	9.773	33.973