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Fault Detection in Compression Refrigeration System with a Fixed Orifice and Rotary Compressor

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ABSTRACT: In compression refrigeration systems such as air conditioning, chiller, split unit, which the refrigerant gas compression is used for cooling, the operation of the device is always dependent on parameters such as pressure, the temperature of different points, and consumed ampere. A tangible change in each of these items represents the existence of a potential fault in the cycle. The basic problem often arises from the fact that there is a time gap between the occurrence of fault and detection of it by the operator, causing damage to the device irreparably and the coefficient of performance is affected. Simulation has been performed by changing the refrigerant gas charge from 40% to 150%, causing condenser and evaporator clogging up to 30% and 60%, and also creating leakage in the compressor and fault detection and diagnosis is done with these parameters. In this paper, it is shown that a slight change in any of these parameters causes a change in the operation of the refrigeration cycle. In this study, Fault detection it was shown that the superheat value in refrigerant overcharge fault increasing to 16.5°C and in dirty condenser fault decreasing to 2.1°C and reduced evaporator air flow fault decreasing to 1.7°C. Also sub-cooling value in refrigerant undercharge, dirty condenser, reduced evaporator air flow, compressor failure fault decreasing to 4.2°C, 12.6°C, 12.8°C, 10°C.

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1. Introduction

Air conditioning and refrigeration play an important role in energy consumption and economics. In 2015, the department of energy estimates that about 25% of used energy in buildings is consumed in the air conditioning and refrigeration [1]. On the other hand, incorrectly maintenance of refrigeration systems and its failures can impose a high cost of repairs [2]. One of the methods for fault detection in refrigeration systems is to check the changes of the main parameters and compare them with standard conditions. The existence of the fault in the part of the cycle has changed the other parameters and changes the Coefficient Of Performance (COP). Having information on the parameters of the refrigeration cycle helps to identify the fault. The use of Fault Detection and Diagnosis (FDD) is evaluated to reduce energy costs and the cost of repairs and prevents long-term damages to the device. It also increases the reliability of the refrigeration system for places where the cooling system is important (such as server rooms).

Stylianou and Nikanpour [3], investigate the defect diagnosis in a reciprocating chiller and performance monitoring is done. Rossi and Braun [4], stated that by measuring the refrigeration temperatures in rooftop air-conditioning systems, five common faults were identified. Braun [5], states that condenser clogging and refrigerant deficiency can be detected by measuring thermodynamic changes. Han et al. [6], study of fault (flaw- defect) detection with the FDD method in compression refrigeration systems. Janecke et al. [7], static and dynamic fault detection methods for transcritical refrigeration. This analysis showed that although the use of the dynamic FDD method can be useful, the increase in the number of sensors is limited and will increase costs. Choi and Kim [8], excessive charge or lack of charge affects the capacity and cycle efficiency greatly. Holder [9], presents a table that shows the relationship between sub-cooling values for different outdoor temperatures and indoor wet-bulb temperatures. Siegel [10], Assessing the amount of charge and fault (flaw- defect) detection using the superheat measurement method with three different methods. Castro [11], tested a 12 ton air-cooled chiller with a constant speed, reciprocating compressor. In a research through study of “liquid to liquid chiller of 4.0 kW nominal cooling capacity with a reciprocating compressor and R404a refrigerant” has been proved that the highest COP in the refrigeration cycle occurs at a time when the charge rate of gas without any reduction or increase is in the appropriate amount, and the reduction or increase of gas charge has a direct effect on the change of COP (Fig. 1) [12].

Wang et al. [13], study of enhanced chiller fault detection using bayesian network and principal component

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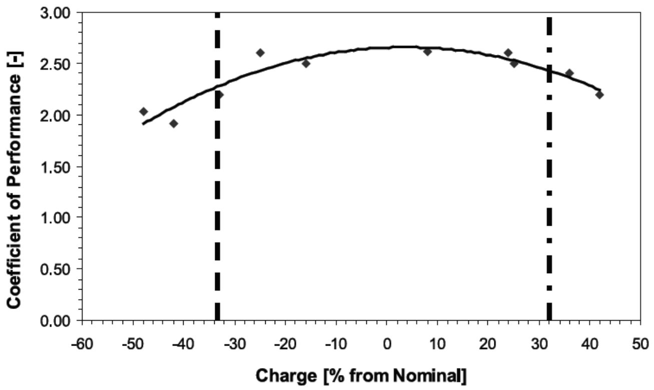


Fig. 1. Diagram of the gas charge effect on the Coefficient of performance [12].

analysis. Bogdanovská et al. [14], study of failure analysis of condensing units for refrigerators with refrigerant R134a, R404A. In a research, study of a Variable Refrigerant Flow (VRF) charge fault diagnosis method based on expert modification C5.0 decision tree [15]. Mao et al. [16], study of chiller sensor fault detection based on empirical mode decomposition threshold denoising and principal component analysis. Liu et al. [17], knowledge discovery of data-driven-based fault diagnostics for building energy systems: a case study of the building variable refrigerant flow system. Wang et al. [18], a practical chiller fault diagnosis method based on discrete bayesian network.

In this study, fault detection in compression refrigeration system with a fixed orifice and rotary compressor as a Room Air Conditioning (RAC), with the algorithm obtained. This algorithm has not been studied)with the conditions mentioned such as fixed orifice, rotary compressor and room air conditioning(in any of the previous articles. also, the use of this algorithm, which leads to defect determination, is presented in this article.

The fault which has arisen in the refrigeration system are divided into two major categories:

1- The fault that cause the refrigeration cycle to stop, such as the burning of the compressor or the failures of the electrical circuit of the system.

2- Fault that cause long-term problems in the refrigeration cycle and reduce the coefficient of performance of the refrigeration cycle, such as decreasing or increasing the charge of refrigerant or condenser and evaporator.

This paper reviews the second-order defects in fixed orifice systems. In case of fault, in order to solve the category of fault, a technician's presence is necessary to repair and check the condition of the refrigeration system.

2. Methodology

Superheat is a measured value, it is the difference between two temperatures. Superheat is measured as the difference between the actual temperature of the refrigerant vapor and the saturation temperature of the refrigerant at that same point. Superheat on the system's low side can be divided into two types: evaporator superheat and compressor superheat. For measuring the evaporator superheat, we need two parameters, suction line temperature and suction line pressure.

Start the refrigeration system and run it for at least 6 minutes to establish steady-state temperatures and pressure [19]. Connect the refrigerant manifold gauges to the suction line between the evaporator and the compressor. Connect the thermometer to the suction line near the suction service valve. Measure the suction line pressure using the refrigerant pressure gauge. Record this pressure and the suction line temperature from the thermometer. Use the refrigerant temperature/pressure chart to convert the pressure gauge reading to evaporator saturation temperature. According to Eq. (1), this difference is the evaporator superheat. Suction superheat is presented in Fig. 2, line 1-1`.

$$T_e - T_{@psat} = T_{sh} \tag{1}$$

Adequate superheat can cause liquid refrigerant to return to the compressor, resulting in compressor damage. Incorrect superheat can also indicate improper refrigerant charge and a dirty condenser coil. A low charge will give a high superheat. An overcharge will give a low superheat along with a higher compression ratio.

In the system's condenser, conversion of vapor to liquid involves removing heat from the refrigerant at its saturation condensing temperature. Any additional temperature decrease is called sub-cooling. For measuring sub-cooling, we have two parameters, condenser discharge temperature and condenser pressure.

Run the refrigeration system to establish steady-state temperatures. Connect the refrigerant manifold gauges to the discharge service valve, and connect the thermometer to the refrigerant line after the discharge of the condenser. Measure the condenser pressure at the service valve by reading the pressure on the refrigerant manifold gauges. Read the temperature on the thermometer. Use the refrigerant pressure/temperature chart to convert the pressure to the condenser

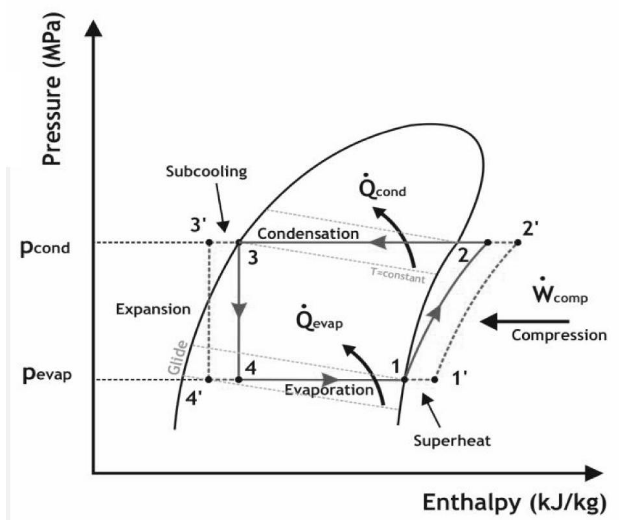


Fig. 2. Refrigeration cycle on the p-h diagram.
1-1` suction Superheat, 3-3` sub-cooling, point 1: saturated vapor point of point 1`, point 1`: suction, point 2`: discharge, point 3: saturated liquid of point 3`, point 3`: subcooled liquid at the expansion valve, point 4`: evaporator input.

saturation temperature. According to Eq. (2), this difference is the sub-cooling of the system. Sub-cooling is presented in Fig. 2, line 3-3`.

$$T_{@psat} - T_c = T_{sc} \quad (2)$$

This is the amount of sub-cooling, Inadequate sub-cooling can result from a variety of problems, including inadequate airflow over the condenser and insufficient refrigerant charge.

3. Experiments

This paper is based on a test facility consisting of an Air cooled split unit of 2.64 kW nominal cooling capacity and 530 grams with R22 refrigerant. The split unit with a hermetic rotary compressor and the type of condenser and evaporator is tube and fins and a capillary tube for expansion device. Circulation air flow of evaporator fan is 480 m3/h, Fig. 3) a). A schematic diagram of the Split unit system, including instrumentation points, is shown in Figs. 3(b) and 3(c). According to Fig. 3, the vapor is compressed at approximately constant entropy and exits the compressor superheated.

In accordance with Table 1, the temperature and pressure at different points in the refrigeration cycle are measured (Fig. 3). Different conditions are simulated in accordance with Table 2 and numbers are recorded to allow fault analysis. During the measurement, it should be taken into account that read data is recorded in the steady state.

Table 1. Description parameters measurement in the cycle.

Parameters	Description
T1	Compressor Suction Temperature
T2	Compressor Discharge Temperature
T3	Condenser Discharge Temperature
T4	Liquid line Outlet Temperature
T5	Compressor Oil Temperature
T6	Air Inlet Condenser
T7	Air Outlet Condenser
T8	Inlet Evaporator
T9	Air Outlet Evaporator
P1	Compressor Suction Pressure
P2	Compressor Discharge Pressure

In this experiment, to measure the pressure using a sensor Hogller pressure transmitter, -1 to 25 bar is range of pressure measurement and output 4 to 20 milliampere. To measure the temperature using a Negative Temperature Coefficient (NTC) sensor are typically used in a range from −55°C to 200°C. Auto ranging ACcumulator (AC) digital clamp ammeter to measure current consumption.

3.1 Description fault

N: Normal, This parameter is a normal system work without any fault.

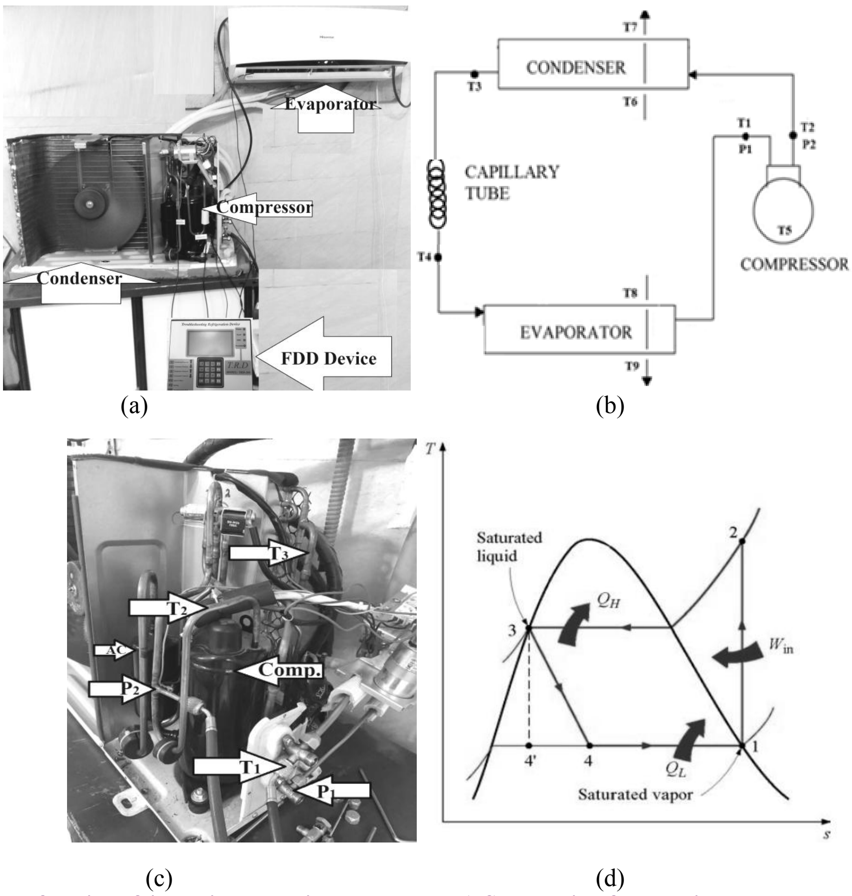


Fig. 3. Schematic diagram of basic refrigeration experimental setup. a) Schematic of the main components of the refrigeration cycle. b) Schematic location of temperature and pressure measurement in the cycle. c) Sensor location and measurement information. d) Refrigeration cycle on the T-S diagram.

Table 2. Description of studied faults.

Faults Type	Abbreviations	Simulation
System work without fault (Normal)	N	System work normally without fault
Refrigerant Undercharge	RU	Reducing the amount of gas at a specified rate
Refrigerant Overcharge	RO	Increasing the amount of gas at a specified rate
Dirty Condenser	DC	Blocking of air passage from the condenser by paper
Reduced Evaporator air Flow	REF	Decrease the air evaporator with paper
Compressor Failure	CF	Compressor suction and compression to each other

RU: Refrigeration Undercharge, when the refrigerated gas is injected to the device less than the required amount. In this case, the device's superheating will increase and the pressure of compressor suction will be less than the required amount. In this test, we calculate the parameters in different modes with 40%, 30%, 20% and 10% decrease in refrigerant charge.

RO: Refrigeration Overcharge, when the refrigerant is charged more than the required amount. In this case, the superheat is reduced and the possibility of entering the refrigerant fluid to the compressor increases. The pressure of compressor suction should also be increased. In this test, we calculate the parameters in different modes with 50%, 40%, 30 %, 20% and 10% increase in refrigerant charge. Dirty DC and clogging of condenser occur due to dust when part of the condenser surface is dislodged and prevents the exchange of heat between the evaporator and the environment. In this case, due to the lack of cooling of the condenser, the efficiency of the refrigeration cycle is greatly reduced.

REF: Reduced evaporator air flow, when the dust and sediment cause an obstruction on the evaporator surface, a decrease occurs in the flow of water or air from the evaporator or the flow of the fan is lower than the limited amount.

CF: Compressor failure, Compressor failure due to gas leakage from compressor valves, which does not condense part of the refrigerant gas at the compression stage through internal leakage and reduce compressor efficiency.

4. Results and Discussion

In this test, for simulation of undercharging and overcharge refrigerant, the refrigerant charge is varied from 0.318 to 0.795 kg. Designed system charge of approximately 0.530 kg, representing a range between 40% undercharge and 50% overcharge conditions. For simulation of dirty condenser, blocking of air passage from the condenser by paper. For simulation of reduced evaporator air flow, Blocking of air passage from the evaporator by paper. The obtained data from this test are recorded in accordance with Table 3.

According to Fig. 4 in the test, the lower refrigerant temperature relative to normal conditions increases the temperature of the compressor outlet pipe. The reason for this, it is because of the increase in the amount of superheated suction due to the decrease in the flow rate of the refrigerant passing through the evaporator, which has the direct effect on the compressor outlet superheat. This decreasing trend continues even with an increase of 20% of the refrigerant volume. However, as the gas charge increases, due to the increase of condensation pressure and compressor coil warming, the compressor outlet temperature increases. According to Fig. 5, this result is also confirmed by Tassou and Grace [12].

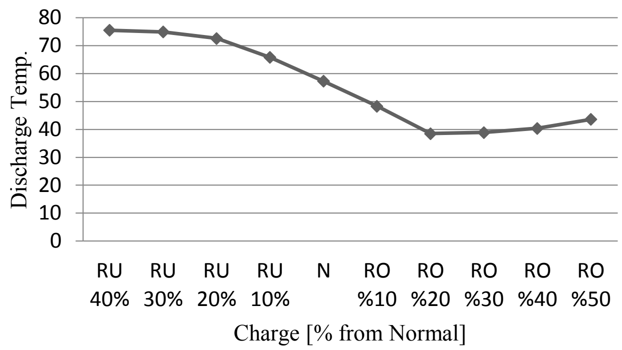


Fig. 4. The effect of refrigerant charge on compressor discharge temperature (oC).

As shown in Fig. 6, with a decrease in the amount of refrigerant, superheat is strongly increased and in normal conditions, the amount of superheat in this system is about 3-6 ° C. The increase in the superheat is due to a decrease in the amount of injected liquid refrigerant into the evaporator,

Table 3. Obtained data from the experiment.

Faults	*Pe* [psi]	*Pc* [psi]	*ΔT*[ºC]	*T1* [ºC]	*T2* [ºC]	*T3* [ºC]	*Amp.*	T_{sh} [ºC]	T_{sc} [ºC]
N	56	205	15	2.8	57.3	25.1	3.1	3.5	14.7
RU 40%	44	175	12.2	10.3	75.5	29.6	2.8	16.5	4.2
RO 50%	72	255	9.3	8.2	43.6	24.7	4.1	2.4	23.9
REF 60%	52	195	19.1	-0.7	50.7	25.1	2.9	1.7	12.8
DC 60%	66	290	12.3	5.6	67.6	41.5	3.9	2.1	12.6
CF	88	180	12.5	5.8	43.8	24.9	2.8	-	10

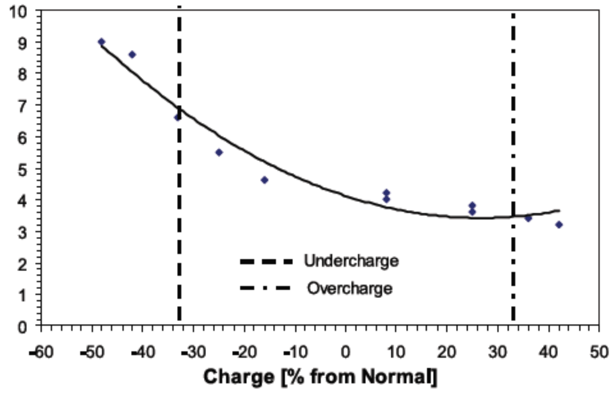


Fig. 5. The effect of refrigerant charge on compressor discharge temperature through study of "liquid to liquid chiller of 4.0 kW nominal cooling capacity with a reciprocating compressor and R404a refrigerant [12].

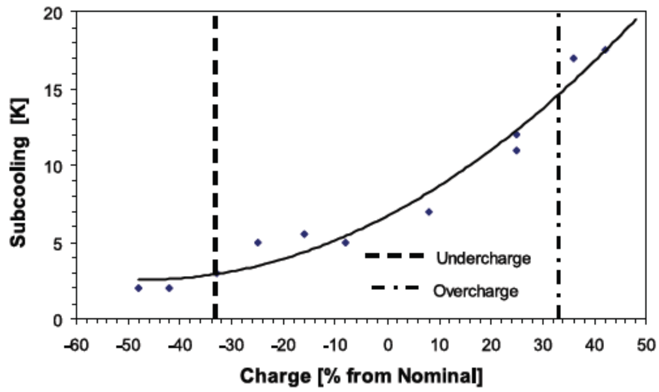


Fig. 8. The effect of refrigerant charge on compressor discharge temperature through study of "liquid to liquid chiller of 4.0 kW nominal cooling capacity with a reciprocating compressor and R404a refrigerant [12].

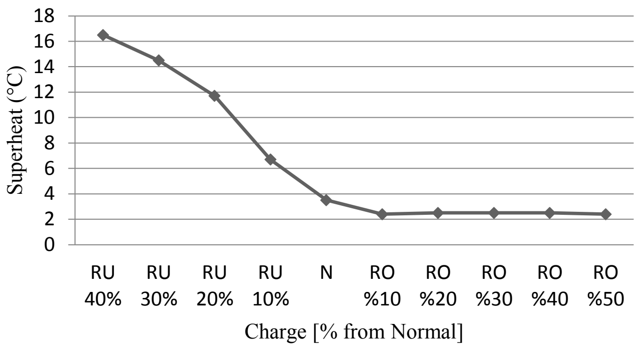


Fig. 6. The effect of refrigerant charge on evaporator superheat.

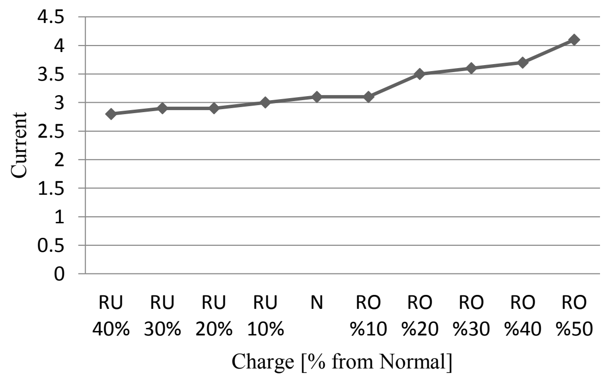


Fig. 9. Effect of refrigerant charge on consumed ampere

which leads to an increase in suction superheat and an increase in compressor outlet superheat and according to Fig. 1, there is a negative effect on the coefficient of performance. By increasing the refrigerant charge, there is no significant change in the amount of superheat. The number of subcooled increases with an increase in refrigerant charge and decreases with a decrease of refrigerant charge (Fig. 7). According to Fig. 8, this result is also confirmed by Tassou and Grace [12].

As shown in Fig. 9, electricity consumption increases due to an increase in the charge of refrigerant gas and it is reduced due to a shortage of refrigerant. The flow of refrigerant through the evaporator and the condenser is reduced by diminishing of refrigerant and ultimately leads to a decrease in the amount of heat absorption in the evaporator and COP reduction. Fig. 10 shows the amount of refrigerant charge has a great impact on the air temperature difference of the inlet and outlet. The maximum temperature difference is in the normal charging mode.

Also, in the study of the effect of the reduced evaporator air flow on the superheat, sub-cooling and Pressure Ratio (PR) parameters, according to Fig. 11, by decreasing the evaporator air flow, the amount of superheat decreases and the amount of subcooled is reduced. According to Fig. 11(c), the pressure ratio has slightly increased. By comparing the

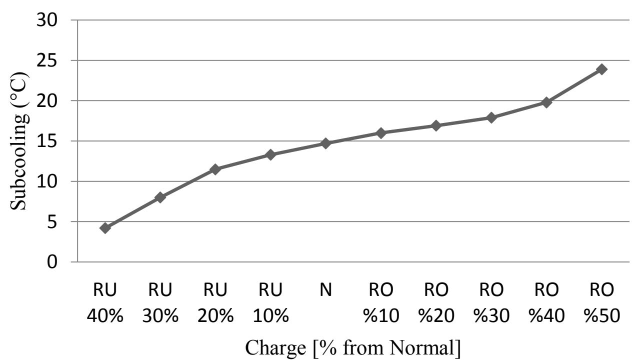


Fig. 7. The effect of refrigerant charge on the amount of subcooling.

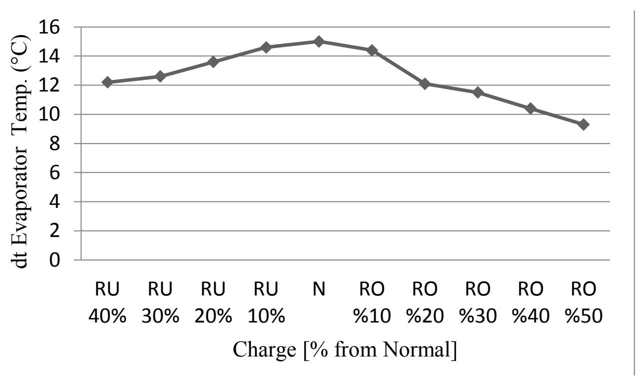
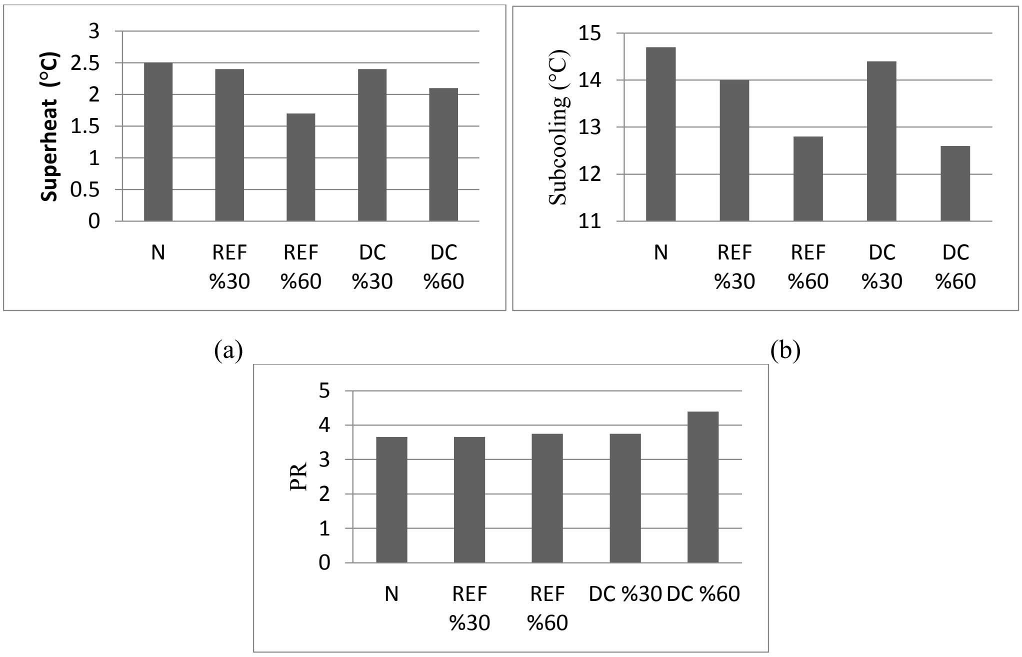


Fig. 10. Differences between inlet & outlet temperature of the evaporator.



(a) (b)

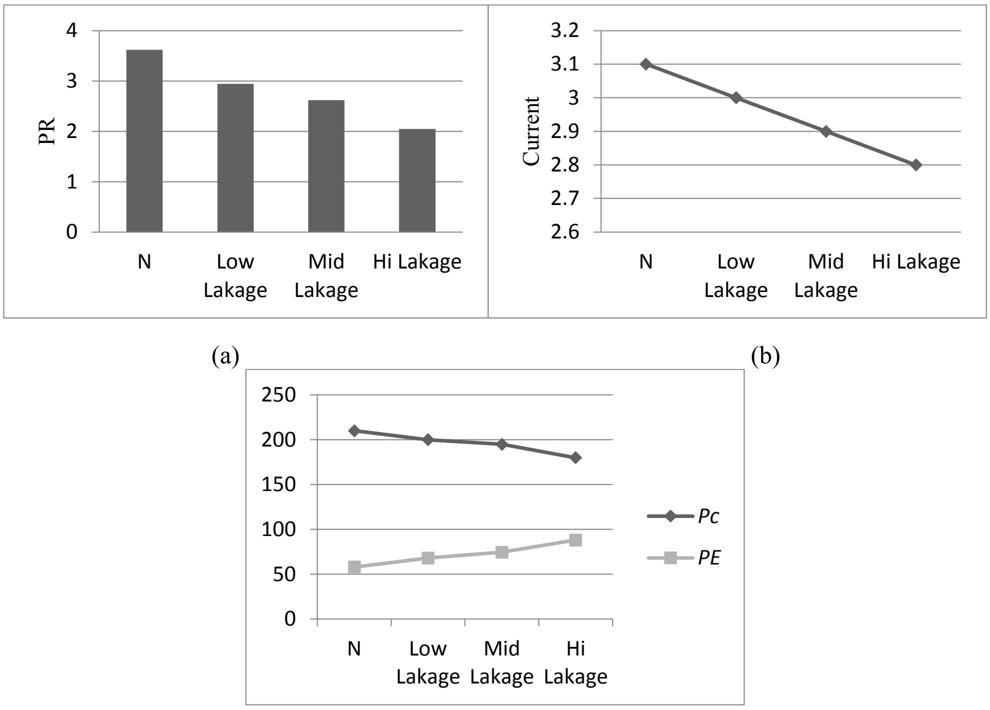
(c)

Fig. 11. a) Effect REF & DC fault in Superheat value. b) Effect REF & DC fault in Sub-cooling value. c) Effect REF & DC fault in PR value

conditions of the dirty condenser according to Fig. 11, it is observed that the superheat, sub-cooling are decreased and the pressure ratio is increased relative to the normal state.

Pressure ratio is the ratio of the gas pressure exiting the compressor to the gas pressure entering the compressor [20].

In order to simulate compressor failure, compressor suction and compression evacuation methods have been used. This defect is usually caused by leakage of the suction or evacuation valve and has an unpleasant effect on the operation of the refrigeration cycle. In this experiment, according to Fig. 12, it is shown that by increasing the refrigerant leakage rate, the pressure ratio decreases and the consumed power by



(a) (b)

(c)

Fig. 12. a) Effect compressor failure in PR value. b) Effect compressor failure in Current value. c) Effect compressor failure in Pe & Pc value.

Table 4. Change in any of parameters in the faults.

Fault	Cheng Parameters					
	P_e	P_c	T_{sh}	T_{sc}	T_{dt}	Current
N	N	N	N	N	N	N
RU	--	--	++	--	--	--
RO	++	++	=	++	--	++
DC	++	++	-	--	--	++
REF	-	-	--	--	--	-
CF	++	--	0	--	--	--

the device is reduced (Fig. 12(b)). Also in this situation, the pressure of the evaporator (Pe) increases and the pressure of the condenser (Pc) is decreased.

The results of this laboratory work for an air-cooled split unit of 2.64 kW nominal cooling capacity are obtained in accordance with Table 4. In this table, (N) represents normal conditions, (-) representing a slight decrease, (--) indicating a significant decrease, (+) indicating a slight increase, (++) represents a high increase, (0) indicating unknown state.

The validity of the results from the modeling was confirmed by previous work on healthy. For the validation of the FDD algorithm, the experimental data in Kim and Kim [21] were utilized. The six single-fault cases–compressor leakage, improper outdoor (OD) air flow rate, improper indoor (ID) air flow rate, liquid-line restriction, refrigerant undercharge, and refrigerant overcharge–were tested. Tested a water-to-water heat pump system with an Electronic Expansion Valve (EEV) driven by an open-type variable-speed compressor. Depending on the cooling load, the compressor was operated in two modes, variable speed or constant speed. The authors provided two separate rule-based charts depending on the operating mode accordance with Table 5.

Table 5. Water-to-water heat pump with an EEV and variable-speed compressor [21].

Fault	T_{sh}	T_{sc}	T_{dt}	Current
Refrigerant leakage	--	--	0	--
Condenser fault	0	--	0	++
Evaporator fault	0	++	0	-

In this paper Kocyigit et al. [2] tested a hermetic reciprocating compressor, a finned type air cooled condenser, an automatic expansion valve and a unit type evaporator, The system was charged with 600 g of R134a. The compressor has a swept volume of 7.95 cm3 rev_1 and it has an average speed of 2800 rpm.

Table 7. Measurement uncertainties

Measurement	Range	Uncertainty at the 95 % Confidence Level
Temperature Difference	0 - 28 °C	±0.3°C
Refrigerant Mass Flow Rate	0 -544 kg/h	±1.0 %
Low Pressure Difference	0 - 90 psi	±1 psi
High Pressure Difference	100 -300 psi	±1 psi
Suction Superheat Value	0 - 20 °C	±0.5 °C
Subcooling Superheat Value	0 - 30 °C	±0.5 °C

Swept volume is the volume displaced by the piston during its compressor motion inside the cylinder. The volume swept over the unit of a compressor work cycle is shown by cm3 rev_1.

Tables 7 and 8 lists uncertainties of the major quantities measured during this work. Table 7 illustrate the amount of uncertainty at the 95% confidence level of Measurement and Table 8 illustrate uncertainty of sensors.

5. Conclusions

The failure of the refrigeration equipment always challenges the utility set. For example, a cooling system that serves the cooling of telecommunications systems, in the event of an interruption in operation or occurrence of any form of bug, it could inflict irreparable damage to the telecommunication equipment. In the compressed air cooling system of offices, in case of shutdown and change in system performance, employee's comfort conditions are affected. In many cases, the failure of the device with the presented method in this article can be predicted for several hours or even several days ago and, with the troubleshooting of the fault, it avoids major breakdowns. In many cases, a small defect does not cause the device to fail in the short term, but it will reduce the capacity of the device or increase the power consumption of the device. The use of this fault diagnostic method can be used in all compression refrigeration system such as air condenser chillers, gas coolers, air conditioners, Direct Expansion (DX) coil air conditioners with a fixed orifice expansion device which is used in buildings.

In this study it was shown that the superheat value increasing in RU fault and decreases in DC and REF fault. Also sub-cooling value decreases in RU, DC, REF and CF fault and increasing in RO fault. lower refrigerant temperature relative to normal conditions increases the temperature of the compressor outlet pipe and with a decrease in the amount of refrigerant, superheat is strongly increased and

Table 6. Air cooled condenser, an automatic expansion valve whit reciprocating compressor [2].

Fault	P_e	P_c	T_{sh}	T_{sc}
Compressor failure-doesn't work	very high	very low	no value	no value
Restricted filter-drier	partially low	partially low	high	partially high
Restricted automatic expansion valve	very low	partially low	very high	no value
Compressor valve leakage	high	low	low	partially low
Refrigerant undercharge	very low	low	very high	very high
Refrigerant overcharge	high	partially high	very low	high
Dirty condenser	partially high	very high	high	partially high
Evaporator fan failure	low	very low	very low	low

Table 8. Uncertainty of sensors

Measurement	Range	Uncertainty at the 95 % Confidence Level	Condition
Temperature Meter with Remote Temp Sensor Thermometer	-50°C to + 110°C	±0.1°C	humidity:5% ~ 80% Distinguishing temperature: 0.1°C
digital clamp meter	0 to 600.0/1000A	±2.0%rdg±5dgt (50/60Hz) ±3.5%rdg±5dgt (40 – 500Hz)	read current up to 1000A AC/DC
Pressure Sensor	40 bar (580.15 psi) 0 bar (0 psi)	±1 psi	Process temperature: -25 °C to 125 °C
Scales	0 – 50 kg	50 g	-

in normal conditions. By increasing the refrigerant charge, there is a negative effect on the coefficient of performance. Electricity consumption increases due to an increase in the charge of refrigerant gas and it is reduced due to a leak of refrigerant. By decreasing the evaporator air flow, the amount of superheat value decreases and the amount of sub-cooling value is reduced and pressure ratio has slightly increased. By comparing the conditions of the dirty condenser, it is observed that the superheat, sub-cooling value are decreased and the pressure ratio is increased relative to the normal state.

Nomenclature

P_{sat}: Saturation Pressure
T_c: Temperature of condenser
T_e: Temperature of evaporator
T_{sh}: Superheat Temperature
T_{sc}: Sub-cooling Temperature
W_{comp} : Compressor Power
Q_{cond} : Condenser Heat Reject
Q_{evap} : Evaporator Heat absorb
T: Temperature

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