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The Effect of Thermostat Faults on Vehicle Engine Performance

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ABSTRACT: The aim of this research is to diagnose the condition and performance of the engine if the thermostat valve is damaged (completely closed or open) by measuring the temperatures of the cooling water and the water flow rate in the engine and comparing them with the temperature of the coolant as it exits the engine to the appropriate system (healthy condition). Laboratory tests were carried out on a four-stroke gasoline engine and a conventional cooling system for Hyundai Accent with a spark of 1300 cc. In addition to some parts and sensors used to obtain the required data from the cooling system and data analysis, adding a coolant flow meter between the coolant outlet and the engine block inlet, in addition to adding two coolant temperature sensors, the first detects the temperature of the coolant outlet the engine, and the second to detect coolant temperature between the outside of the radiator, and another sensor was used to record the engine speed, and all tests were conducted under different operating conditions, speed from 1000 to 2500 rpm, at different loads (25%, 35%, 45%) of the total load.

When the engine is running heavy duty at 2500 rpm at 45% load, the temperature of the healthy system is 64.33˚C and increases 74.89˚C, if the thermostat valve is damaged (completely closed) at a rate of 16%, and the coolant flow rate decreases by 80% compared to the performance of the cooling system in the proper condition because the thermostat valve (completely closed) prevents any coolant from passing into the radiator and this is because the engine is still running and the coolant absorbs The heat from around the combustion chambers and the coolant is unable to flow out of the engine and go to the radiator until it is cooled by radiation and then through the cooling fan to reach the operating temperature of the cooling fan, which is 88 ˚C. When the engine is running heavy duty at 2500 rpm, at 45% load, it was found that the temperature of the coolant when leaving the engine for the proper system is 83.92˚C and decreases to 78.61˚C, i.e. decreases by 6.33% in the event of a thermostat malfunction (always open), and the coolant flow rate increases by 21% compared to the performance of the cooling system in the proper condition because the thermostat valve is (fully open), and this is because the coolant is flowing through the radiator since the first moment of the test and is given A better chance of the coolant being cooled better and resulting in an increase in the time to reach the operating temperature of the engine and an increase in fuel consumption and an increase in emissions.

KEYWORDS: Internal combustion engine, preventive and corrective maintenance, durability and reliability, heat exchanger.

I. INTRODUCTION

During the operation of automotive internal combustion engine at full throttle, found that the operating temperature can reach to 2700˚C for combustion gasses. Most engine's material is not able to sustain this high temperature and could fail if the engine components are not properly cooled. Overheating the engine can cause lubrication to breakdown, oil to thin, engine moving parts to be damaged and engine parts to expands. So, removing heat from the engine is very important for proper operation of internal combustion engine. Most of the engine's heat dissipate by convection to the ambient air [1,2]. The cooling radiator is kind if heat exchanger and

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important component in the automotive cooling system. Its main function is moving the excessive heat from the engine to the ambient air, which guarantee reliable operation of the internal combustion engine [3-5]. Condition monitoring aims to avoid unplanned equipment breakdown, decrease associated hazard and make the most of the plant availability [6]. One of the most useful parameters is temperature to indicate the structural health of the equipment. Therefore, coolant temperature monitoring of the equipment or processes has been specified as one of the best predictive maintenance techniques [7]. Researchers present that 50% of vehicle failure is account from engine failure, and cooling system faults accounts for around 50% of engine failure [8]. Automotive Cooling system faults are divided into 5 categories: thermostat fault, fan fault, lack of coolant, radiator clogged in, and pump fault. Mathematical model of each element is settled, judgment basis is given and design fault diagnosis algorithm [9]. Engine is coupled system between electrical and mechanical systems, all controls are optimized to achieve best energy management and conversion. Cooling system one of the important ways for engine thermal management and the cooling fan is the core component of the cooling system [10]. There are many methods for cooling fault diagnosis, physical model-based method and data-driven method are the main fault diagnosis for cooling systems [11-13].

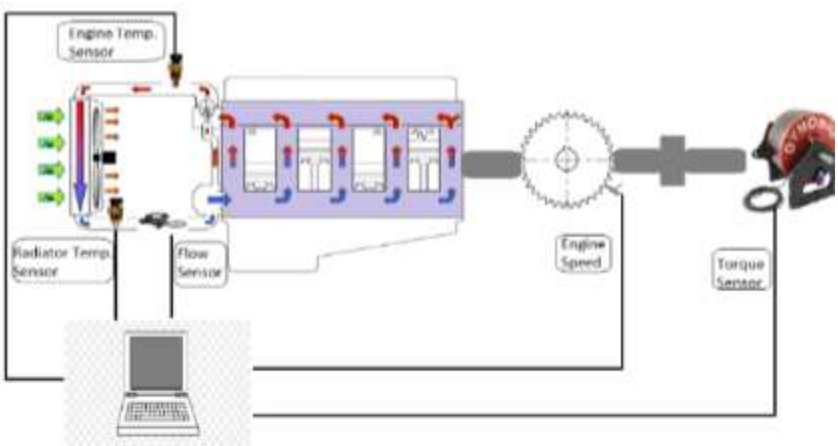

Figure (1): Schematic Diagram of the test rig and Instrumentations

Nemati established different models for different components, gave the judgment according to fault conditions and designed the diagnostic algorithm, which present good diagnostic results [14]. We used the difference between the actual and the model coolant temperature to accurately diagnose thermostat fault in the cooling system [15]. Liet al. used for fault detection of chillers the Beyesian nonlinear estimation, which has good fault diagnosis and classification effect and good robustness [16]. Zhanet al. used a fuzzy SVM algorithm as fault diagnosis method for refrigerator system, which can effectively separate fuzzy information and can map data to high dimension by karnel function [17]. If the state of the working engine can be accurately diagnosis in time, determined the fault position without disassembling the engine. It will effectively enhance the security and reliability for the automotive engines. During the engine running, its signals of impulsion, noise and vibration contains abundant information for the faults, which can present the real-time running states of the engine and it consider as important source of information for fault diagnosis [18,19].

- **TEST RIG DESCRIBTION**

Fig. (1) represent the schematic diagram of the test rig and Instrumentations, which contain the conventional cooling system of Hyundai Accent has been used in these studies, but we add some parts and sensors which help us to get the required data from the cooling system and analyse the data.

The coolant flow meter was used in the hosing between the radiator outlet and the engine block inlet, and two coolant temperature sensors (NTC type) was used which one is in the thermostat hosing to detect the coolant temperature as the engine temperature and another coolant temperature sensor is in the hosing between the radiator outlet and the engine block inlet to detect the coolant temperature as the radiator temperature and added pulley and speed sensor between the flywheel and dynamometer to detect and record the

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engine speed. The engine Specifications of Hyundai Accent, which is four stoke spark ignition, internal combustion engine with dual drive cam shaft, as showed in Table (1).

Table (1): IC Engine Technical Specifications

Swept Volume	1300 CC
Cylinder Array	In line 4 Cylinders
Valves Per Chamber	3 Valves
Compression Ratio	10:1
Cylinder Bore	71.5 mm
Cylinder Stroke	83.5 mm
Max. Torque	110 N.m @ 3000 rpm
Max. output Power	63 KW @ 5500 rpm

An electric constant cooling fan is used to create forced air flow through radiator pipes to increase the heat exchange between radiator and the ambient and decrease the coolant temperature inside the radiator pipes. The fan starts rotating at certain engine coolant operation temperature. The cooling system equipped with aluminium radiator core consists of a cross flow pipes and fins to submit the effect of the radiator is increasing the temperature emission to the ambient by the effect of air passing through the element and decrease the temperature of the coolant, the two coolant temperature sensors are used to measure the coolant temperature in two different locations, the first location at the thermostat hosing at the outlet path from the engine block to measure the engine coolant temperature and another location at the radiator hoses at the radiator outlet path to measure the radiator coolant temperature.

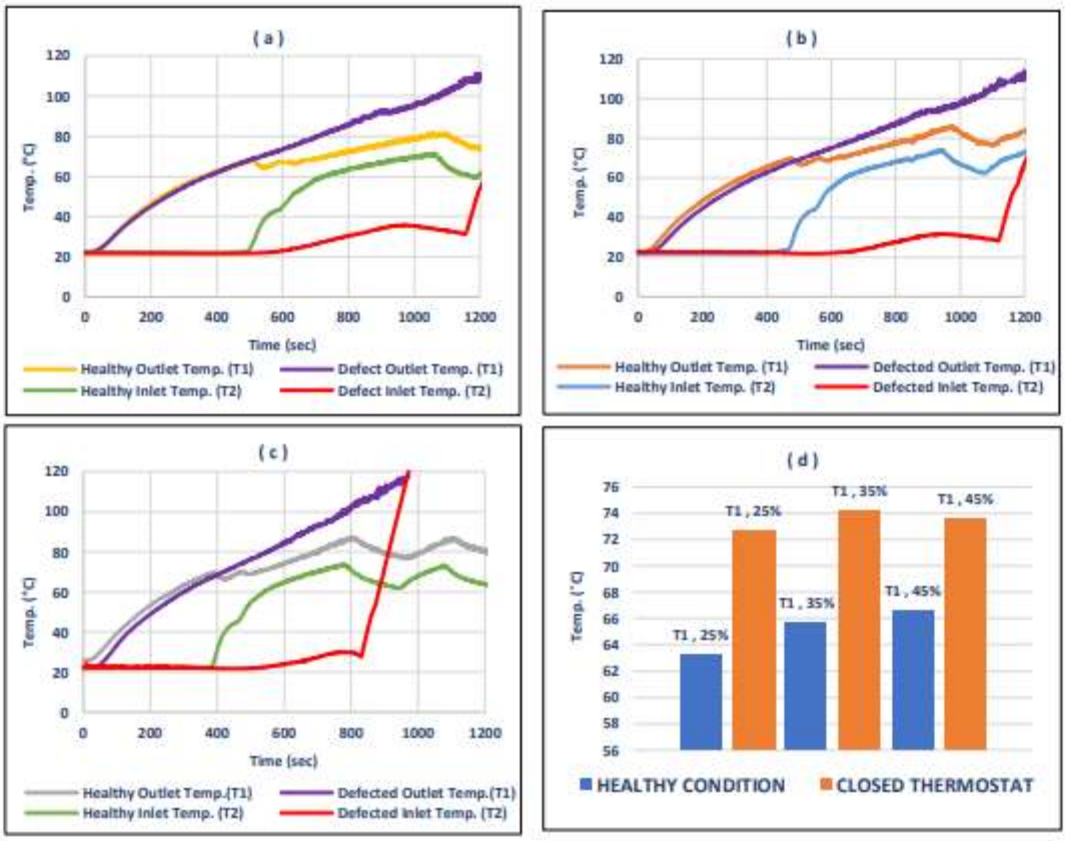

Figure (2): Engine coolant temperature behavior. (a) Engine coolant Temp. behavior at 1000 rpm and engine load 25%, (b) Engine coolant Temp. behavior at 1000 rpm and engine load 35%, (c) Engine coolant Temp. behavior at 1000 rpm and engine load 45%, (d) AVG for T1 at engine speed 1000 rpm and different loads (25%, 35% and 45%).

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Both of Coolant Temperature Sensors type were NTC. Dynamometer was used to load on the engine with different loads and run the engine under different loads and different Engine rpm.

II. EXPERMINTAL

Case One: Defected Thermostat (fully closed)

This experiment represents a simulation of the performance of the engine cooling system during thermostat malfunction (fully closed) by using a damaged thermostat valve and adjusting it so that it does not open at any temperature. Without any malfunctions in the system, by measuring the temperature of the coolant while it is leaving the engine and measuring the temperature of the coolant while it is exiting the radiator, in addition to measuring the coolant flow rate and through this comparison we can get indications that are used in diagnosing valve malfunctions thermostat

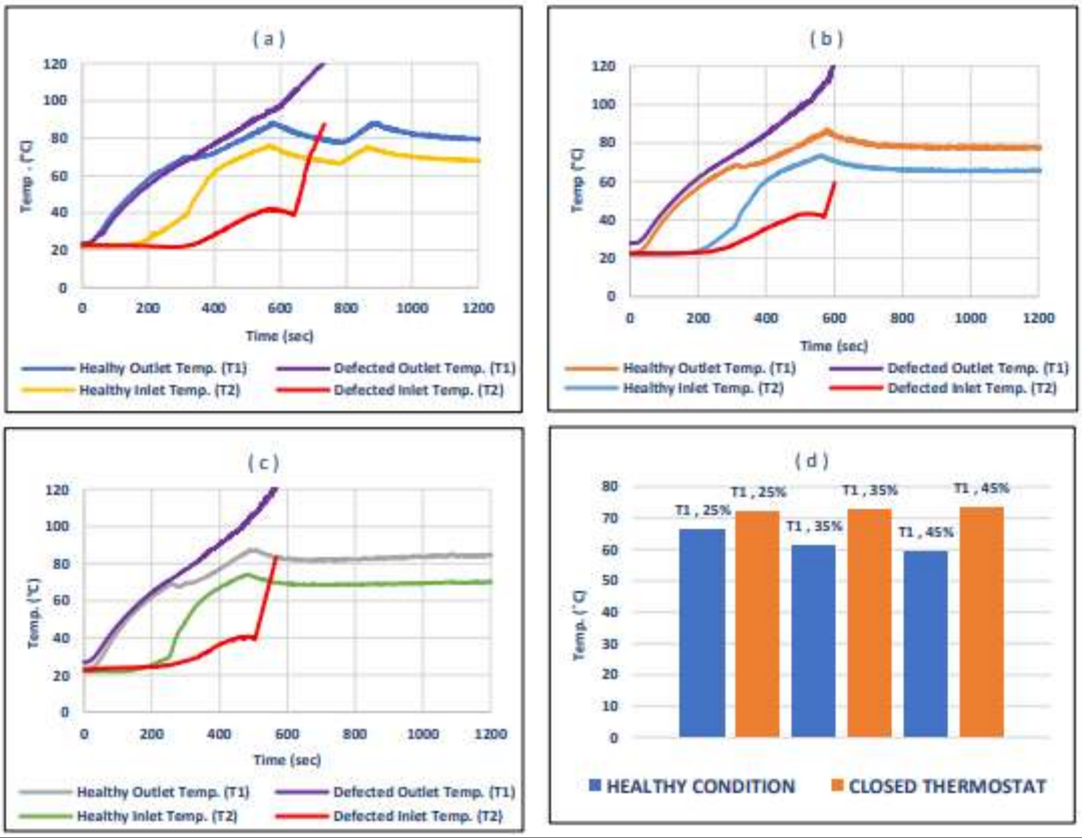

Figure (3): Engine coolant temperature behavior, (a) Engine coolant Temp. behavior at 2000 rpm and engine load 25%, (b) Engine coolant Temp. behavior at 2000 rpm and engine load 35%, (c) Engine coolant Temp. behavior at 2000 rpm and engine load 45%, (d) AVG for T1 at engine speed 2000 rpm and different loads (25%, 35% and 45%).

Coolant Temperature behaviour for 1000 rpm:

To measure the performance of the cooling system under the operating conditions of an engine of 1000 rpm and at a load of 25%, as shown in Figure (2.a), it was found that the average temperature of the coolant during its exit from the engine to the proper system is 63.22˚C and the temperature increases to 72.64˚C if the thermostat valve is damaged (completely closed) at a rate of 15%, and when the engine is running With a load of 35%, as shown in Figure (2.b), it was found that the average temperature of the coolant during its exit from the engine to the proper system was 65.66˚C and the temperature increased by 74.16˚C if the thermostat valve was damaged (completely closed) at a rate of 13%, and when the engine was running at a load of 45%, as shown in Figure (2.c), it was found that the average temperature of the coolant during Exit from the engine to the proper system 66.49˚C and 73.55˚C temperature increases in case the thermostat valve is damaged (completely closed) at a rate of 11% because the engine is still running and the coolant is still absorbing heat from around the combustion

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chambers and the coolant is unable to flow out of the engine and into the direction To the radiator until it is cooled by radiation and then through the cooling fan to reach the operating temperature of the cooling fan, which is 88˚C, and the temperature of the coolant increases while it is constantly leaving the engine and the cooling system becomes out of control. Figure (2.d) illustrate all ratios and rates of change in temperature under the same conditions of the operating conditions of an engine of 1000 rpm, and different loads (25%, 35% and 45%)

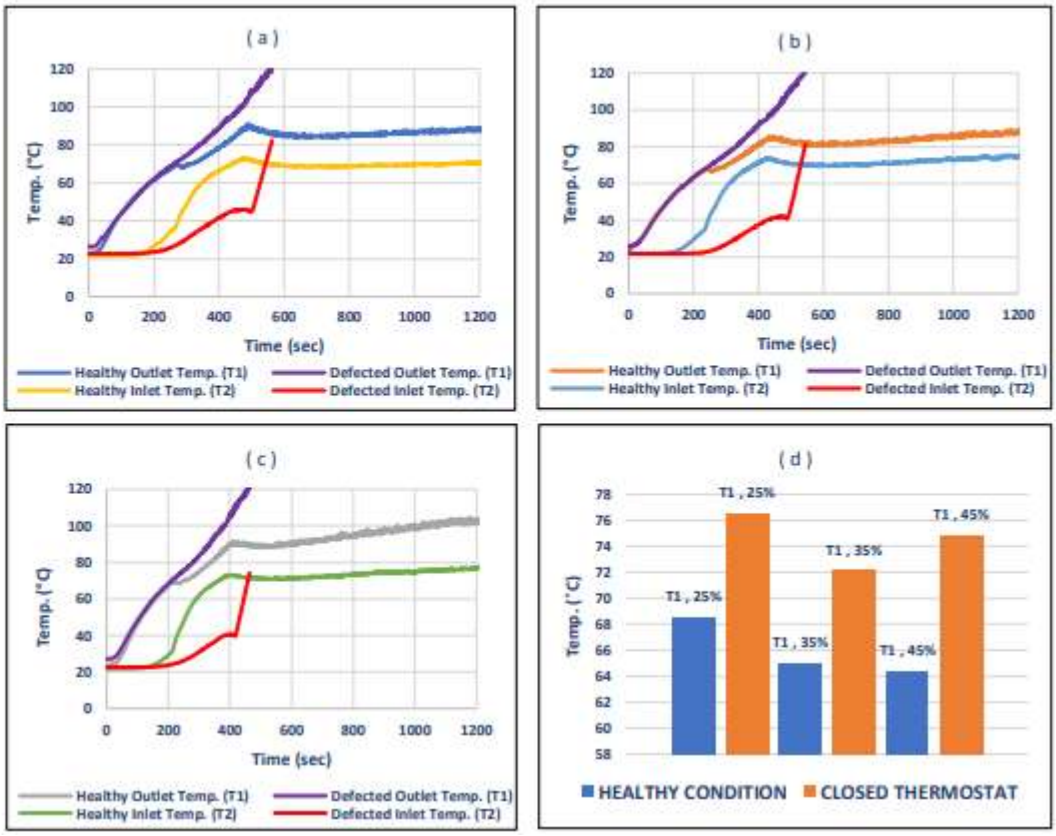

Figure (4): Engine coolant temperature behavior, (a) Engine coolant Temp. behavior at 2500 rpm and engine load 25%, (b) Engine coolant Temp. behavior at 2500 rpm and engine load 35%, (c) Engine coolant Temp. behavior at 2500 rpm and engine load 45%, (d) AVG for T1 at engine speed 2500 rpm and different loads (25%, 35% and 45%)

Coolant Temperature behaviour for 2000 rpm:

To measure the performance of the cooling system under the operating conditions of an engine of 2000 rpm and with a load of 25%, as shown in Figure (3.a), it was found that the average temperature of the coolant during its exit from the engine to the proper system is 66.27 ˚C and the temperature increases 72.0 ˚C if the thermostat valve is damaged (completely closed) at a rate of 9%, and when the engine is running With a load of 35%, as shown in Figure (3.b), it was found that the average temperature of the coolant during its exit from the engine for the proper system is 60.72˚C, and the temperature increases by 72.0˚C if the thermostat valve is damaged (completely closed) at a rate of 19%, and when the engine is running at a load of 45%, as shown in Figure (3.c), it was found that the average temperature of the coolant during Exit from the engine to the proper system 59.11˚C and 73.28˚C temperature increases if the thermostat valve is damaged (completely closed) at a rate of 24% and this is because the engine is still running and the coolant is still absorbing heat from around the combustion chambers and the coolant is unable to flow out of the engine and into the radiator until it is cooled by radiation and then by the cooling fan to reach the operating temperature of the cooling fan, which is 88 ˚C, and the temperature of the coolant increases while leaving the engine constantly and the cooling system becomes out of control. Figure (3.d) illustrate all ratios and rates of change in temperature under the same conditions of the operating conditions of an engine of 2000 rpm, and different loads (25%, 35% and 45%).

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Coolant Temperature behaviour for 2500 rpm:

Figure (4.a) showed the performance of the cooling system under the operating conditions of an engine of 2500 rpm and a load of 25%, it was found that the average temperature of the coolant during its exit from the engine to the proper system was 68.49˚C, and the temperature increased by 76.48˚C if the thermostat valve was damaged (completely closed) at a rate of 12%, and when the engine was running With a load of 35%, as shown in Figure (4.b), it was found that the average temperature of the coolant during its exit from the engine to the proper system was 65.05˚C, and the temperature increased by 72.14˚C if the thermostat valve was damaged (completely closed) at a rate of 11%, and when the engine was running at a load of 45%, as shown in Figure (4.c), it was found that the average temperature of the coolant during Exit from the engine for the proper system 64.33˚C and 74.89˚C temperature increases if the thermostat valve is damaged (completely closed) at a rate of 16%, and this is because the engine is still running and the coolant absorbs heat from around the combustion chambers and the coolant is unable to flow out of the engine and go to the radiator even It is cooled by radiation and then by the cooling fan to reach the operating temperature of the cooling fan, which is 88˚C, and the temperature of the coolant increases while leaving the engine constantly, and the cooling system becomes out of control. Figure (4.d) illustrate all ratios and rates of change in temperature under the same conditions of the operating conditions of an engine of 2500 rpm, and different loads (25%, 35% and 45%).

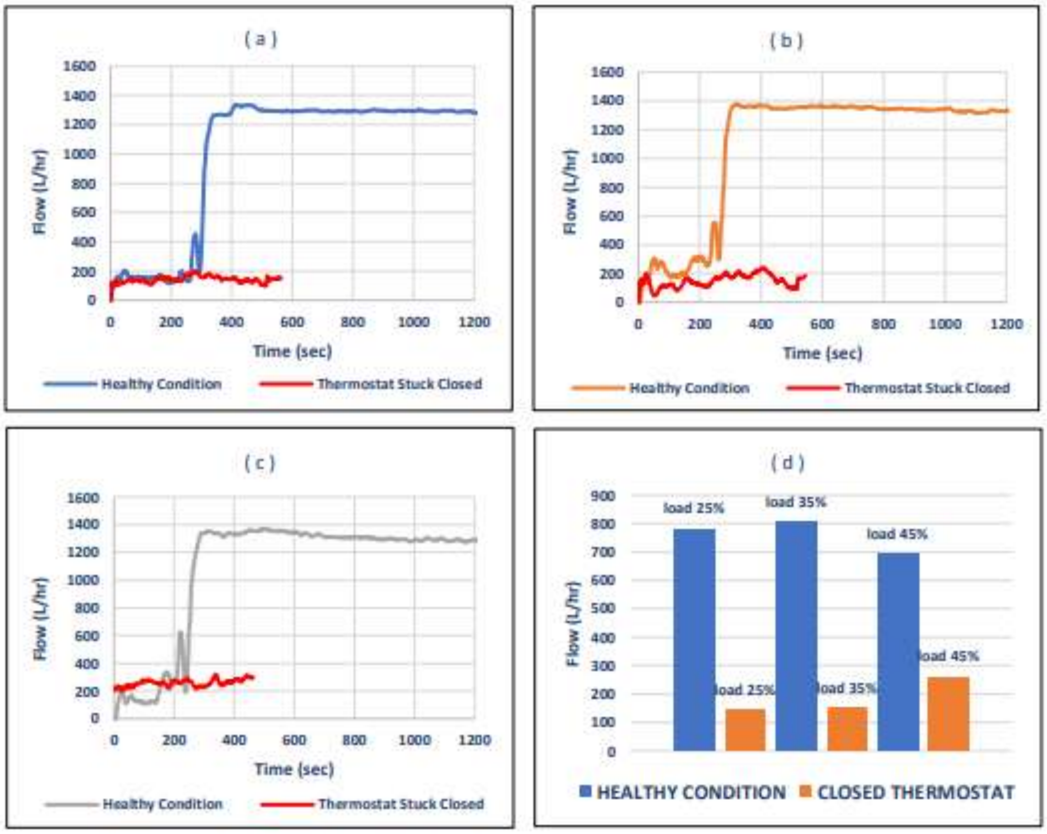

Figure (5): Engine coolant flow rate. (a) Engine coolant flow rate behavior at 2500 rpm and engine load 25%, (b) Engine coolant flow rate behavior at 2500 rpm and engine load 35%, (c) Engine coolant flow rate behavior at 2500 rpm and engine load 45%, (d) AVG for flow at engine speed 2500 rpm and different loads (25%, 35% and 45%)

Coolant flow behaviour for 2500 rpm:

Figure (5.a) shewed the coolant flow rate when the engine is running at a speed of 2500 rpm, and at a load of 25%, is reduced by 90% compared to the performance of the cooling system in the proper condition because the thermostat valve is (completely closed), and when the engine is running at a load of 35%, as shown in Figure (5.b), the coolant flow rate is reduced by 88 % compared to the performance of the cooling system in the proper condition because the thermostat valve is (completely closed), and when the engine is running at a load of 45%, as shown in Figure (5.c), the coolant flow rate decreases by 80% compared

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to the performance of the cooling system in the proper condition because the thermostat valve (completely closed) prevents the passage of any coolant To the radiator, even after the temperature of the coolant leaving the engine reaches a temperature of 70˚C, which is the theoretical opening point for the thermostat valve. Figure (5.d) illustrate all ratios and rates of change in coolant flow rate under the same conditions of the operating conditions of an engine of 2500 rpm, and different loads (25%, 35% and 45%).

Case Two: Defected thermostat (fully opened):

This experiment represents a simulation of the performance of the engine cooling system during a thermostat malfunction (always open) by removing the thermostat valve from the cooling system. By measuring the coolant temperature during its exit from the engine and by measuring the coolant temperature during its exit from the radiator, in addition to measuring the coolant flow rate. Through this comparison, we can obtain indications that are used in diagnosing thermostat valve malfunctions.

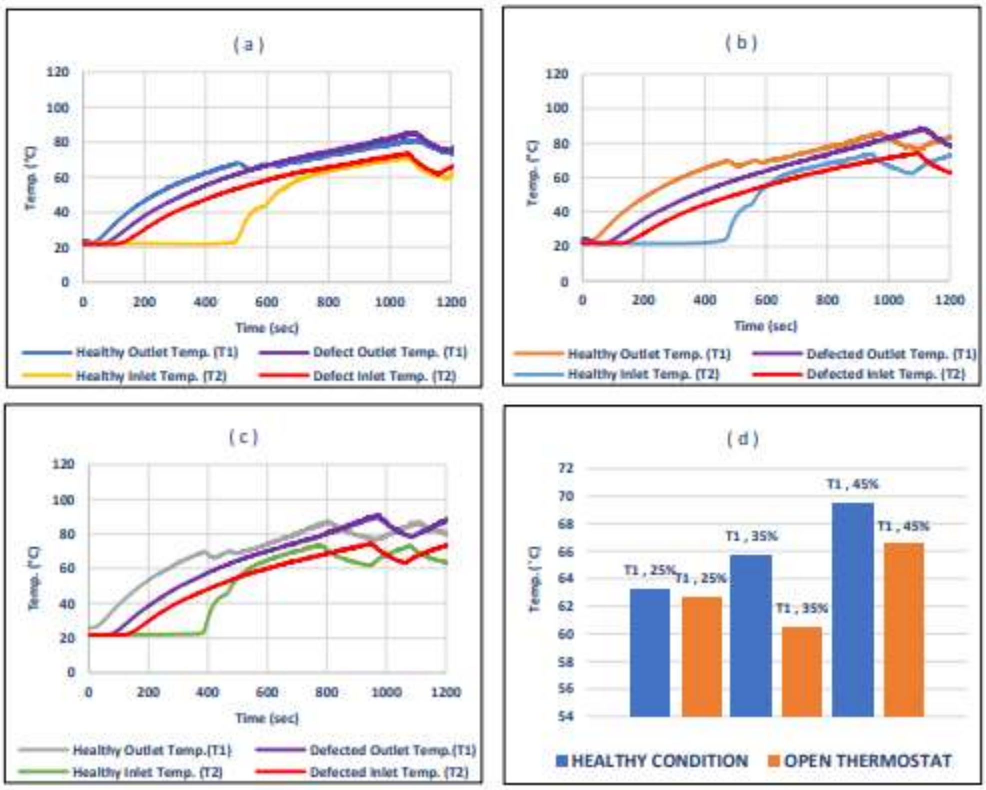

Figure (6): Engine coolant temperature behaviour. (a) Engine coolant Temp. behaviour at 1000 rpm and engine load 25%, (b) Engine coolant Temp. behaviour at 1000 rpm and engine load 35%, (c) Engine coolant Temp. behaviour at 1000 rpm and engine load 45%, (d) AVG for T1 at engine speed 1000 rpm and different loads (25%, 35% and 45%).

Coolant Temperature behaviour for 1000 rpm:

Figure (6.a) showed the performance of the cooling system under the operating conditions of a 1000 rpm engine and with a load of 25%, it was found that the temperature of the coolant during its exit from the engine to the proper system was 63.22˚C, and in the case of damage to the thermostat valve (fully opened) it decreased to 62.5˚C, meaning that the coolant in the healthy condition, the temperature of the coolant is greater than the temperature of the coolant in the event of a thermostat malfunction (always open) of 1.01%, the engine at a load of 35%, as shown in Figure (6.b), it was found that the temperature of the coolant in healthy system is 65.66˚C and decrease in case of damage to the thermostat valve (fully opened) is 60.47 ˚C, that is due to the coolant in the healthy condition is the higher temperature of the coolant in the event of a thermostat malfunction (always open) of 7.91%, and at load of 45%, as shown in Figure (6.c), it was found that the temperature of the coolant while leaving the engine for the proper system is 69.46˚C and drops to 66.47˚C,meaning that the coolant in the healthy condition higher than the temperature of the coolant in the case of the thermostat malfunction

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(always open) of 4.3%, and this is due to the coolant is flowing through the radiator from the first moment of the test and gives a better chance for the coolant a It is cooled better and results in an increase in the time to reach the operating temperature of the engine and an increase in fuel consumption and an increase in the proportion of emissions. Figure (6.d) illustrate all ratios and rates of change in temperature under the same conditions of the operating conditions of an engine of 1000 rpm, and different loads (25%, 35% and 45%).

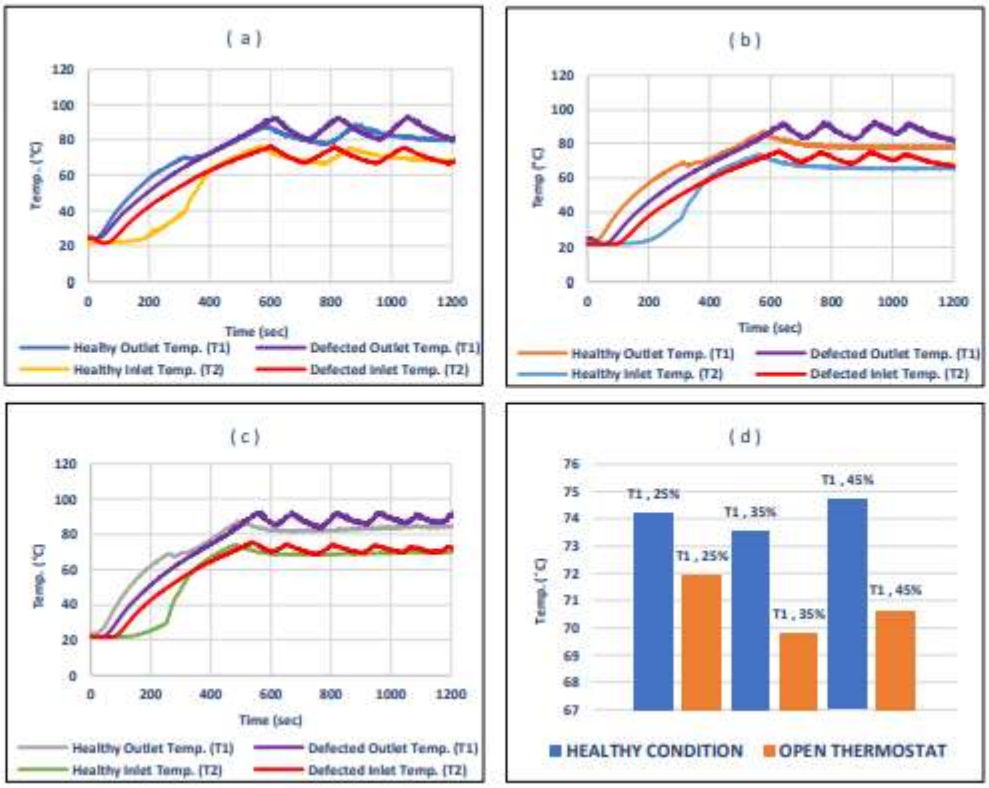

Figure (7): Engine coolant temperature behaviour, (a) Engine coolant Temp. behaviour at 2000 rpm and engine load 25%, (b) Engine coolant Temp. behaviour at 2000 rpm and engine load 35%, (c) Engine coolant Temp. behaviour at 2000 rpm and engine load 45%, (d) AVG for T1 at engine speed 2000 rpm and different loads (25%, 35% and 45%).

Coolant Temperature behaviour for 2000 rpm:

Figure (7.a) showed that the performance of the cooling system under the operating conditions of an engine of 2000 rpm and with a load of 25%, it was found that the temperature of the coolant during its exit from the engine to the healthy condition is 74.22˚C, and in the event of damage to the thermostat valve (fully opened) it drops to 71.95˚C, meaning that the coolant is in healthy condition, the temperature is higher than of the coolant in the case of thermostat malfunction (always open) of 3.07%, when the engine at a load of 35%, as shown in Figure (7.b), it was found that the temperature of the coolant in healthy system is 73.55˚C and decrease in case of damage to the thermostat valve (fully opened) is 69.80˚C, that is due to the coolant in the healthy condition is the higher temperature of the coolant in the event of a thermostat malfunction (always open) of 5.1%,and when the engine at a load of 45%, as shown in Figure (7.c), it was found that the temperature of the coolant while leaving the engine for the proper system is 74.71˚C and drops to 70.64˚C, meaning that the coolant temperature in the healthy condition is higher than the temperature of the coolant in the event of a thermostat failure (always open) of 5.45%, and this is due to the coolant is flowing through the radiator from the first moment of the test and gives a better chance for the coolant that it is cooled better and entails an increase in the time to reach the operating temperature of the engine and an increase in fuel consumption and an increase in the percentage of emissions. Figure (7.d) illustrate all ratios and rates of change in

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temperature under the same conditions of the operating conditions of an engine of 2000 rpm, and different loads (25%, 35% and 45%).

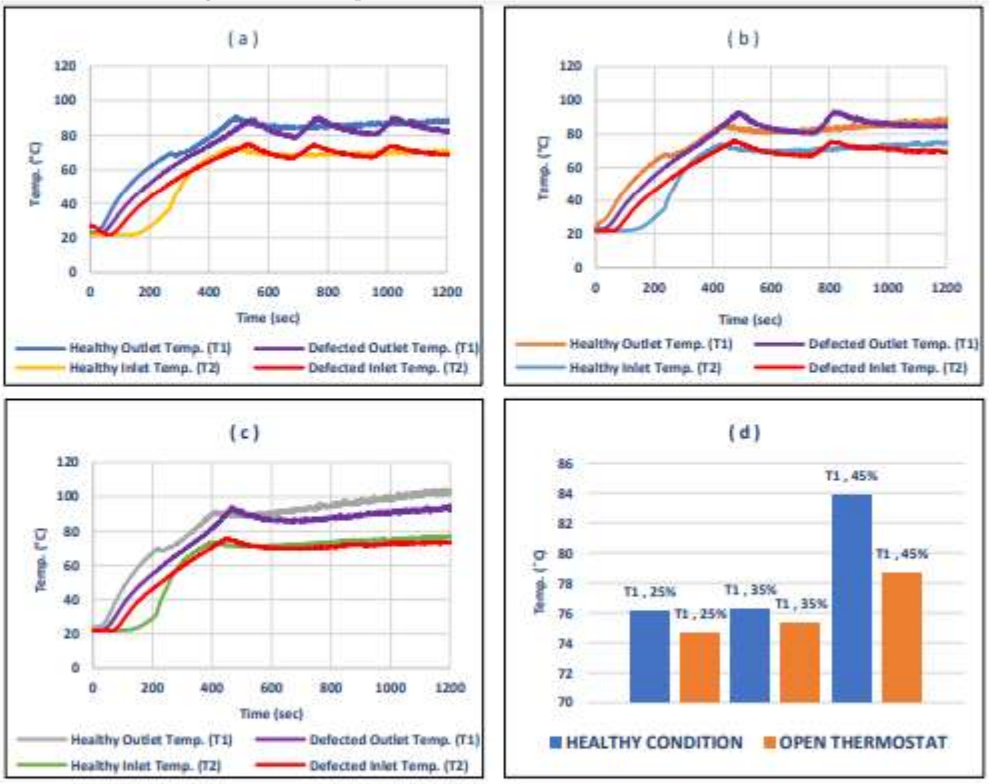

Figure (8): Engine coolant temperature behaviour, (a) Engine coolant Temp. behaviour at 2500 rpm and engine load 25%, (b) Engine coolant Temp. behaviour at 2500 rpm and engine load 35%, (c) Engine coolant Temp. behaviour at 2500 rpm and engine load 45%, (d) AVG for T1 at engine speed 2500 rpm and different loads (25%, 35% and 45%).

<u>Coolant Temperature behaviour for 2500 rpm:</u>

Figure (8.a) showed that the performance of the cooling system under the operating conditions of an engine of 2500 rpm and at a load of 25%, it was found that the temperature of the coolant at the engine outlet to the proper system is 76.11˚C, and in the case of damage to the thermostat valve (fully opened) it drops to 74.65˚C, meaning that the coolant is in the healthy condition is higher the temperature of the coolant in the case of thermostat failure and when the engine at a load of 35%, as shown in Figure (8.b), it was found that the temperature of the coolant in healthy system is 76˚C and decrease in case of damage to the thermostat valve (fully opened) is 75˚C, that is due to the coolant in the healthy condition is the higher temperature of the coolant in the event of a thermostat malfunction (always open) of 1.28%, and when the engine at a load of 45%, as shown in Figure (8.c), it was found that the temperature of the coolant while leaving the engine for the proper system is 83.92˚C and drops to 78.61˚C, meaning that the coolant in the healthy condition is greater than the temperature of the coolant in the case of the thermostat malfunction (always open) by 6.33%, and this is due to the coolant is flowing through the radiator from the first moment of the test and gives a better chance for the coolant that it is cooled better and entails an increase in the time to reach the operating temperature of the engine and an increase in fuel consumption and an increase in the percentage of emissions. Figure (8.d) illustrate all ratios and rates of change in temperature under the same conditions of the operating conditions of an engine of 2500 rpm, and different loads (25%, 35% and 45%).

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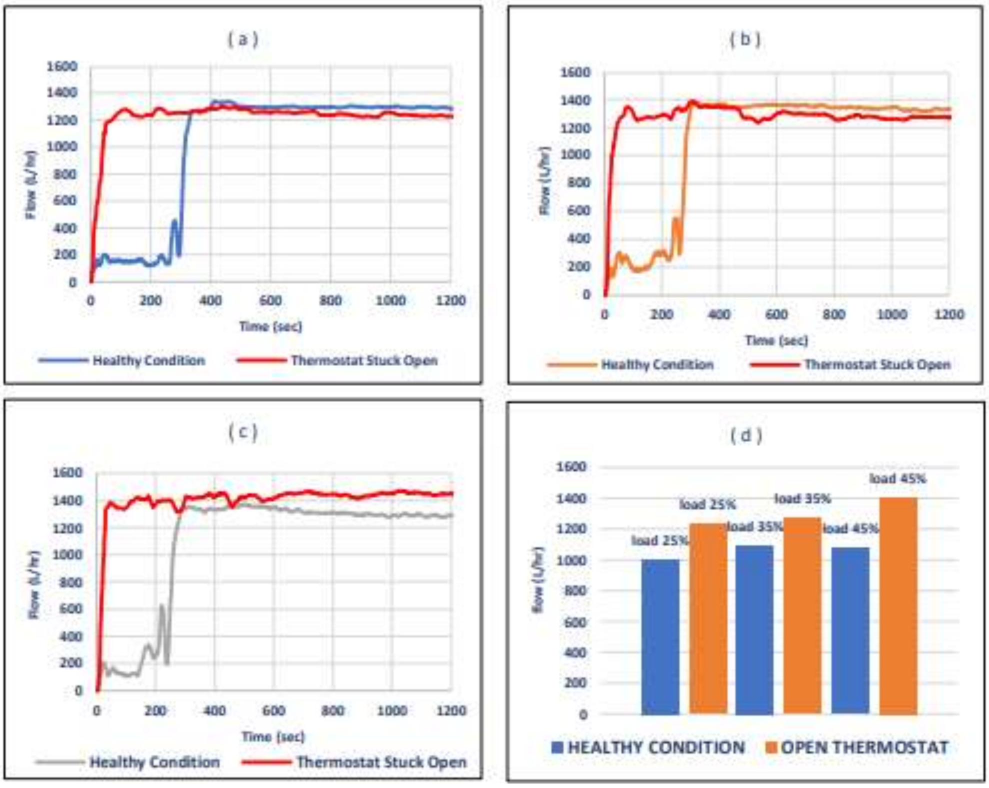

Figure (9): Engine coolant flow rate, (a) Engine coolant flow rate behaviour at 2500 rpm and engine load 25%, (b) Engine coolant flow rate behaviour at 2500 rpm and engine load 35%, (c) Engine coolant flow rate behaviour at 2500 rpm and engine load 45%, (d): AVG for Flow at engine speed 2500 rpm and different loads (25%, 35% and 45%).

Coolant flow behaviour for 2500 rpm:

Figure (9.a) showed that the coolant flow rate when the engine is running at 2500 rpm, 25% load, increases by 23% compared to the performance of the cooling system in the proper condition because the thermostat valve is (fully opened), and when the engine is running at 35% load, as shown in Figure (9.b), the coolant flow rate increases by 16% compared to the performance of the cooling system in the proper condition because the thermostat valve is (fully opened), and when the engine is running at a load of 45%, as shown in Figure (9.c), the coolant flow rate increases by 21% compared to the performance of the cooling system in the proper condition because the thermostat valve is (fully opened), because the thermostat valve allows the coolant to pass from inside the engine to the thermostat, then to the radiator, and then to the engine again since the beginning of the test without waiting for the coolant temperature to reach 70˚C. Figure (9.d) illustrate all ratios and rates of change in coolant flow rate under the same conditions of the operating conditions of an engine of 2500 rpm, and different loads (25%, 35% and 45%).

III. CONCLUSION

A simulation of the performance of the engine cooling system during thermostat failure (completely closed and open) was conducted using the thermostat valve in a healthy condition to make a comparison between the two cases.

The experimental results are concluded as follows,

- The new diagnostic system relied on making malfunctions in some parts of the cooling cycle and then measuring the temperatures of the cooling water to and from the engine, as well as measuring the flow rate of water in the engine, during thermostat failure (completely closed and open) malfunctions and comparing these results with the first case without any malfunctions (the health condition of the engine).
- The laboratory experimental results showed that the effect of changing the temperatures of the coolant leaving the radiator is not effective in diagnosing the temperatures of the engine that are used in the diagnosis, and that is why the study focus was on the temperatures of the coolant leaving the engine.
- When the engine is running in heavy duty condition at 2500 rpm and at 45% load, the

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temperature of the healthy system is 64.33˚C and increases 74.89˚C, if the thermostat valve is damaged (completely closed) at a rate of 16%, and this is because the engine is still running and the coolant absorbs the heat from around the combustion chambers and the coolant is unable to flow out of the engine and go to the radiator until it is cooled by radiation and then through the cooling fan to reach the operating temperature of the cooling fan.

- Coolant flow rate when the engine is running in heavy duty condition at 2500 rpm, and at 45% load, the coolant flow rate decreases by 80% compared to the performance of the cooling system in the proper condition because the thermostat valve (completely closed) prevents any coolant from passing into the radiator even after the arrival of the temperature of the coolant leaving the engine to a temperature of 70˚C, which is the theoretical opening temperature of the thermostat valve.
- When the engine is running in heavy-duty conditions at 2500 rpm and at 45% load, it is found that the coolant temperature from the engine in a healthy state is 83.92˚C and drops to 78.61˚C, i.e. decreases by 6.33% in the event of thermostat faults (always open), because the coolant flows through the radiator from the first moment of the test and gives a better chance to cool the coolant better, which leads to an increase in the time to reach the engine operating temperature, increased fuel consumption and increased emissions.
- Coolant flow rate when the engine is running in heavy duty condition at 2500 rpm, and at 45% load, the coolant flow rate increases by 21% compared to the performance of the cooling system in the healthy condition because the thermostat valve is (fully open), because the thermostat valve allows the passage of coolant from inside the engine to the thermostat, then to the radiator, and then to the engine again since the beginning of the test without waiting for the coolant temperature to reach 70˚C.

REFERENCES

[1]. G.M. Carlomagno, G. Cardone, Infrared thermography for convective heat transfer measurements, Exp. Fluids. 49 (2010) 1187-1218.
[2]. T.Astarita, G.M. Carlomagno, Infrared thermography for thermos-fluid-dynamics, Springer, 2013.
[3]. S.D. Oduro,J. Ampofo,Effect of radiator fins blockage by clay soil on the engine cooling temperature, Int. J. Eng. Tech.2 (6)(2012) 1002-1009.
[4]. S.C. Pang, M.A. Kalam, H.H. Masjuki, M.A.Hazrat, A review on air flow and coolant flow circuit in vehicles' cooling systemInt. J. Heat Mass Transfer 55 (2012) 6295–6306. trucks. Appl. Therm. Eng. 30 (2010) 1438-1446.
[5]. Y.Cao, K. Kengskool, An automotive radiator employing wickless heat pipes, MAESC Conference,Memphis, TN. 2009.
[6]. R.A. Epperly, G.E. Heberlein, L.G. Eads, A tool for reliability and safety: predict and prevent equipment failures with thermography, in: IEEE Petroleum and Chemical Industry Conference, Banff, Alta, 1997, pp. 59–68.
[7]. S. Bagavathiappan, B.B. Lahiri, T. Saravanan, J. Philip, T. Jayakumar, Infrared thermography for condition monitoring – A review. Infr. Phys. & Tech.60 (2013) 35–55.
[8]. Haghighat A K, Roumi S, Madani N, et al. An intelligent cooling system and control model for improved engine thermal management[J]. Applied Thermal Engineering, 2017, 128(10): 253-263.
[9]. Nemati M, Seyedtabaii S. On-board diagnosis of vehicles cooling system[C]. Electrical Engineering. Tehran, Iran: IEEE Press, 2015: 1317-1322.
[10]. H.R.Li.Fault Diagnosis and Elimination of Electronic Cooling Fan for Buick Junwei Automobile.[J].Vehicle Maintenance And Repair,2015(07):34-35.
[11]. Zhou J, Xu L. The fault diagnosis of marine engine cooling system based on artificial neural network (ANN). IEEE, 2010.
[12]. Beghi A, Cecchinato L, Peterle F, et al. Model-based fault detection and diagnosis for centrifugal chillers[C]// 2016 Conference on Control and Fault-Tolerant Systems (SysTol). IEEE, 2016.
[13]. L.Y.Chu. Research on Fault Diagnosis Method of Automobile Engine Cooling System, [D]. Chongqing university of posts and telecommunications,2019.
[14]. Nemati M, Seyedtabaii S. On-board diagnosis of vehicles cooling system[C]// 2014 22nd Iranian Conference on Electrical Engineering (ICEE). IEEE, 2014.
[15]. Design of Engine Cooling Control System and Diagnosis of Thermostat, [D]. Chongqing jiaotong university,2017.
[16]. Li L, Zhou D H, Liu K D. Robust Fault Diagnosis of Nonlinear Systems Based on

an Unknown Input Extended Kalman Observer[J].
[17]. The Application of Binary Tree-Based Fuzzy SVM Multi-Classification Algorithm to Fault Diagnosis on Modern Marine Main Engine Cooling System[C] IUCE 2010.
[18]. Qiang Hang, Yongchang LIU, huimeng LIU, “Fault diagnosis Study of the Inlet and Exhaust system Based on Vibration Signal”, Vehicle Engine, No.5 (Serial No.141), Oct. 2002, pp. 34-37. Yihuai Hu, Shuzi Yang, Yongchang Liu, Yichen Zhou, “Studies on Vibration Diagnosis Mechanism for Diesel Engine Tribological Faults”, Transactions of CSICE, Vo1.16 (1998) No.1, pp.50-61.