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Experimental Investigation of Air Pressure Drop Variations on Cooling Performance in Engine Radiators

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Abstract

Radiators are among the essential parts of car engines, and any weakness or defect in them can cause severe damage to the engine. The most critical tasks of radiators is effective heat transfer between air and fluid inside the radiator tubes, which is done by fans. Since the air temperature has a direct relationship with its pressure, measuring the air pressure before and after the radiator is necessary. In this research, three different methods have been used to calculate the air pressure drop at speeds of 3, 5, and 8 m/s. The purpose of this work is to introduce the best possible method to reduce the risks that are caused by the wrong reading of the air pressure drop using the accuracy of the obtained results, The point that each part of the radiator is determined by which pressure (static or dynamic pressure) is crucial and plays an essential role for choosing better type of pressure gauge. If this is done, the obtained results will be correct. If the air pressure drop is not calculated correctly, it can cause severe damage to the engine and other car parts. The best method that has the slightest error and the least risk for car radiators is when the pressure gauge calculates the static pressure inside the wind tunnel and the dynamic pressure outside the wind tunnel. In this case, the error of the obtained results comparing to the standard results is 9.16, 15.41 and 10.18%, at speeds of 3, 5 and 8 .

Keywords Car radiator; engine cooling; air pressure drop; cooling water system; Air pressure drop measurement method

Introduction

The car engine cooling system is one of the most vital systems that plays a critical role in every vehicle. This system provides conditions for the car engine to work at its defined standard temperature. It does not allow the temperature to rise or fall below the standard temperature defined for it. The task of the cooling system is to maintain the normal working temperature of the engine. The normal working temperature of the engine is the temperature at which it has its best working efficiency.

On the other hand, the engine's working temperature should not rise too much. The rise in temperature causes damage to the engine parts, such as the cylinder head gasket and valves, and causes other problems as well. Engine cooling systems in cars are with air (air cooling) and with cooling liquid (water cooling) [1]. Radiators are heat exchangers used to cool internal combustion engines, mainly in automobiles, piston-engine aircraft or any similar application where such engines are used. Internal combustion engines are often cooled by circulating a liquid called engine coolant through the engine block and cylinder head, where it heats up and then through a radiator

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that loses heat to the atmosphere and back to the engine. This fluid is usually a mixture of water and antifreeze. The antifreeze is usually ethylene glycol or propylene glycol (with a small corrosion inhibitor). It is common to use a water pump to circulate the engine coolant and an axial fan that draws air through the radiator. [2].

A typical car cooling system includes:

- A series of molds are cast into the engine block and cylinder head which circulates fluid to dissipate heat.
- A radiator, consisting of many small tubes equipped with honeycomb fins for rapid heat dissipation, receives and cools the hot engine fluid.
- A water pump to circulate the coolant.
- A thermostat to control the temperature.
- A fan to draw cool air through the radiator [3].

The radiator transfers heat from the fluid inside to the outside air, cooling the fluid and it causes the engine to cools. Radiators are also often used to cool automatic transmission fluids, air conditioner coolant, intake air, and sometimes to cool engine oil or steering oil [4]. Automotive radiators are made of a pair of metal or plastic tanks connected by a core with many narrow passages, creating a large surface area relative to volume. The core is usually made of stacked layers of sheet metal. For many years, radiators were made of brass or copper cores soldered to brass headers [5]. Modern radiators have aluminum cores which is a help of cost, space and weight. This structure is more susceptible to damage than traditional materials. An earlier construction method was the honeycomb radiator. The round tubes were molded hexagonal at their ends, then stacked and soldered [6].

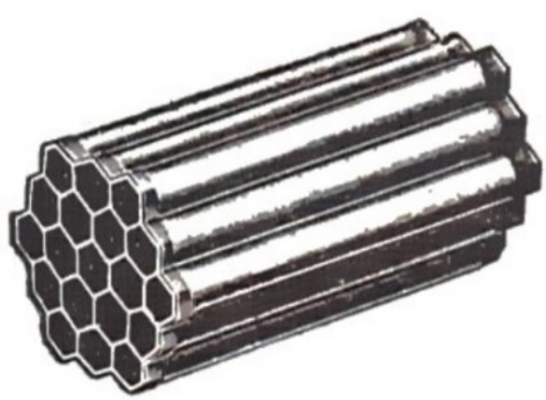

Fig 1. Honeycomb radiator tubes [6]

Radiators first used vertical downward flow. In this system, the coolant in the engine heats up; its density decreases, and therefore it rises. As the radiator cools the fluid, the coolant becomes denser and falls. For years, all cars have used centrifugal pumps to circulate engine coolant [7]. Usually, a system of valves, baffles, or both is generally installed inside the car to operate a small radiator simultaneously. This small radiator and corresponding blower fan is called the heater core. Like a radiator, a heater core removes heat from the engine.

The thermostat primarily controls the engine's temperature. When the engine is cold, the thermostat closes to sense the change in coolant temperature as the engine warms up. The thermostat directs the engine coolant to the pump inlet and directly returns it to the engine. By circulating water, the engine can quickly reach the desired operating temperature. When the coolant reaches the thermostat activation temperature, it opens and allows water to pass through the radiator to avoid temperature rising [8]. Other factors, such as the size of the radiator and the type of radiator fan, affect the engine temperature. The size of the radiator (and therefore its cooling capacity) is chosen to keep the engine at its designed temperature under the most extreme conditions a vehicle will encounter (such as climbing a mountain while on a hot day, it is fully loaded). Motorized fans are often regulated by a fan clutch from the drive belt, which slips at low temperatures and reduces fan speed. In modern vehicles, radiator fans with variable speeds provide more regulation of cooling speed. A thermostatic switch or motor control unit controls electric fans. Electric fans also give good airflow and cooling at low engine speeds or in a stationary state [9]. The general task of fans is to circulate air to cool the water inside the radiator.

Fig 2. Car engine thermostat [9]

We know that in ideal gases, pressure has a direct relationship with temperature, considering that air can be considered an ideal gas. Therefore, calculating the air pressure drop on the sides of the radiator is important and necessary. In addition, according to the national standard of Iran No. 3224, one of the mandatory tests to check the thermal performance of the radiator is to calculate the pressure drop on the sides of the radiator. In this research, a cooling water system is used and three different methods calculate the pressure drop on the sides of the radiator, and the results are compared with the standard results.

Table 1. Measuring devices and the allowed error value of each of them

Measuring device	Device error
air flow meter	±2% of the rated value of the measured devices
Water flow meter	±2% of the stair value of the measured devices
thermometer	± 0.3°C
Temperature difference gauge	± 0.1°C
Pressure difference gauge	±2 percent of the maximum rating value of the measuring device
pressure gauge	±2 percent of the maximum rating value of the measuring device

2. Experimental test

The purpose of this research is to investigate the risks caused by the wrong reading of the air pressure drop of a radiator. For this purpose, the air pressure drop is calculated by three different methods and the obtained results are compared with the standard results. In the following, the components of the device, the location of the pressure gauge tubes, and the shape of these tubes will be checked.

2.1 Device components

The main parts of the radiator shown in Figure 3 are the core, upper tank, lower tank, inlet pipe, outlet pipe, oil cooler for automatic power transmission, filler neck, pressure cap, and drain

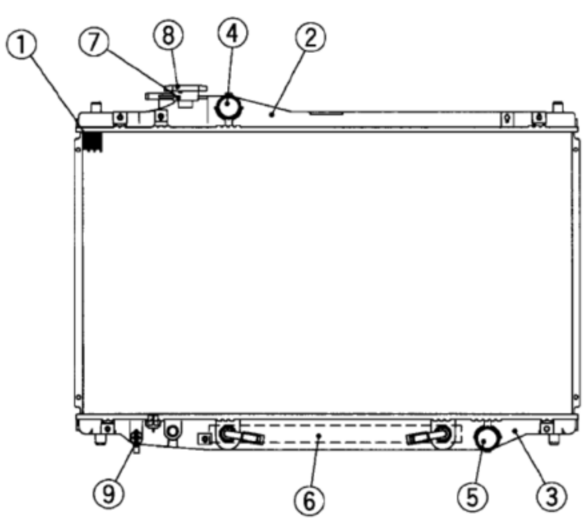

Fig 3. The main components of a radiator: 1) core 2) upper tank 3) lower tank 4) inlet pipe 5) outlet pipe 6) oil cooler for automatic heat transfer 7) filler neck 8) pressure cap 9) drain valve

To calculate the air pressure drop, it is necessary to have a wind tunnel available. The schematic and air pressure drop test device used in this research can be seen in Figure 4. This wind tunnel includes the following:

- Regulating the amount of air passing through the radiator

Fig 4. The device used in the present study

- The connecting pipe between the wind body and the radiator which conforms to the JIS B 8330 standard.
- All the joints of the wind tunnel and connecting pipes and all kinds of measuring holes are sealed.

2.2 Measurement tools and methods

The measuring devices used in this research and the permissible error of each of them are given in Table 1.

As mentioned earlier, air can be considered an ideal gas, considering that pressure and temperature have a direct relationship in ideal gases. On the other hand, because air is used as a cooling liquid inside the radiator, the risks caused by not correctly calculating the air pressure drop

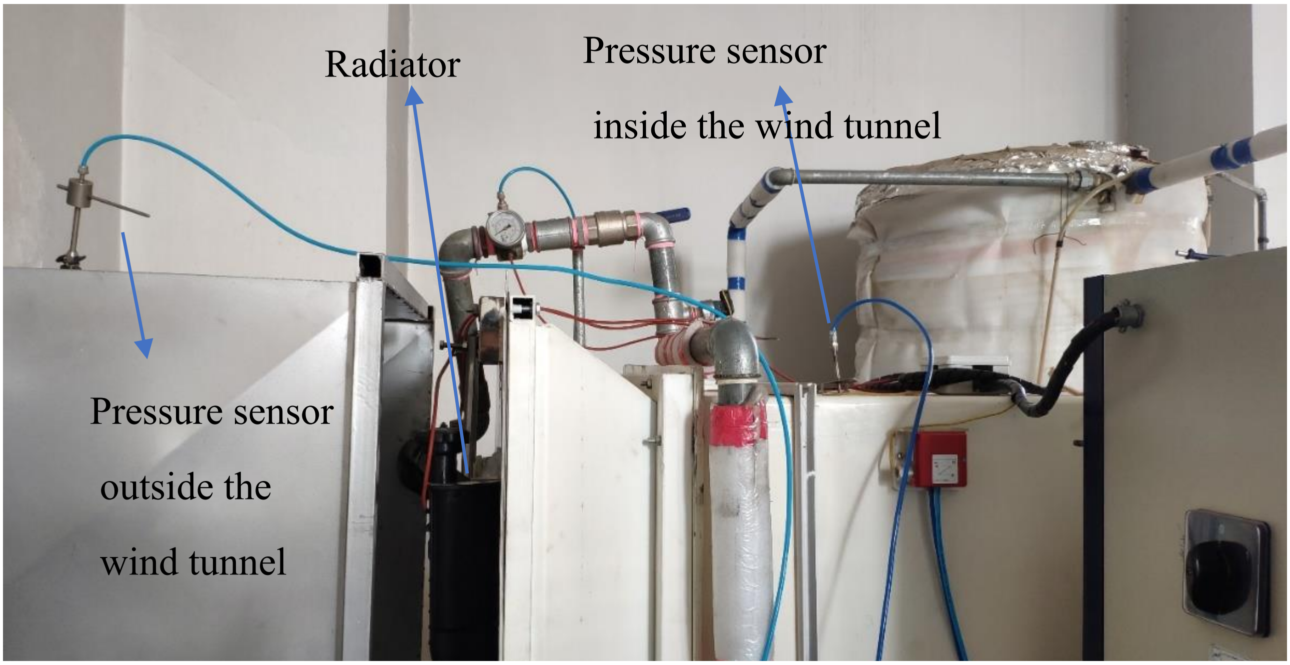

Fig 5. Location of radiator and pressure gauge sensors

can have unpleasant consequences. The radiator must first be connected to the wind tunnel through the connecting pipe to measure the air pressure drop. Then, we increase the air blower to certain speeds and allow the airspeed to reach a stable value. Then, the pressure value shown in the device will be compared with the values provided by partner laboratories.

For this purpose, radiator air pressure drop is measured at 3, 5, and 8 m/s. Three different methods have been used to calculate the air pressure drop, each of which will be explained below. To calculate the pressure drop, pressure sensors can calculate dynamic and static pressure, as seen in Figure 5. Considering that behind the radiator and in the interior of the wind tunnel, static pressure prevails, it is necessary to consider the static pressure for the back of the radiator and in the outer space of the radiator due to the more significant dynamic pressure, it is necessary to calculate the dynamic pressure. In this research, three different methods have been used to calculate the air pressure drop, and the risks of pressure measurement have been investigated.

2.2.1 Using straight pipes to calculate the air pressure on both sides of the radiator

In this case, on both sides of the radiator, there are straight pipes, according to Figure 6. It is used to calculate the air pressure drop in the radiator. By placing straight pipes, only the static pressure of the air is calculated, and the consideration of the dynamic pressure is omitted. By referring to Figure 7, which shows a comparison of the results of the current research and the standard results, it can be seen that the difference in the results is enormous, and this makes this model of pipe placement for pressure measurement The air on the sides of the radiator is not suitable.

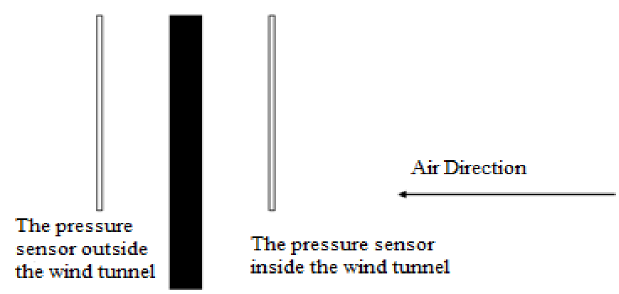

Fig 6. Schematic of the placement and shape of air pressure sensors

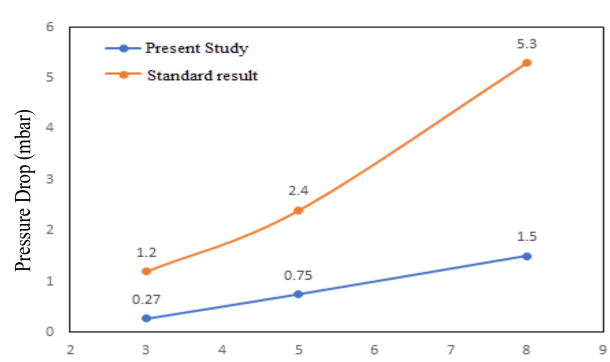

Fig 7. Air pressure drop obtained using Straight pipes

Also, Table 2 shows the difference between the results obtained from the current research and the standard results. By referring to this table, it can be seen that with the increase in speed from 3 m/s to 8 m/s, the difference in the obtained results increases, indicating that the pressure sensors' placement does not work correctly at all.

Table 2. The error of the obtained results in comparison with the results of Standard when using two straight tubes

Air Velocity (m/s)	Error (%)
3	77.5
5	68.75
8	71.69

2.2.2 Using a straight tube in the outer part and an L-shaped tube in the inner part of the wind tunnel to calculate the air pressure on both sides of the radiator

By placing an L-shaped tube according to Figure 8, the dynamic air pressure can be calculated. It was stated earlier that the pressure that prevails inside the wind tunnel is static pressure. But this does not mean the absence of dynamic pressure. In Table 3, which shows the error in this mode, it can be seen that the difference in the results obtained in this mode is more than the previous mode, which makes this method have the lowest accuracy level.

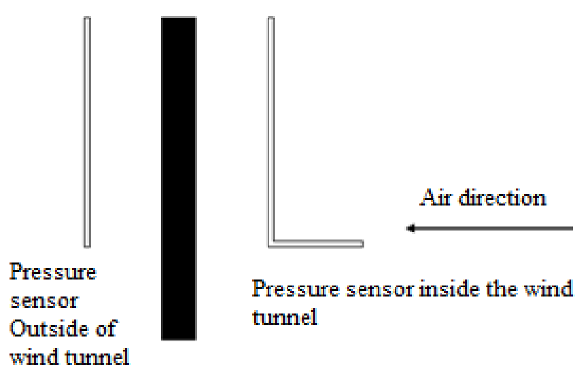

Fig 8. Schematic of the placement and shape of air pressure sensors

Table 3. The error of the obtained results compared to the results of standard when using a straight pipe (outside the wind tunnel) and an L-shaped pipe (inside the wind tunnel).

Air Velocity (m/s)	Error (%)
3	85.83
5	82.91
8	81.69

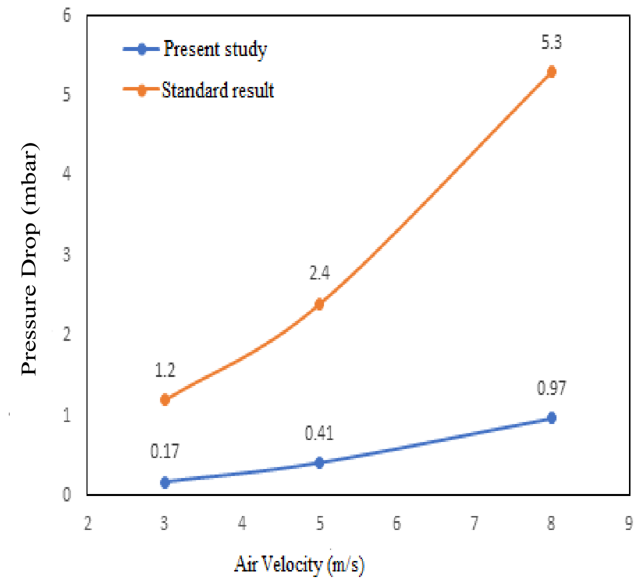

Fig 9. Air pressure drop obtained using a straight tube and an L-shaped tube

2.2.3 Using a straight tube in the inner part and an L-shaped tube in the outer part of the wind tunnel to calculate the air pressure on both sides of the radiator

The third and last state that has been examined in this research can be seen in Figure 10. In this case, the straight tube is placed in the inner part, and the L-shaped tube is placed in the outer part of the radiator. In this case, the static pressure in the inner part of the wind tunnel and the dynamic pressure in the outer part of the wind tunnel can be calculated. As seen in Figure 11 and Table 4, the difference between the results, in this case, has reached its lowest value and makes this pipe arrangement and placement model the best method to calculate the air pressure drop.

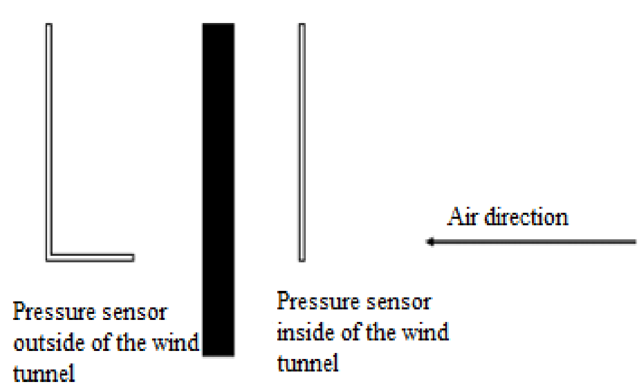

Fig 10. Schematic of the placement and shape of air pressure sensors

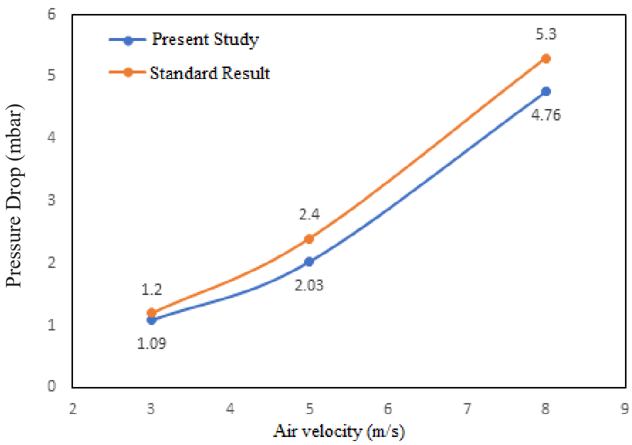

Fig 11. Air pressure drop obtained by using a straight tube in the inner part of the radiator and an L-shaped tube in the outer part of the radiator.

Table 4. The error of the obtained results in comparison with the Standard results when using a straight pipe (inside the wind tunnel) and an L-shaped pipe (outside the wind tunnel)

Air Velocity (m/s)	Error (%)
3	9.16
5	15.41
8	10.18

3. Examining upcoming risks

The previous section observed that if the pressure gauge sensors are placed correctly inside and outside the wind tunnel, the difference between the obtained and correct results will be manageable. If these things are considered, it will prevent poor-quality fans from being used in the radiator section of cars, which can cause damage to the engine. In the following, these damages will be examined.

In the car's front part, a fan or propeller is installed, which is rotating. This part of the cooling system is one of the main components of internal combustion engines. In internal combustion engines, ignition and combustion operations produce much heat. Such a high temperature affects the engine's performance and reduces its efficiency. Also, the risk of damage to other parts increases with the increase in temperature and may lead to their deformation and melting. In the combustion process, the engine produces a lot of heat, and part of this heat is transferred to the outside environment. The water in the vehicle circulates around the engine.

On the other hand, the heat produced by the engine is given to water to reduce the engine's temperature as a coolant. During the cooling process, the water passes through a long path with a small cross-sectional area, and in the meantime, the ambient air collides with the water and causes heat transfer between the water and the ambient air. The function of the fan is to make the airflow and pass it inside the radiator. Therefore, in case of car fan failure, this process is hardly possible. In general, if we want to express the general performance of the engine fan, this part increases the airflow when the engine temperature is high, and by making the airflow flow in the engine, it leads to its cooling.

The previous section introduced three methods of calculating the air pressure drop. The first and second methods were introduced as incorrect methods to calculate the air pressure drop, and only the third method (static pressure inside and dynamic pressure outside the wind tunnel) was the method whose result was slightly different from the standard results. Considering the direct relationship between air pressure and temperature, using the first and second methods can cause severe risks for the engine and other parts.

One of the damages that can be caused to the car engine is an excessive increase in engine temperature. Because the fan has been unable to transfer heat between the water and the environment effectively, the fluid with high temperature constantly circulates inside the radiator. An excessive increase in temperature melts parts such as cylinders, pistons, and cylinder head gaskets. The lack of heat transfer causes thermal accumulation, and this issue can destroy the fan blades and cause the car fan to fail. Car fan failure can cause a lot of noise. Such a sound may be caused by the propeller getting stuck in the fan, which occurs due to the change in the shape of the fan (due to high heat or the use of poor-quality materials). A defective fan can cause overheating of the radiator fan, insufficient cooling of the cabin, and boiling of the coolant. As the coolant boils, its pressure also increases. An increase in the pressure of the cooling liquid can cause damage to the radiator door. The failure of the radiator door itself can cause water to overflow from the car radiator, coolant leakage from the sides of the radiator door, a significant decrease in water over time, and an increase in water amperage. Sometimes, air bubbles form inside the cooling system, and the car radiator gets air. The smallest amount of this air can prevent the proper circulation of the coolant. Failure to maintain pressure is one of the most common reasons for the presence of air in the car radiator, which is due to a faulty radiator cap. On the other hand, excessive cooling in the engine causes incomplete combustion, increased emissions and high fuel consumption. As a result, it is necessary that the radiator's temperature is in a suitable range, and things such as air pressure drop on the sides of the radiator must be appropriately considered and calculated. FMEA method has been used to investigate the risks in this research. The method of analyzing failure factors and their effects (FMEA) has a history of 40 years. Failure mode and effect analysis (FMEA) has been observed for the first time in the 1960s in the American aerospace industry for the construction of the Apollo 11 spacecraft in the American NASA. Then, it was used in the 1970s and 1980s for atomic institutions. In addition, it was also used for the automotive industry from 1977 onwards. Since 2000, this method is one of the most widely used risk assessment methods in all industries. In FMEA, three critical issues should be considered:

- Occurrence: Probability, or in other words, counting the number of failures relative to the number of process executions.
- Severity: Evaluating and measuring the result of failure (if it happens, of course). Severity is an evaluation scale that defines the seriousness of the effect of a failure if it occurs.
- Detect: The probability of detecting a failure before the effect of its occurrence is known. The detection value or rank depends on the control flow. Diagnosis is the ability of control to find the cause and mechanism of failures.

3.1 Calculation of risk priority number (RPN)

According to the information we have about the process or product, we grade the risk based on the three (occurrence - Severity - Detect) factors. This classification is from 1 to 10 (low to high). If we multiply the degrees of these three factors together, we get the risk priority score for each potential failure pattern and its effects. The cause should be investigated quickly for failure patterns with a higher PRN score.

This score is the product of three numbers of severity (S), probability of occurrence (O), and probability of discovery (D).

RPN= Severity × Occurance × Detection

The obtained RPN number is usually called the risk priority number. The final result of numerical calculations will be between 1 and 1000. The crisis level and the obtained RPN number are shown in Figure 12.

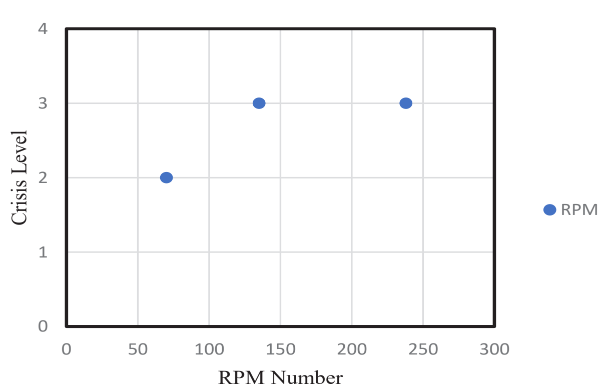

Fig 12. RPM number obtained based on crisis level

When the air pressure drop is calculated in the most correct way (straight pipe inside and L-shaped pipe outside the wind tunnel), the RPM number obtained is equal to 238, when the L-shaped pipe is placed inside and the straight pipe outside the wind tunnel, the RPM number obtained equal to 135 and finally, in the case of using two straight pipes inside and outside the wind tunnel, the RPM obtained was equal to 68.

Conclusion

Considering that the primary function of the radiator is to keep the engine cool and the risks caused by not calculating and accurately checking the amount of effective heat transfer between the fluid inside the radiator and the ambient air can cause severe damage to the engine, the present research examines how to calculate The air pressure drop of car radiators has been paid. In this research, the air pressure drop at constant speeds of 3, 5, and 8 m/s was investigated in three different ways, and the obtained results were compared with the standard results provided by the collaborating laboratories. Three different methods have been used to calculate the air pressure drop. In the first method, two straight pipes were used to calculate the pressure drop of the radiator. In this case, the system can only calculate the fluid's static pressure. Considering the vast difference between the results of this mode and the standard results, using a straight pipe on both sides of the radiator is not considered the correct method for calculating the air pressure drop. The second method was to use an L-shaped tube in the inner part of the wind tunnel and a flat tube in the outer part of the wind tunnel. This mode also cannot be a suitable model due to the enormous difference and wrong air pressure reading. Considering the importance of the fact that the lack of adequate heat transfer between the coolant and the ambient air can cause severe damage to parts such as the piston, cylinder head gasket, piston, radiator cap, etc., these two methods cannot be part of the correct methods of calculating air pressure drop. Finally, in the third model, which used a flat tube in the inner part of the wind tunnel and an L tube in the outer part of the wind tunnel, the difference in the results reached its lowest value. It indicated that the static pressure on the inner side and the dynamic pressure on the side Outside the wind tunnel are dominant. By comparing the results, it was concluded that static pressure prevails inside the wind tunnel, and dynamic pressure prevails in the outer part of the wind tunnel. As a result, the third method can be considered the best model for calculating air pressure drop with an average error of 11.5% and having the lowest risk for the operation of the radiator and other equipment. Also, according to the influence of each of the different situations on the test results, as well as the probability of each of the cases and finally their diagnosis, it was concluded that when a straight tube is used inside and an L-shaped tube outside of the wind tunnel, It is more likely to happen and it is easier to detect. Therefore, if we comply with the subject, we will get the highest quality test results with a lower risk. On the opposite point, when we use the L-shaped pipe inside, and the straight pipe outside of the wind tunnel, paying attention to the probability of occurrence is less likely to affect the test results in the second place of risk.

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Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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