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Original article

Investigation of the Effects of Using Plastic Instead of Aluminum in Tractor Engines, Intercooler Tanks on Engine Performance

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Abstract

In recent years, researchers have been working on more environmentally friendly engine systems and the efficient use of depleting fuel resources. One of these research topics is intercoolers used in turbocharged engines. Intercooler tanks are generally made of aluminum due to their good heat transfer coefficient. In this study, the suitability of the use of plastic tanks was investigated by examining the engine performance changes as a result of using plastic instead of aluminum, which is the traditional material, in the intercooler tanks of an 81 kW Perkins tractor engine. For this purpose, experiments were carried out at 1400 and 2200 rpm for intercoolers with both materials. According to the results obtained from the experiments, a 0.62% torque increase was obtained at 1400 rpm in the engine with a plastic tank material intercooler compared to the engine with an aluminum material intercooler. According to the data obtained from the experiments carried out at 2200 rpm, a power increase of 0.74% was determined. Similarly, it was determined that the effects of parameters such as radiator upper and lower hose temperatures, turbo inlet and outlet air temperatures, and intake manifold inlet temperature on engine performance were negligible. According to these findings, it has been determined that if the tanks of the intercoolers are plastic, there will be a negligible performance loss compared to the traditional material aluminum. Plastic is lighter, cheaper, and easier to manufacture than aluminum. Considering the production and operating conditions, it was concluded that such materials should be researched and developed by manufacturers.

Keywords: Diesel engine, Intercooler, Energy, Torque, Power, Efficiency.

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INTRODUCTION

In recent years, fuel consumption and harmful exhaust emissions regulations have become more stringent in many parts of the world. In the future, it is foreseen that internal combustion engines will be replaced by electric motors in the automotive sector. However, this transformation will take a long time in commercial vehicles such as trucks, pickup trucks, buses, land vehicles, construction equipment, and tractors. In this process, the cost, environmental impact, and sensitivity to depleting fossil fuels are increasing for internal combustion engines (Canlı, 2011). Especially reducing engine volume and using turbocharged systems is one of the main solutions used to reduce fuel consumption (Masakazu et al., 2013). Incomplete combustion occurs because the oxygen level taken into the cylinders is insufficient with the decrease in air density (Darıcı et al., 2012). For this reason, intercooler in turbocharged systems is very important in meeting the operating requirements of the engines and providing sufficient air intake to the cylinders (Zhentao et al., 2020).

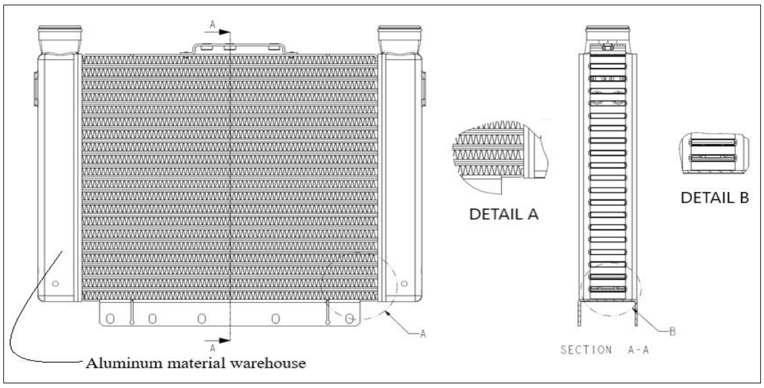
The intercooler used in turbocharged systems used to increase the operating efficiency of today's internal combustion engines is an intercooler used to cool the air heated as a result of the compression of the turbocharger. In this way, with the increase in the density of the cooled air, more oxygen is sent to the cylinders. It has been determined that the pressure increase of the air does not increase the engine power (Şen, 2009). The most important features of intercoolers are their efficiency. It represents the intercooler's ability to cool the charged air down to ambient air temperature. This value is between 1% and 100%. When the intercooler efficiency is 100%, it is understood that the charge air temperature is equal to the ambient air temperature (Canlı et al., 2010). Using an intercooler can improve fuel economy, increase engine power and durability, and reduce emissions with good combustion (Mack Technical Bulletin, 1996). Intercoolers are generally modeled in two ways: water-cooled and air-cooled. In water-cooled intercoolers, the charge air is cooled with water. This system is mostly used in heavy-duty vehicles. Air-cooled intercoolers are generally used in passenger and cargo-passenger cars and light commercial vehicles. Intercoolers consist of three parts: boiler, tube, and fin (Şen, 2009).

When the literature is examined, it can be seen that many studies have been conducted to investigate the characteristics of turbochargers and intercoolers (Nuntaphan, 2010; Ismail et al., 2010; Kays and London, 1998; Wen and Ho, 2009; Pen and Ling, 2009). Also, when examining some of the other studies in the literature, Zhentao et al. (2020) investigated the variation of the heat exchange capacity of the heat exchanger with altitude. For this, they used an intercooler integrated into the aircraft engine. According to their results, they determined that the total efficiency of the intercooler before the aircraft enters the atmosphere decreases by 1.98% for each 1 km increase in altitude and by 3.26% when the altitude is above 11 km. Kim et al. (2014) investigated an assembly consisting of two plastic hoses and an aluminum tube mounted between the air control valve and the intercooler in terms of noise and vibration in a study to develop a lightweight and cost-effective plastic intercooler tube. A study conducted by Darıcı et al. (2012) determined that the intercooler is more suitable for heavy-duty engines, especially tractor engines. Canlı et al. (2010) conducted a theoretical study for intercooling in a real internal combustion engine using a turbocharger system compressor and turbine. According to their results, they obtained 53% more power from the supercharged system compared to the normal atmospheric engine. On the other hand, Kaul et al. (2021) investigated the advanced materials that can be used instead of traditional metal ducts by comparing the performances of different duct materials between the turbocharger and intercooler according to their heat loss properties. Their results concluded that plastic materials allow significant weight reduction and flexible design properties compared to metal materials. As can be understood from the studies, some of which have been examined in the literature, it is seen that studies on increasing engine performance and reducing fuel consumption and emission values at the same time come to the fore.

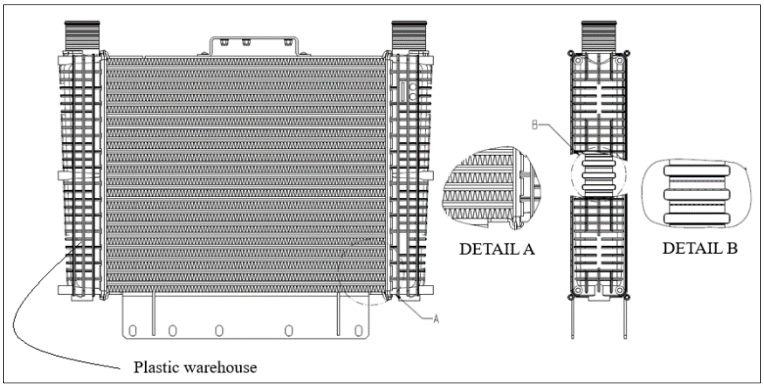
In this study, the effects of the use of plastic tanks produced in the same dimensions instead of the traditional aluminum material used for the intercooler tank on the engine performance were investigated with the experiments carried out on the tractor engine. In addition, the examined plastic material is lighter, more flexible, and easier to produce than aluminum material, as well as taking advantage of its cheaper production costs and being more sustainable towards the environment.

MATERIALS and METHODS

The experiments to compare the engine performance of the plastic tank intercooler with the aluminum tank intercooler were carried out on an 81 kW Perkins tractor engine. Before starting the experiments, the tractor engine was run for 30 minutes and brought to the regime temperature. For the data obtained from the experiments to be as appropriate as possible to the data obtained in real working conditions, the speeds at which the experiments were carried out were selected as 1400 rpm, which is the speed at which the tractors are mostly used in field conditions, and 2200 rpm, which is the speed at which they are used in areas other than the field, and repeated five times for each tank with both materials. The engine performance parameters examined were torque, power, and system temperature changes, such as radiator upper and lower hose temperatures for cooling water, air temperatures at the inlet and outlet of the turbocharger, and intake manifold inlet temperature. The schematic representations of the aluminum and plastic material intercooler tanks are shown in Figure 1, the engine-mounted images are shown in Figure 2, and the properties of the materials are presented in Table 1.



a. Aluminum intercooler

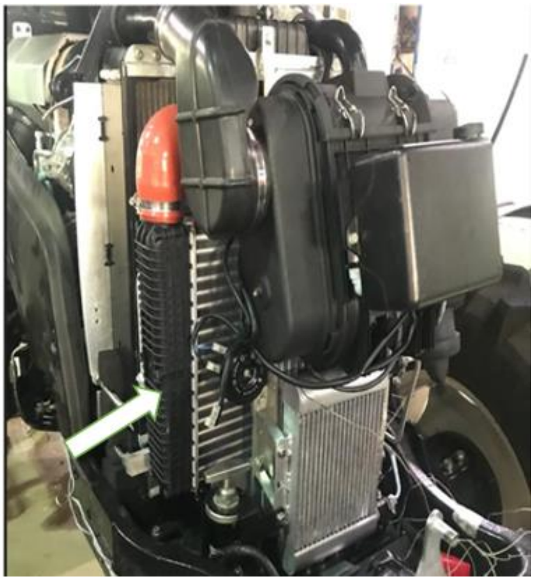


b. Plastic intercooler

Figure 1. Schematic representations of intercoolers

When Figures 1a and 1b are examined, it can be seen that the tanks with aluminum and plastic materials are completely manufactured by the intercooler.

a. Aluminum intercooler



b. Plastic intercooler

Figure 2. Assembled images of intercooler tanks

Table 1. Technical specifications of the warehouses

Intercooler Tank Material	Aluminum	Plastic
Core Dimension (mm)	420 x 398 x 50	420 x 352 x 50
Tube Type	Flat	Flat
Tube Dimension (mm)	49 x 7	49 x 7
Tube Quantity	18	22
Fin Type	Wavy	Wavy
Fin Quantity	19	23
Fin Height (mm)	12	10
Fin (FPI)	10	12

RESULTS and DISCUSSION

The performance data of aluminum and plastic intercooler tanks are the data obtained as a result of five tests performed at 1400 and 2200 rpm. The averages of the data obtained were taken, and the results are presented in Table 2 for 1400 rpm and in Table 3 for 2200 rpm. The negative values in the percentage difference column given in the tables show that the plastic material tank loses value compared to the aluminum material tank.

Table 2. Experimental data were obtained at 1400 rpm.

1400 rpm			
Parameter	**Aluminum material**	**Plastic material**	**Difference (%)**
Power (kW)	54.35	54.3	-0.09
Torque (Nm)	427.58	430.26	0.62
Radiator, Top Hose (°C)	90.95	88.05	-3.19
Radiator, Bottom Hose (°C)	85.1	82.45	-3.11
Turbo In Air (°C)	29.7	26.4	-11.11
Turbo Out Air (°C)	127.75	122.2	-4.34
Induction Manifold Inlet (°C)	53.65	51.5	-4.01
Intercooler, Front-Bottom (°C)	30.6	37.75	23.37
Air Filter Inlet (°C)	28.25	24.45	-13.45

Table 2 shows the percentage changes of the data obtained for the plastic material tank based on the aluminum material and the average of the data obtained from the five repetitive experiments performed at 1400 rpm. For example, when using an intercooler with a plastic tank, it is seen that there is an increase of 0.62% in torque value. More detailed analyzes of the investigated parameters are presented in Figure 3.

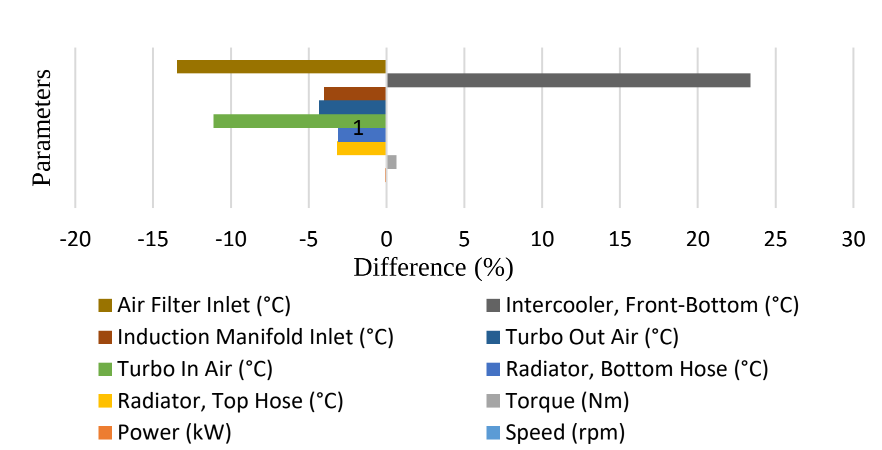


Figure 3. Percentage changes of parameters at 1400 rpm

When Figure 3 is examined, it is seen that at 1400 rpm, the highest percentage change among the parameters studied in the intercooler with a plastic tank compared to the intercooler with an aluminum tank is the temperature change measured on the front-bottom surface of the intercooler with a value of 23.37%. There was a 13.45% decrease in the air filter inlet temperature and an 11.11% decrease in the turbocharger air inlet temperature. However, there was an increase of 0.62% in the torque value, while the changes in the other parameters examined were negligible.

Table 3. Experimental data were obtained at 2200 rpm.

2200 rpm			
Parameter	**Aluminum material**	**Plastic material**	**Difference (%)**
Power (kW)	67.95	68.45	0.74
Torque (Nm)	348.20	337.58	-3.03
Radiator, Top Hose (°C)	86.60	85.28	-1.53
Radiator, Bottom Hose (°C)	81.35	77.25	-5.04
Turbo In Air (°C)	27.05	24.08	-11.00
Turbo Out Air (°C)	138.75	134.90	-2.77
Induction Manifold Inlet (°C)	53.68	52.25	-2.65
Intercooler, Front-Bottom (°C)	32.68	32.05	-1.91
Air Filter Inlet (°C)	25.50	23.23	-8.92

When the values taken at 2200 rpm are compared with the values taken at 1400 rpm, it has been determined that the power, torque, and turbo outlet temperature for both materials used increase with the number of revolutions. In Figure 4, a comparison of the investigated parameters for both materials at 2200 rpm is presented.

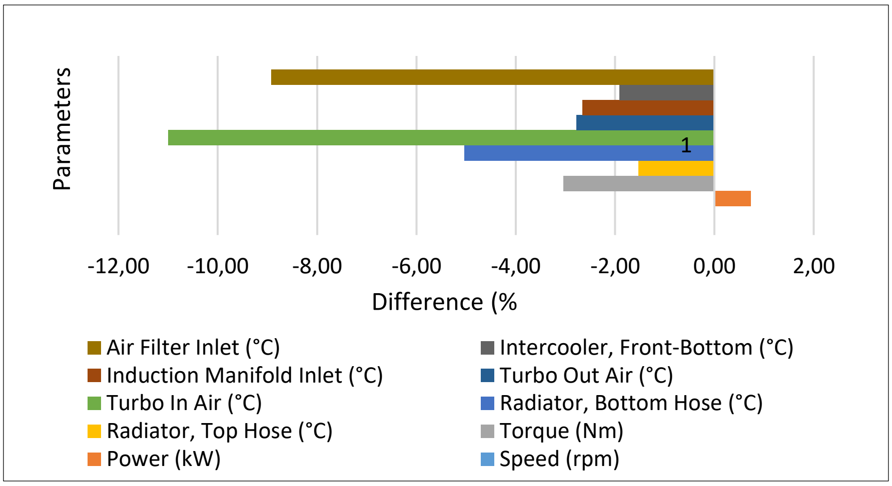


Figure 4. Percentage changes of parameters at 2200 rpm

According to the data obtained from the experiments carried out at 2200 rpm, it was determined that only the power value increased by 0.74%, while the other parameters decreased. It was determined that the parameter with the most decreasing value occurred in the air temperature measurement at the turbo inlet, with a value of 11%. In addition, the value of the decrease in the air filter inlet temperature was determined as 8.92%.

Conclusion

In this study, the changes in engine performance were investigated when a plastic material was used instead of aluminum material in the intercooler tank of a Perkins tractor engine with 81 kW power. According to the findings obtained from the experiments carried out at 1400 and 2200 rpm, a torque increase of 0.62% was determined at 1400 rpm in the engine with an intercooler made of plastic material compared to the engine with an intercooler made of aluminum material. According to the data obtained from the experiments carried out at 2200 rpm, a power increase of 0.74% was achieved. Similarly, it was determined that the effects of other parameters examined on engine performance were at negligible levels. Depending on the results obtained from the experiments, it was concluded that the use of the intercooler tank with plastic material instead of aluminum causes negligible performance losses, while considering that plastic material is lighter, cheaper, and more flexible than aluminum material, such materials should be evaluated by manufacturers.

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