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Studying the effect of Al_2O_3 nanoparticles in the heat exchanger effectiveness used in marine diesel engine

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Abstract

Generally, diesel engines are used as a prime mover to obtain the mechanical power represented in rotating motion. Marine diesel engine is used to rotate the propeller of the ship (axial pump) to create the axial thrust force to drive the ships. Diesel engine is one of the internal combustion engine that generate explosion inside the cylinder volume by reaching to the self-ignition temperature of the diesel fuel. Then the explosion, piston moves downward. So, the diesel engine is known as compression ignition engine. Fresh water is considered the coolant of the engine that enter with 90° and cooled to 65°C through heat exchanger. The heat exchanger effectiveness was enhanced by increasing the heat transfer coefficient using Nano Al_2O_3 particles contents in the primary coolant (Nano fluid). The heat exchanging process is performed by another coolant that is called secondary coolant (sea water). This technique has several advantages as deceasing the sea water flow rate as much as possible in order to gain less heat exchanger tube fouling, less maintenance intervals, and machine long life time. Different weight percentages of Nano particles (0.1, 0.2, 0.3, and 0.4%) were added to the primary coolant with different particle sizes. The heat exchanger effectiveness is represented in the primary coolant outlet temperature from the heat exchanger that was measured for each Nano fraction and compared with each other in a bar chart at different machine loads. It was concluded that the optimum Al_2O_3 particle size is 10 nm for all loads and the optimum weight percentages is 0.3% at half load, 0.4% at full load, and free content in no load condition.

Keywords: *Author Guide, Article, Camera-Ready Format, Paper Specifications, Paper Submission.*

1. Introduction

The diesel engine is an internal combustion engine. The fuel ignition is obtained by raising the temperature of the air in the cylinder during compression stroke. Thus, the diesel engine is called compression-ignition engine (CI engine). Air temperatures reach to 520 °C. The diesel engine is considered the prime mover for the rotating equipment that generates mechanical work. Maine diesel engine is one of the diesel engine type that used to drive the propeller of the ships as shown in (figure 1). The propeller is an axial pump that flow a huge amount of water in the direction which create thrust force in the opposite direction. The thrust force is the acting force of the ship movement.

Fig. 1. Diesel engine drives the propeller

There are two types of marine diesel engine; four stroke and two stroke. A 4 stroke engine can be installed on the ship to produce electrical power and also to propel the ship. This engine takes 4 cycles to complete the transfer of power from the combustion chamber to the crankshaft as shown in (figure 2). It is indicated as below:

1. Suction stroke - suck the air inside the cylinder.
2. Compression stroke - compress the air-fuel mixture.
3. Power stroke - the explosion takes place.
4. Exhaust stroke – flow the used gases out of cylinder.

Fig. 2. Four Stroke Diesel engine

While the two stroke engines are used only to turn the propeller and it is bigger in size as compared with four stroke engines. Theory of operation for two stroke diesel engine is shown as below and shown in (figure 3):

1. Suction and compression stroke – which is the piston down to draw the air and up to compress the air-fuel mixture.
2. Power and exhaust – which is the piston down because of the explosion inside the chamber followed by purging the exhaust during the piston up.

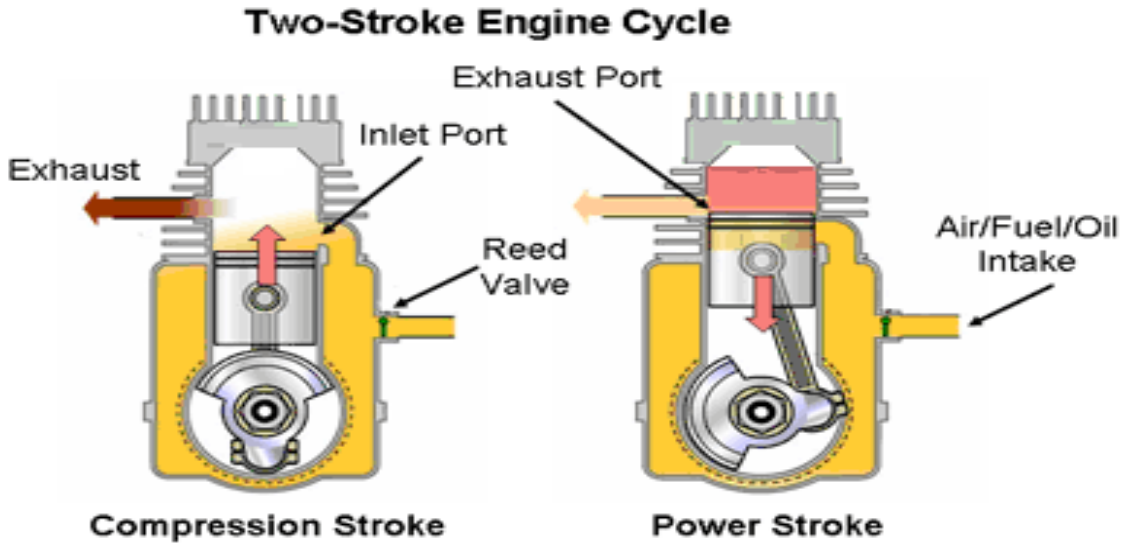

Fig. 3. Two Stroke Diesel engine

Each engine type has cooling cycle. The cooling cycle contains the following parts:

- Primary coolant used in closed cycle to cool the engine parts. Fresh water is often used as primary coolant.
- Secondary coolant used in open cycle to cool the primary coolant. Sea water is often used as secondary coolant.
- The primary coolant is cooled by the secondary one in shell and tube heat exchanger.

The cooling cycle is represented in (figure 4). The cooling cycle effectiveness depends on several factors as below:

- Heat transfer coefficient of fresh water.
- Heat transfer coefficient of sea water.

- Sea water flow rate

A Nano liquid is a liquid containing nanoparticles. The nanoparticles used in Nano fluids are made of metals, oxides, or carbides. Nanoparticles are distributed uniformly in a Nano fluid that improve the thermal performance of Nano fluids.

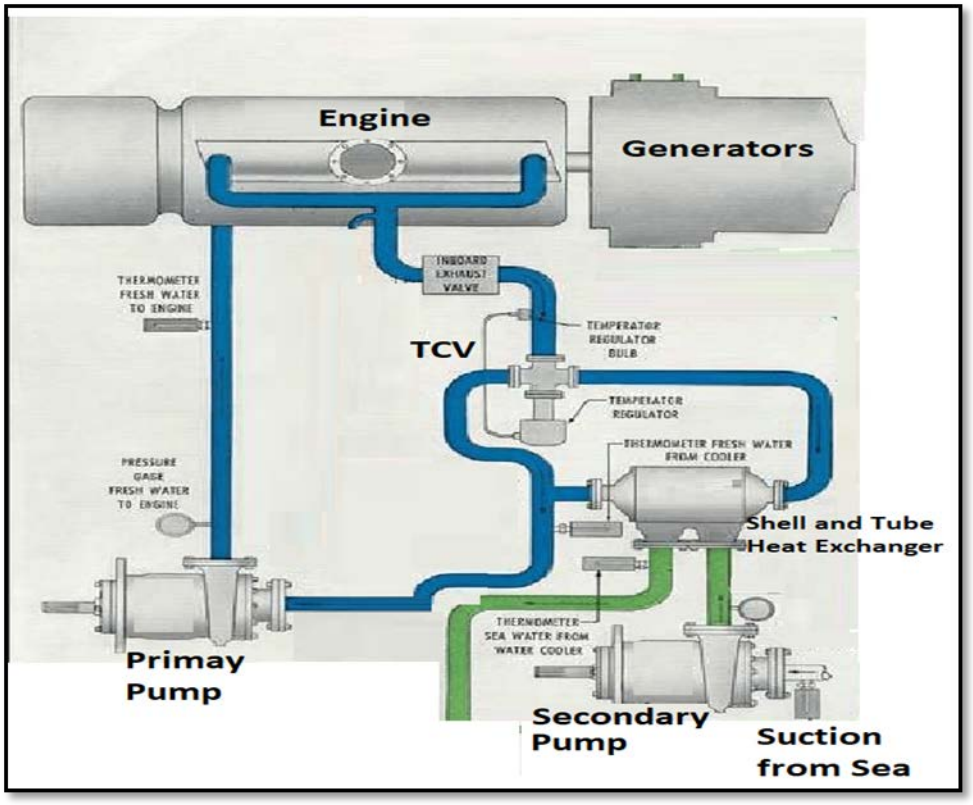

Fig. 4. Primary and secondary cooling cycle

2. Material and Methods

2.1. Nano particles Specifications

Nano particles were prepared with different size ranges from 10 to 40 nm. The Nano particles specifications are shown as in table 1.

Table 1. Nano particles specifications

Quality Level	100
Form	Dispersion nanoparticles
Concentration	20 wt. % in isopropanol

particle size	10 - 40 nm
PH	8-10
Density	0.79 g/cm^3 at 25 °C

2.2. Test Methodology

In this study, Al_2O_3 Nano particles were added to the fresh water with different particle sizes and different weight percentages in order to increase the heat transfer coefficient of fresh water and heat exchanger effectiveness. The most proper particle size and weight percentage that has the highest heat exchanger effectiveness was determined for different diesel engine RPM (load). So, a test rig was designed and constructed for marine diesel engine "Model No. 3116-CAT" to monitor the Nano fluid outlet temperature from the heat exchanger.

To study the effect of Nano particles in heat exchanger effectiveness, the outlet temperature of Nano fluid was measured for the following cases and the results will be compared:

- The engine was operated at half load condition (1800 RPM). Nano particles samples from Al_2O_3 were prepared with different particle size with the same weight percentage.
- The engine was operated at no load condition (idle speed - 700 RPM). Nano particles samples from Al_2O_3 were prepared with different weight percentage with the same particles size.
- The engine was operated at half load condition (1800 RPM). Nano particles samples from Al_2O_3 were prepared with different weight percentage with the same particles size.
- The engine was operated at full load condition (2400 RPM). Nano particles samples from Al_2O_3 were prepared with different weight percentage with the same particles size.

2.3. Instruments Used

To adjust the Nano particles weight percentage in the fresh water, digital balance was used. Its specifications are as in table 2:

Table 2. Digital Balance Specifications

Manufacturer	KERN
Max. Weight	5000 grams
Min. Weight	5 grams
Error	1 gram
Precision	0.1 gram

Also, temperature indicator was installed on the inlet / exit pipe of heat exchanger – primary coolant.

3. Results and Discussion

3.1. Effect of Nano particle size in Heat exchanger effectiveness

The Nano particles Al_2O_3 was prepared with concentration 0.1% weight of fresh water with different particle sizes; 10, 20, 30, and 40 nm. Each sample was added to the fresh water and circulated through the heat exchanger. Then, the exit temperature was measured for each case but at the same machine load (half load 1800 RPM). From (figure 5), it is shown that the higher heat transfer and higher heat exchanger effectiveness was obtained at smaller particle size 10 nm. So, the most proper Nano particle size embedded in the fresh water is 10 nm.

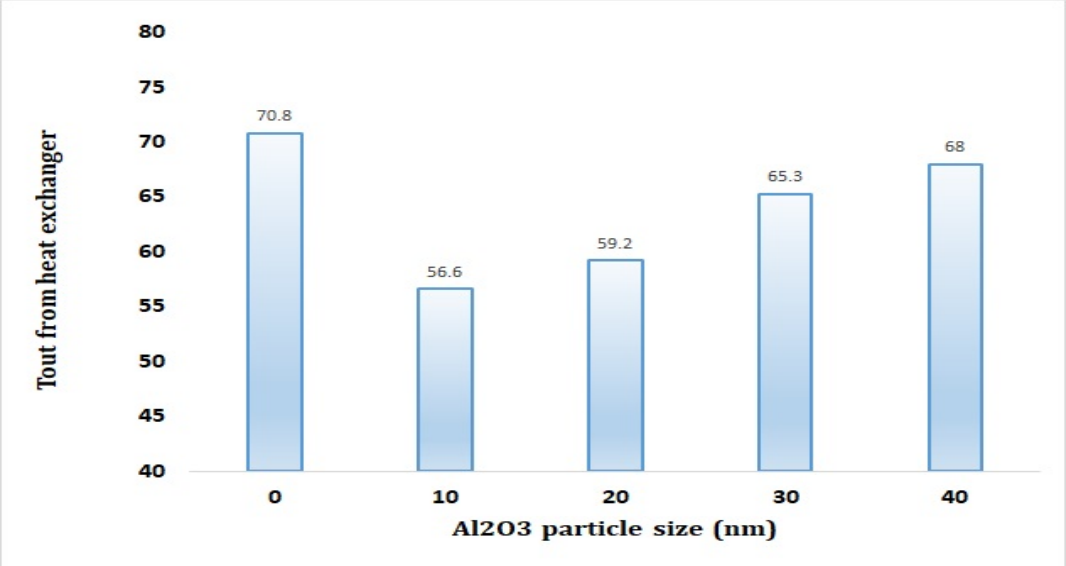

Fig. 5. Effect of nano particle size

3.2. Effect of Nano particle weight percentage at no load in Heat exchanger effectiveness – Constant particle size

The Nano particles Al_2O_3 was prepared with size 10nm for different weight percentage 0.1, 0.2, 0.3, and 0.4% weight of fresh water. Each sample was added to the fresh water and circulated through the heat exchanger. Then, the exit temperature was measured for each case at no load condition (idle speed – 700 RPM). From (figure 6), it was shown that there were no significant changes in exit temperature.

The primary cause behind the minor changing is that the diesel engine was in idle speed mode and no excessive heat generated inside the engine.

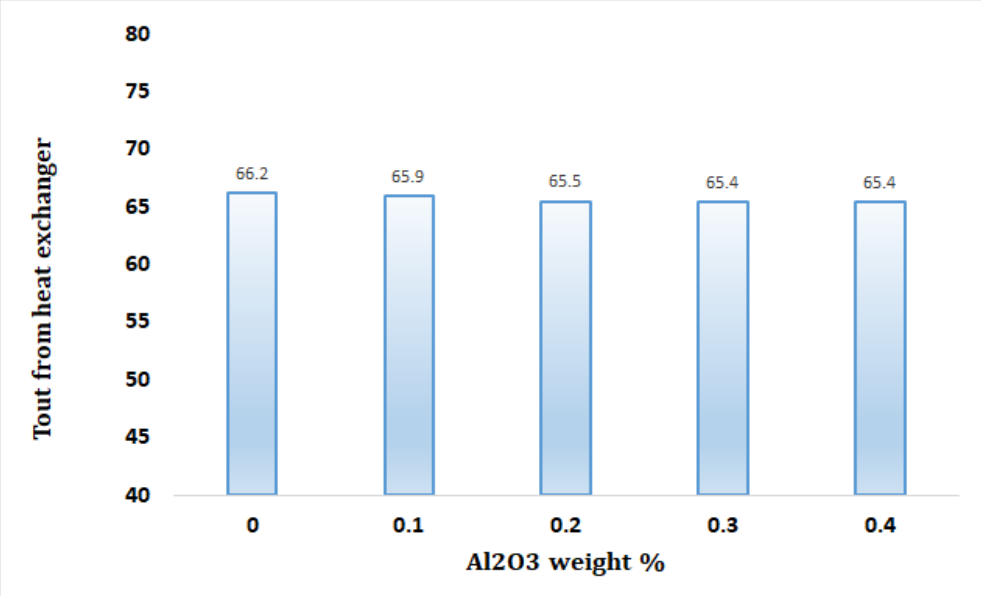

Fig. 6. Effect of nano particle weight % at no load

The heat exchanger temperature difference for free and 0.4% weight Nano particle is shown in (figure 7). So, at no load condition, it is recommended not to use Al_2O_3 nanoparticles.

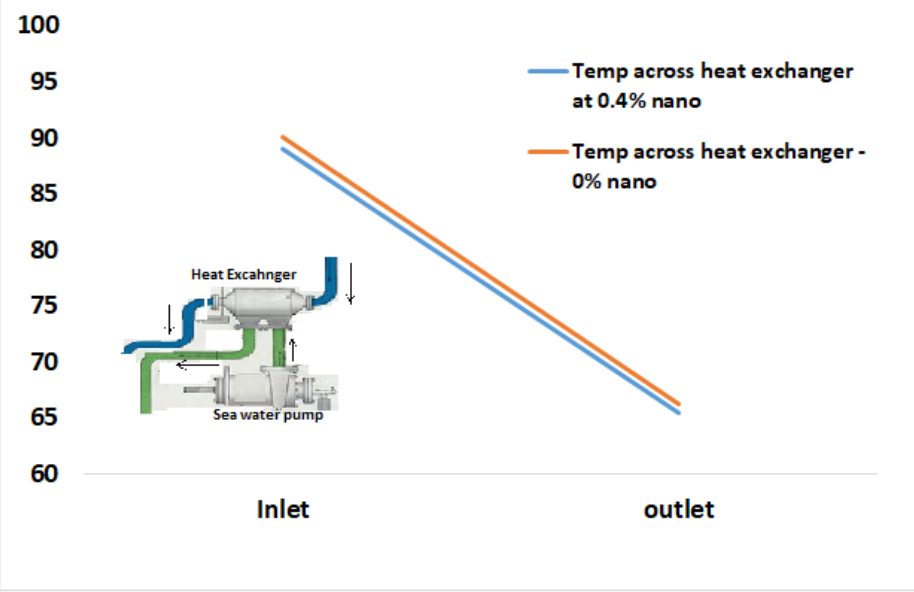

Fig. 7. Temperature across the heat exchanger for fresh water at no load

3.3. Effect of Nano particle weight percentage at half load in Heat exchanger effectiveness – constant particle size

The Nano particles Al_2O_3 was prepared with size 10nm for different weight percentage 0.1, 0.2, 0.3, and 0.4% weight of fresh water. Each sample was added to the fresh water and circulated through the heat exchanger. Then, the exit temperature was measured for each case at half load condition (1800 RPM). From (figure 8), it was shown that as increasing the nanoparticle weight percentage in fresh water, the heat exchanger effectiveness increases significantly.

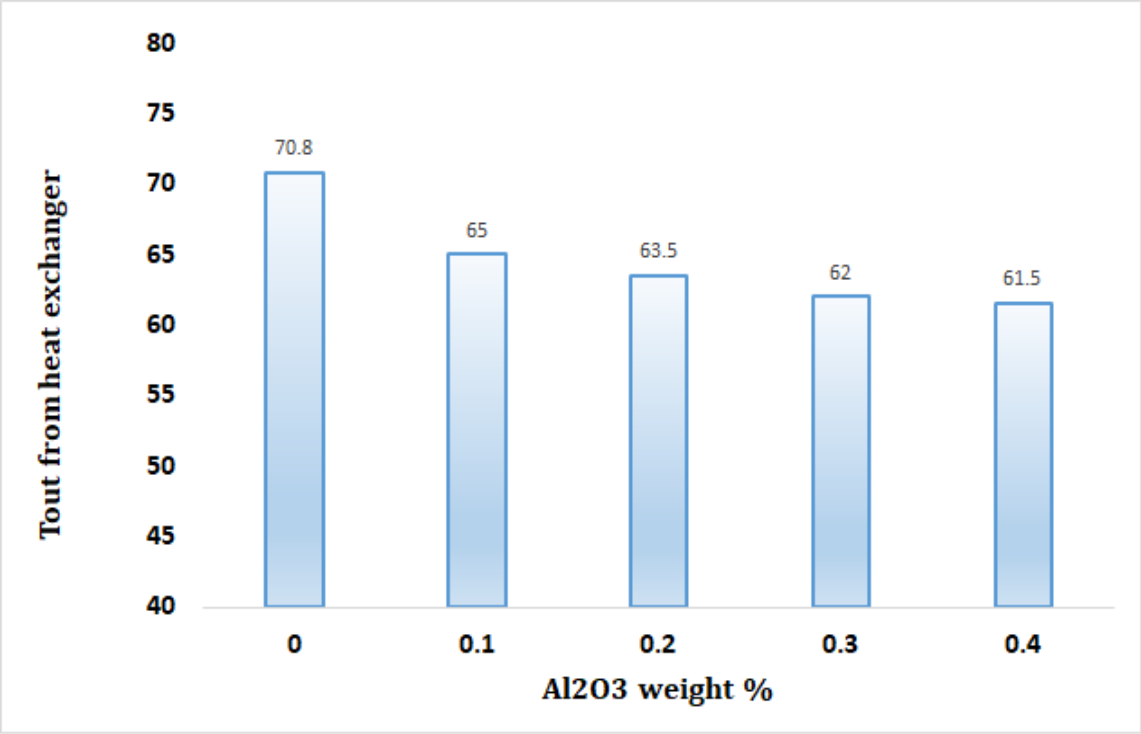

Fig. 8. Effect of Nano particle weight % at half load

The heat exchanger temperature difference for free and 0.4% weight Nano particle is shown in (figure 9). However and from figure 3.4, 0.3% Nano can be used because there is no significant change occurred between usage of 0.3 and 0.4% nano particles. So, 0.3% weight percentage of Nano Al_2O_3 is much recommended.

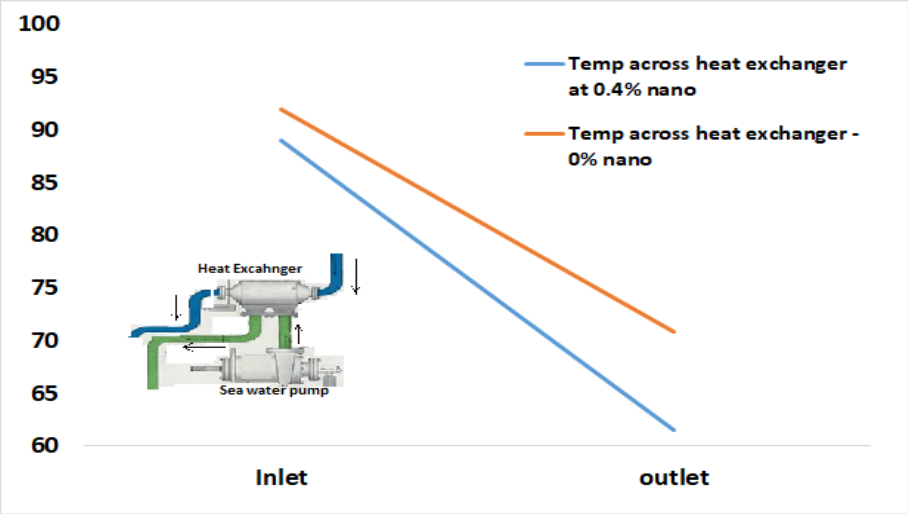

Fig. 9. Temperature across the heat exchanger for fresh water at half load

3.4. Effect of Nano particle weight percentage at full load in Heat exchanger effectiveness

As before, the Nano particles Al_2O_3 was prepared with size 10nm for different weight percentage 0.1, 0.2, 0.3, and 0.4% weight of fresh water. Each sample was added to the fresh water and circulated through the heat exchanger. Then, the exit temperature was measured for each case at full load condition (2400 RPM). From (figure 10), it was shown that as increasing the Nano particle weight percentage in fresh water, the heat exchanger effectiveness increases significantly.

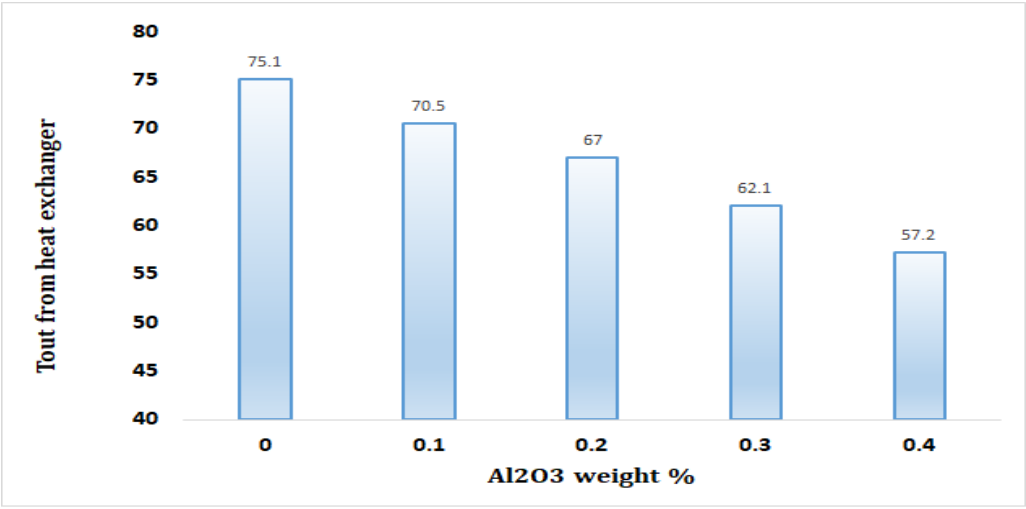

Fig. 10. Effect of Nano particle weight % at full load

The heat exchanger temperature difference for free and 0.4% weight Nano particle is shown in (figure 11). High content of Nano Al_2O_3 increases the heat transfer and enhances the heat exchanger effectiveness significantly. So, 0.4% weight percentage of Nano Al_2O_3 is much recommended.

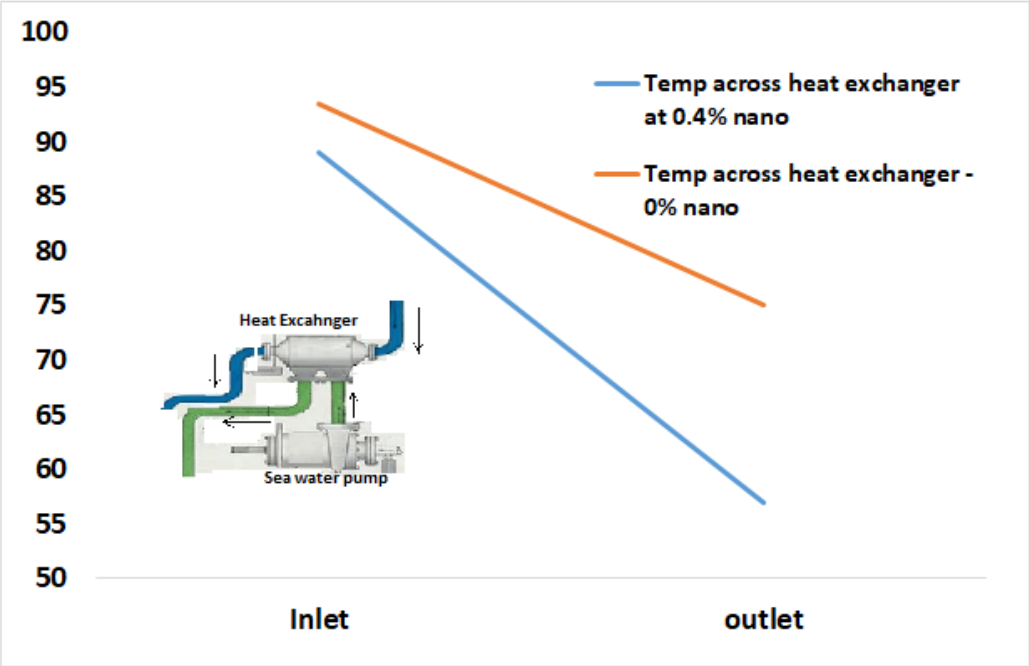

Fig. 11. Temperature across the heat exchanger for fresh water at full load

4. Conclusion

To increase the heat transfer and heat exchanger effectiveness; Nano Al_2O_3 was added to the fresh water as the primary coolant for the marine diesel engine. It was added with a several weight percentages and particle sizes. The experimental study confirm and validate the following results for marine diesel engine "Model No. 3116 CAT":

- As increasing the particle size of Nano particles in the Nano fluid, the heat transfer decreases compared with smaller nanoparticles.
- As increasing the weight percentage of Nano particles in the Nano fluid, the heat transfer increases and the exit temperature of heat exchanger decreases. The effect of increasing depends on engine load.

So, it is recommended to perform the following conditions to have the highest heat exchanger effectiveness:

- Use 10 nm of Al_2O_3 as a particle size.
- Don't use Nano Al_2O_3 at engine idle speed (no load condition).
- Use 0.3% weight percentage of Nano Al_2O_3 at engine half load (1800 RPM).
- Use 0.4% weight percentage of Nano Al_2O_3 at engine full load (2400 RPM).

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