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Original Research Article



# Water pump filter removal and filter performance study at heavy commercial vehicle engine

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**ABSTRACT**

Cooling systems are one of the essential systems for internal combustion engines. They prevent damage to engine parts and extend the engine's life by removing the high heat generated by the combustion from the engine. These systems vary depending on the engine's volume, combustion pressure, coolant flow, and types and may differ in light commercial and heavy commercial vehicles. These differences are generally observed in the water pump used, type of refrigerant, filter systems, and pump control mechanisms. The most apparent differences are in the water pump and filter systems. Light commercial vehicles do not have a filtration system, while most of the heavy commercial vehicles have a filtration system. There are many studies in the literature focusing on the performance and durability of the filter systems.

In this study, the necessity of the filter system in the cooling systems of heavy commercial vehicles, system filtration performance, and whether it is possible to work without a filter were investigated. A water pump performance test setup was used to simulate the real engine condition. The test was performed at 110°C coolant temperature, 1 barg input pressure, and with 53.195gr contamination. Results of the study showed that removing the filter from the coolant system after the first service shortens the life of the water pump.

**Keywords:** Heavy Commercial Vehicle, Filtration, Water Pump, Test, Performance

## 1. Introduction

One of the most significant factors determining the life of engine parts in internal combustion engine systems is the amount of heat released due to combustion. When this heat is not controlled, the occurring high-temperature values reduce the life of the engine's internal parts such as piston, crankshaft, and the external parts connected to the engine such as EGR and Turbo due to the heat transfer caused by convection and radiation. To be able to remove this heat from the engine and keep the temperatures under control, a sub-system called "cooling system" consisting of many parts has been designed for internal combustion engines. If this system does not work correctly and efficiently, the engine will become unusable [1]. Establishing engine thermal management models and developing correct assumptions are among the most common workgroups performed throughout the relevant system. Pizzonia and Bova developed a new control model to control the cooling system in gasoline engines by using the MPC (Model Predictive

Control) method [2]. This model solved the engine's heat balance equations with flow rate data. In the study, taking into account the local boiling, the water pump was operated at the minimum speed. Similarly, Cortana and Onder modeled the cooling system parts of the engine and developed a pump control on this model [3]. When a cooling system is examined, it is seen that it consists of many sub-parts such as a water pump, radiator, and thermostat [4, 5]. The most important of these parts is the water pump that provides circulation in the engine, consumes engine power, and directly affects fuel consumption. According to Cao and Zhang, since the cooling system plays an active role in the reliable, stable, and efficient operation of the engine, water pump designs should go parallel with the cooling system development [6]. They also explained the development, production, and testing processes of a water pump in detail (Figure 1).

When the tests indicated in table 1 and the engineering specifications of OEM companies are examined, it has been seen that only numerical and experimental performances are not enough for water pumps to have a long life and to get the sign-off approval [7]. In the technical reports published by USMW, CATERPILLER, and GMB companies, the problems encountered in water pumps are explained in detail together with the examination. It has been concluded that the following reasons cause most of the problems [8, 9, 10]:

- Failure to Comply with Pump Production and Assembly Procedures or Incorrect Application
- Loss of Chemical Properties of the Coolant Used in the System
- Contamination/Deposit Formation in the coolant and Interactions with Internal Parts
- Insufficient Amount of Coolant in the System and Creating the Risk of Cavitation

Among the related issues, the effects of coolant and coolant types (traditional or long-life type) on the engine and cavitation effect in water pumps are among the most researched topics in the literature. A study conducted by Scott, Orth, and Miller formulated and shared the effect of coolant types on water pump damage rates [11]. Based on the data obtained from field vehicles, the authors determined that water pump damage was 15% less in vehicles using long-life coolers containing carboxylic acid. Consequently, they revealed that the total distance traveled was extended (from 101816 km to 145756 km), and service time increased. On the other hand, in the study conducted by Hudgens and Hereamp, organic acid technology and traditional coolant technologies were compared [12]. It was observed that the water pump failure rates did not change. This result showed that organic acid technology tested in coolants and conventional technology has the same effect. In addition, the authors also examined the effects of engine protection additives (Borate/Nitrite or Silicate/Low Nitrite) in detail, and they explained that if too much additive is added, a large amount of deposit may occur in the system due to the fluid chemical, and this will have a negative effect on the pump.

Table 1. Water Pump Development and Sign-Off Test [6]

| Test name | Test objective | Test requirements |
|---|---|---|
| Leak test | Chek pump leakage | Leakage: cover total: 2.5 ml/min; assembly: 6 ml/min |
| Index point performnace test | Performance meets requirements | Performance to achieve the target point requrements |
| Cavitation's test | Performance meets requirements | No cavitations' occurs when importing 0 Kpa |
| Evaporation test | Comprehensive performance water seal | No more than 300 mg/hr |
| Seal Face Temperature Measurement | Matching of water seal and assembly | The difference between the water surface temperature and the inlet temperature is less than 6 °C |
| Reliability test | Reliability | More than 1000 hours |

## 2. Materials and Methods

Particles thrown into the coolant to protect the engine or chemicals disposed to increase heat transfer and cooling efficiency cause deposit accumulation in the engine coolant and adverse effects on the pump or cooling in later stages. Engine problems are related to cooling systems, especially in 40% of diesel vehicles [12]. The positive benefits of using the filtration system were discussed in the literature [13]. In the study conducted by Eaton and Duvnjak, over 70 heavy commercial vehicle filters were examined, and the results of these examinations were reported [14]. Their results showed that there are parts on the filters due to oily contamination, assembly, production, and corrosion. If these parts are not kept in the filter, they increase cavitation, accelerate the part surface erosion, cause damage to the pump bearings, and create a deposit problem in the cooling system. Based on this, they revealed the necessity of using filtration systems in heavy commercial vehicles. In another study conducted by Howard, a new method for cleaning the cooling system was proposed [15]. In the mentioned study, it was stated that during the maintenance and repair operations on the engines of the GMC Company, flow tests were applied on the radiators older than six months, and 17-22% of the radiators that entered these tests failed the test. It was noted that 95% of the radiators that failed the test were completely blocked and there was no flow. For this reason, it was mentioned that the radiator fan had to work 100% at all times [15]. In addition, when this situation is considered for the engine, it is evident that it will both increase fuel consumption and change vehicle emission values. Therefore, the importance of filtration in heavy commercial vehicles is emphasized once again. Hudgens and Hercamp compiled previous studies on filtration in heavy commercial vehicle engines and did a general literature review [16]. Their study showed that unfiltered systems cause more problems than filtered systems. It was stated that the needs for heavy commercial vehicles are higher together with light commercial vehicles. It was indicated that the reason for this is the increase in the number of aluminum parts used in the engines and the increase in the amount in the cooler due to the aluminum erosion, the extension of the service of the coolant cleaning process, and the addition of extra components such as EGR to the engines [16].

It has been emphasized in the studies that filter systems should be changed at certain kilometers depending on the operating conditions of the engine. However, the engine's filtering systems require additional maintenance costs in terms of both the customer use and the manufacturer's engine production process. Thanks to the developing technology, the development of long-life antifreeze and the addition of soluble additives with cleaning properties to the systems have led to different strategies in today's heavy vehicle truck engines. One of these strategies is to remove the water filter from the system. However, in the benchmark studies, it has been determined that some heavy commercial OEM companies do not use water filters in their engines.

This study focuses on whether heavy commercial vehicles can operate without a filter. If it is possible to operate without a filter, it will be planned to disassemble the filter at the first service time and continue to operate without a filter. The test cycles in the study were created specifically for this scenario. In this way, it will be ensured that;

- a part that may cause problems in the engine will be eliminated,
- no additional costs will arise for the customer due to filter replacement during service times.

In order for this study to be successful;

- Without a filter, the pump performance should not decrease.

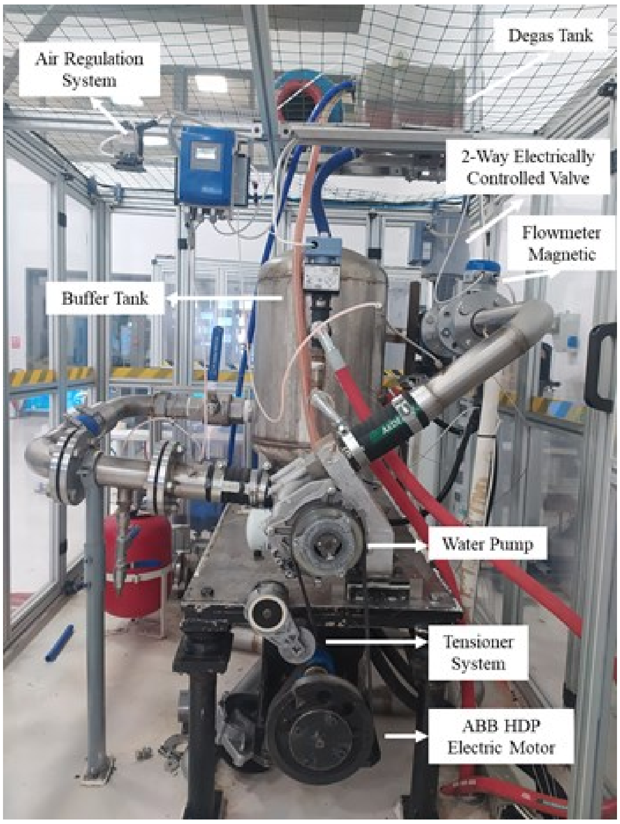
It is necessary not to face any problem affecting the performance of the pump mechanical parts after operating without the filter.

## 3. Test Setup and Instrumentations

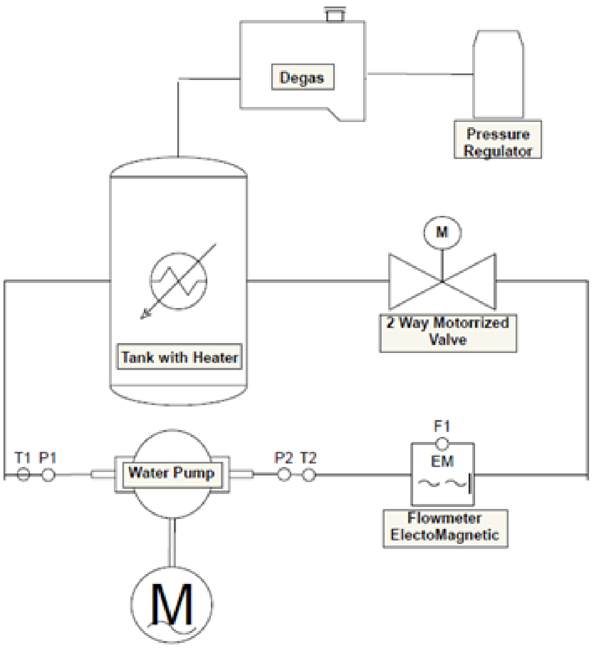
In the context of this study, the unfiltered operation of the pump was simulated after the filter was replaced during the first service. At the end of this study, the effects of contamination on the water pump flow rate and mechanical components were investigated after removing the filter. In addition to that, the performance of the filter was calculated.

For this research, a water pump performance test setup was built in the laboratory and used. The general features of the test setup, the measuring equipment, and the instrumentation points are shown in detail in Figure 1.

The main element of the test setup is the water pump. The AC motor provides the operation of the water pump at different speeds. Movement transfer from the motor to the water pump is done with a belt.




a.




b.

Figure 1. a) Water pump performance test setup b) Schematic drawing of the test setup

There is a 100lt water tank in the system. There is a 2-way valve on the test bench to simulate the water pump's back pressure in the engine. With the help of this valve, the system can be tested under the engine conditions of the water pump by adjusting the system according to the pump speed and flow values obtained from the engine or the manufacturer at the beginning of the test. In the tank, there is a heater providing performance and life tests at different engine water temperatures (50-120°C). A pneumatic regulator is connected to the tank line for testing the system at different pump inlet pressures.

There are six instrumentation points:

- Pump Water Inlet Temperature, (°C), K Type Class-1 Thermocouple
- Pump Water Outlet Temperature (°C), K Type Class-1 Thermocouple
- Pump Water Inlet Pressure (barg), Piezoresistive Gauge Pressure Sensor
- Pump Water Outlet Pressure (barg), Piezoresistive Gauge Pressure Sensor
- Flow (kg/hr), Electromagnetic Flowmeter
- Pump Speed (rpm)

## 4. Test Procedure

The test procedure consisted of 4 different stages.

### 4.1. First Stage (Pre-Road Process) (Before Service)

At this stage, until the first service time, the maximum amount of contamination (53.195g) that the filter could absorb was mixed into the coolant. The aim was to simulate the operation of the pump until the first Service. The calculation details of the contamination are presented in Table 2.

The pump was operated for 20 hours with a contaminated coolant at the most intensely used point by the customer (3000rpm pump speed, one barg pump inlet pressure, 100 ° C water temperature). The first test was determined for 20 hours because the filters reduce water pollution to a minimum of 6-10 hours, as indicated by the manufacturer and studies mentioned above. Figure 2 shows the results of the coolant filter draw-down test.

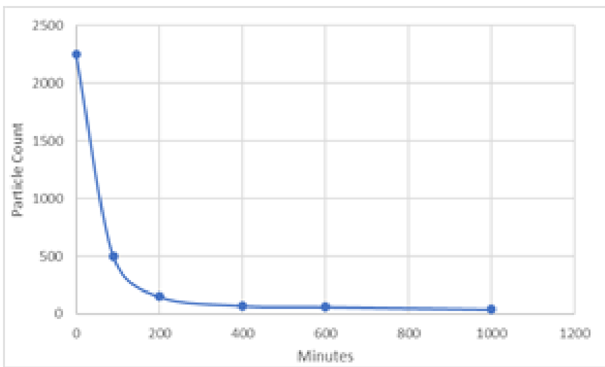



Figure 2. Coolant Filter Draw-Down Test

Table 2. Contamination Calculation and Details

| Particule | Cantents | Mg/lt | Mg/tot | g/tot | |
|---|---|---|---|---|---|
| 0 – 150 micron | Casting sand (13 mg) | 13 | 2 561 | 2.561 | |
| 150 – 300 micron | Casting sand (43 mg) | 43 | 8 471 | 8.471 | |
| 300 – 500 micron | Casting sand (41 mg)<br>Al Chips (41 mg) | 82 | 16 154 | 16.154 | |
| 500 – 800 micron | Contaminants from hot test (3.5 mg)<br>Al chips (13.5 mg)<br>Casting sand (13.5 mg) | 30.5 | 6 008.5 | 6.0085 | |
| --- | Arizona dust | 400 | 78 800 | 20 | 20 gr. Contamination added instead of 78.8 gr. |
| | | | | **53.195** | |

## 4.2. Second Stage (Service Process)

In the second stage of the test, the service moment was simulated. At this stage, the filter at the pump inlet was removed, and a plug was installed. All coolant was replaced with a new mixture. Before and after the filter change process was shown in Figure 3.

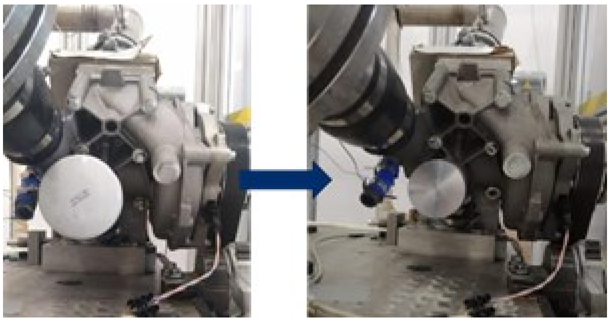


Figure 3. Filter Exchange

## 4.3. Third Stage (Road Process) (After Service)

The pump was operated without the filter for 200 hours under the limit conditions in the pre-test (3000 rpm pump speed, one barg pump inlet pressure, 100 °C water temperature).

## 4.4. Fourth Stage (Investigation)

The pump whose test was completed was sent to the manufacturer for inspection and final performance tests. In addition, the filter was dried in quality assurance laboratories, and the particle retention performance of the filter was calculated.

# 5. Test Results

## 5.1. Water Pump Filter Investigation

The water pump, which was disassembled in the first stage, was heated at 90 °C in the furnaces and weighed for two months in the quality assurance laboratories. Weighing results and their graphical distribution are shown in Table 3.

Table 3. Filter Weight Measurement Table

| Date | Time | Filter Weight (gr) | Differences (gr) |
|---|---|---|---|
| 22.08.2019 | 11:00 | 943.31 | |
| 23.08.2019 | 11:15 | 855.87 | 87.43 |
| 24.08.2019 | 17:05 | 786.55 | 69.32 |
| 26.08.2019 | 11:57 | 722.51 | 64.04 |
| 27.08.2019 | 17:20 | 681.53 | 40.98 |
| 28.08.2019 | 10:18 | 669.32 | 12.21 |
| 29.08.2019 | 18:35 | 657.9 | 11.42 |
| 30.08.2019 | 17:50 | 632.02 | 25.88 |
| 31.08.2019 | 17:25 | 628.15 | 3.87 |
| 2.09.2019 | 10:47 | 625.01 | 3.14 |
| 4.09.2019 | 11:21 | 618.75 | 6.26 |
| 5.09.2019 | 15:48 | 614.69 | 4.06 |
| 6.09.2019 | 11:13 | 612.86 | 1.83 |
| 9.09.2019 | 13:20 | 605.37 | 7.49 |
| 10.09.2019 | 10:36 | 603.33 | 2.04 |
| 11.09.2019 | 10:36 | 600.81 | 2.52 |
| 12.09.2019 | 14:10 | 597.92 | 2.89 |
| 13.09.2019 | 13:05 | 596.47 | 1.45 |
| 14.09.2019 | 15:30 | 594.21 | 2.26 |
| 16.09.2019 | 15:40 | 589.83 | 4.38 |
| 18.09.2019 | 10:38 | 585.9 | 3.93 |
| 19.09.2019 | 10:30 | 583.06 | 2.84 |
| 20.09.2019 | 11:20 | 580.86 | 2.2 |
| 23.09.2019 | 16:40 | 577.45 | 3.41 |
| 24.09.2019 | 16:25 | 575.17 | 2.28 |
| 25.09.2019 | 17:15 | 572.46 | 2.71 |
| 26.09.2019 | 17:25 | 569.81 | 2.65 |
| 27.09.2019 | 17:20 | 568.58 | 1.23 |
| 28.09.2019 | 17:20 | 568.06 | 0.52 |
| 30.09.2019 | 17:20 | 566.93 | 1.13 |
| 1.10.2019 | 21:47 | 566.62 | 0.30 |
| 2.10.2019 | 23:00 | 566.35 | 0.26 |
| 3.10.2019 | 19:30 | 566.06 | 0.29 |
| 4.10.2019 | 21:40 | 565.7 | 0.35 |
| 5.10.2019 | 22:20 | 565.35 | 0.35 |
| 7.10.2019 | 13:00 | 565.01 | 0.34 |
| 8.10.2019 | 13:00 | 564.68 | 0.33 |
| 9.10.2019 | 13:00 | 564.39 | 0.28 |
| 11.10.2019 | 10:10 | 563.66 | 0.73 |
| 12.10.2019 | 13:30 | 563.41 | 0.25 |
| 14.10.2019 | 13:30 | 563.16 | 0.25 |
| 16.10.2019 | 15:00 | 562.65 | 0.50 |
| 17.10.2019 | 14:35 | 562.52 | 0.12 |
| 18.10.2019 | 14:11 | 562.4 | 0.12 |
| 21.10.2019 | 14:11 | 562.3 | 0.10 |

For weighing, a precision balance of 0.01 gr was used. After the operation, the filter performance was determined as 13.76% as a result of the calculation made according to the following equation.

$$\%_{Performance} = \left(\frac{Mfilter_{Last} - Mfilter_0}{M_{Contamination}}\right) x\ 100 \quad (1)$$

$$\%_{Performance} = \left(\frac{562.3gr - 554.98gr}{53.195gr}\right) x\ 100 \quad (2)$$

$$\%_{Performance} = 13.76 \quad (3)$$

### 5.2. Water Pump Investigation

The following performance and capability tests were performed on the pump sent to the manufacturer after the test (the pump was torn down for visual inspection). The tests and their results are detailed below.

#### 5.2.1. Water Pump Performance Test

After the performance tests were performed, it was observed that the pump rates decreased by more than 10%.
Results of the pump flow control tests performed with different pump rates are shown in Figure 5.

#### 5.2.2. Water Pump Leakage Test

For the leakage test, the pump was connected to the relevant system. As a result of the test, it was observed that there was no problem with pump sealing.
The leakage rate (12Pa @ 3.00bar) was below the limit value (35Pa @ 3.00bar) as shown in Figure 4.

#### 5.2.3. Water Pump Clutch Test

After the tear-down, the pump clutch system was tested on a special control mechanism shown in Figure 6. In the related test, the clutch system was controlled from 3 points, and it was found that the system remained within the determined limits (0.20 - 0.60 mm).

#### 5.2.4. Water Pump Pulley Test

After the test performed to see if the pump pulley had undergone any deformation, it was determined that the pulley profile remained within limits (± 15mm). The pulley control test system is shown in Figure 7.

#### 5.2.5. Water Pump Tear Down

After the tear-down of the pump, heavy pollution on the pump parts and deformation on the pump winglet were observed. Tear-down pictures are shown in Figure 9.

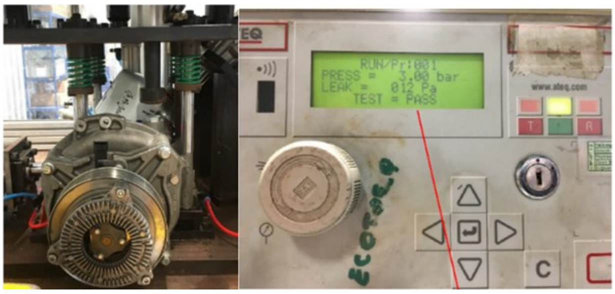



Figure 4. Leakage Test and Results

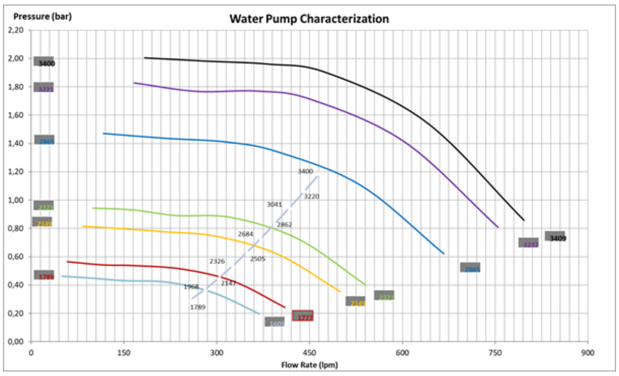



Figure 5. Water Test Pump Performance Test

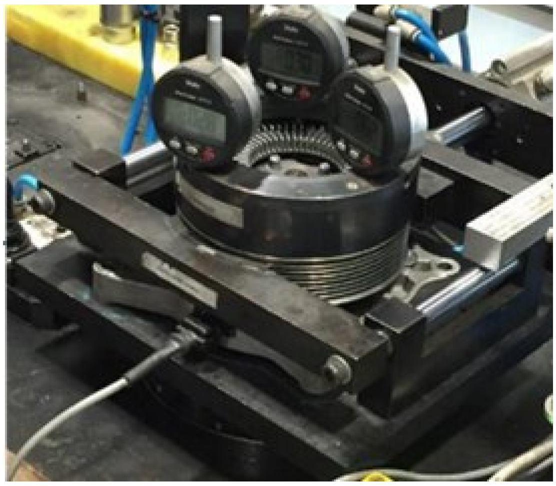


Figure 6. Clutch Test

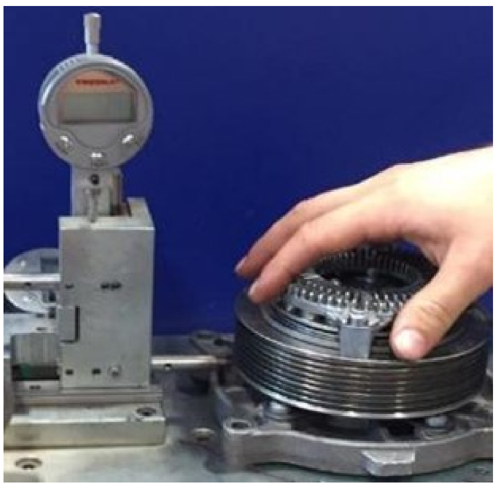


Figure 7. Pump Pulley Test

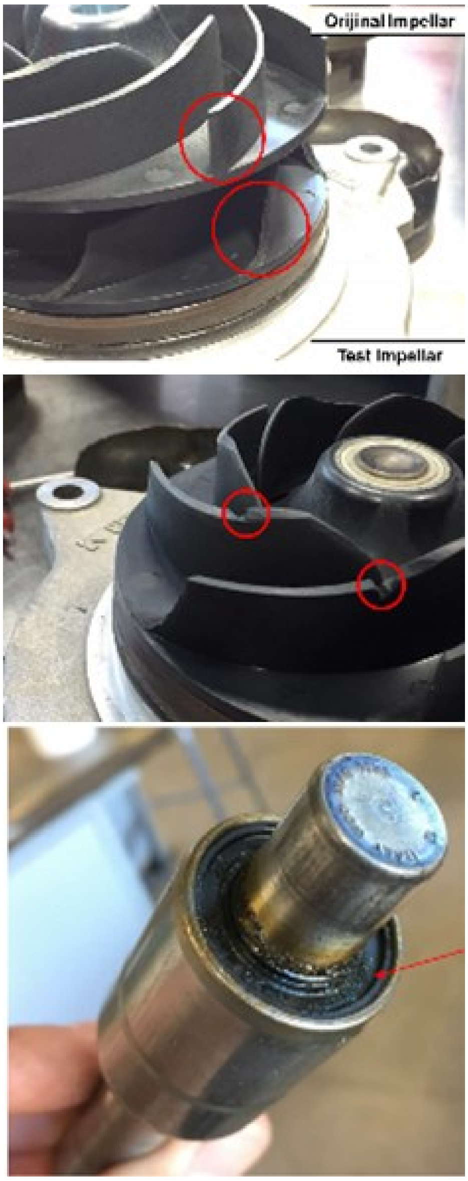



Figure 8. Test Pump Tear-Down

## 6. Conclusion

As a result of tests and analyses carried out in this study, it was observed that 13.76% of the contamination added to the water pump system was retained in the filter and the remainder in the pump and sub-equipment. In the inspections made on a piece-by-piece basis, no damage and, therefore, no leakage was observed on the pump seal, although it was exposed to heavy pollution. Contamination accumulating on the pump and returning to the system caused damage to the pump blades.

The results of the study revealed that the idea of removing the filter after the first service period, which was the purpose of the test, was not successful. On the other hand, the pollution boundary condition accepted in the test consisted of a mixture of long-term deposits and metal particles from the engine from production. In addition, no new generation organic acid technology antifreeze mixture or additives to prevent sediment accumulation were used in the study. At this point, it is thought that it may be possible to remove the filter from the system after the first service with an effective washing system to be made before the engine assembly and a complicated secondary washing system to be made at the end of the line. Therefore, for a future study, it is considered that vehicle and the dynamometer tests should be completed after removing the filter from the system.

**CRediT authorship contribution statement**

Ismail Hakki Savcı: Writing - original draft, Investigation, Supervision, Conceptualization, Methodology, Yavuz Can Özkaptan. Investigation, Writing-review & editing. Software, Testing, Mehmet Demir: Testing, Problem Definition,

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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