# Enhancing vehicle's engine warm up using integrated mechanical approach

**T. M. Ibrahim*[1], A. Z. Syahir[1], N. W. M. Zulkifli[1], H. H. Masjuki[1], A. Osman[2]**
[1]Department of Mechanical Engineering, Faculty of Engineering, University of Malaya
[2]Powertrain Department, Engineering Division, Proton Malaysia

E-mail: *ymtmis@um.edu.my

**Abstract.** Transportation sector covers a large portion of the total energy consumption shares and is highly associated to global warming. Growing concern over the harmful gases being emitted from vehicles and their environmental implications has urged the need for pollutant reduction through more efficient engines. Good engine thermal management especially during cold-start warm up phase has been proven to enhance the engine efficiency in terms of fuel economy and greenhouse emissions specifically. In this study, the viability engine split cooling system was tested in two separate test. The parameters of interest include coolant and transmission temperature as these both parameters indicate the internal engine condition and highly associated with engine efficiency. In the first idle test, coolant temperature within the modified cooling configuration reached the optimum coolant temperature of 60 °C about 41.28% faster when compared to baseline configuration. The modified configuration also heat up the transmission oil around 4 times faster. In the second NEDC test which simulates the real time driving condition, the coolant of the modified vehicle reached the optimum temperature around 28.26% compared to the baseline.

## 1. Introduction

Energy generation through combustion is expected to remain as the most important method for at least another 30 years [1]. Currently, transportation sector covers most of the total energy consumption shares and accounted to 13.5% of the total global warming [2, 3]. Growing concern over the harmful gases being emitted from vehicles and their environmental implications has urged the need for pollutant reduction through more efficient engines. High demands for efficient engines are also attributed to stringent environmental regulations and high fuel cost. Most of the spark ignition (SI) engines used today are well optimised in terms of combustion efficiency, with approximately 95-98% of the fuel energy content being released during combustion [4, 5]. However, the useful energy leaving the engine (brake power) is only around 40% of the fuel energy [5, 6]. Owing to the above implications, thermal efficiency for internal combustion engines (ICE) has become the main design criteria for academic societies and engine designers.

It is largely accepted that one of the purpose of thermal management is to decrease engine warm up time, consequently reducing the fuel consumption [7]. During engine warmup phase, the engine thermal efficiency is low as more fuel is consumed due to; 1) high friction at engine components exerted by cold lubricant at 2) less efficient combustion at cold condition. Energy loss due to friction within engine during the early stages of warm-up (in the range of 20 ºC) was estimated to be 2.5 times higher compared to when in optimum temperature condition [6, 8]. In different studies, Trapy and Damiral [9] and Will and Boretti [8] reported that during cold-start warm up phase, only 9% of energy from the fuel is converted to effective work, a reduction of approximately 30% compared to warm (optimum) engine condition. Figure 1 presents the energy thermal balance during warm up phase. It can be observed from the right-hand chart that only 4% of the transferred heat is used to warm up the engine oil while 52% from the total heat transfers were found to be unused, in other way lost directly to the environment.

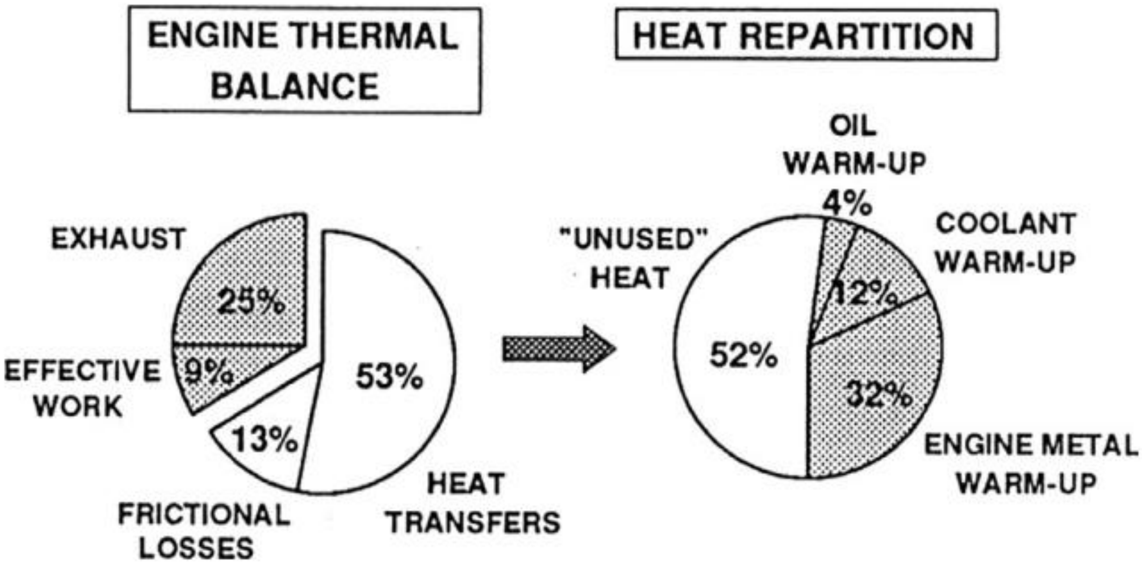


**Figure 1.** Thermal balance diagram during warm-up phase [9]

Samhaber et al. [10] predicted and increases in fuel consumption can be up to 13.5% during the warm up phase of an engine in a cold-start scenario of around 0 ºC. Therefore, a number of strategies and potential solutions have been proposed in the effort of shortening the engine warm up time. By shortening the time in which the engine is operating inefficiently, more fuel can be saved, leading to lower amounts of pollutant emissions will be emitted [11]. The engine components also will experience lower amount of wear corresponding to efficient lubricants performance at optimum temperature, resulting in longer engine life. Previous studies have tried the possibility of controlling the thermal status of the engine (over- and under-cooling) by the implementation of special mechanisms that could manipulate the coolant flow through engine and radiator [12, 13]. Suggested improvements include the utilization of electronically controlled coolant pumps [14-16], fans, thermostats and shutters [17, 18]. In a study, Torregrosa et al. [19] did some modifications on the baseline engine cooling system based on the simulation carried out in their earlier studies. Five different configurations were tested. The results suggested that one of the selected configurations reduced the warm-up period by approximately 159 s when compared with the baseline configuration. Reductions in fuel consumption and pollutant emissions (HC and CO) were also obtained.

In recent years, the feasibility of engine split cooling system as an alternative solution in reducing engine warm up time is gaining in interest. Engine split cooling configuration include the separation of head and block cooling to allow the engine blocks get hot in relatively shorter time while keeping the engine head cool. Engine head operated at a high temperature can experience cracking, subsequently causing catastrophic damage to the engine. Meanwhile, getting the engine blocks to an elevated temperature is important to reduce the warm up time and permitting to increase compression ratio which improves thermodynamic engine efficiency. Using mathematical modelling, Cipollone et al. [7] analysed the reliability of engine split cooling system and proposed two potential solutions. The first solution is that the coolant is let to flow into the engine head first. As it flows out, only a part of it is used to cool the blocks, the remaining part is by passed through and re-mixed together outside the engine. The second solution is that the block cooling is done with a greater coolant flow rate with respect to that crossed the engine head. This can be achieved by re-mixing a part of coolant leaving the engine before re-entering the engine block.

In this study, engine split cooling system will be further explored to prove its scientific viability. Two separate test were conducted. The first test was the idle test to check viability of the split cooling configuration in reducing engine warm up time in a typical cold start condition. In the second test, road tests will be carried out using instrumented vehicle equipped with split cooling system running at different drive cycles as per New European Driving Cycle (NEDC) requirements. The parameters of interest include coolant and transmission temperature as these both parameters indicate the internal engine condition and highly associated with engine efficiency. Test using baseline vehicle was conducted for comparative analysis and therefore to determine whether it is practical and beneficial to replace the existing cooling system with engine split cooling system.

## 2. Methodology

### *2.1 Equipment*

#### *2.1.1 Chassis dynamometer*

Chassis dynamometers is used for complete road simulation in measurement of vehicle emission, fuel consumption, and vehicle performance. A chassis dynamometer can be referred as a rolling road, measures power delivered to the surface of the "drive roller" by the drive wheels. The vehicle is often parked on the roller or rollers, which the car then turns, and the output measured thereby. This machine would be used in conducting the New European Driving Cycle (NEDC) test.

#### *2.1.2 Data collection systems*

Integrated Calibration and Acquisition System (INCA), a leading software in automotive industry is used for measurement, calibration and diagnostic. This software is connected to Engine Calibration Unit (ECU) to read and record the data taken from the engine system and built-in sensors of the engine. This software is used on both NEDC and Idle test. Graphtec Data Logger Model GL-820 is used for temperature data logging. The temperature of the targeted point is read and recorded by channelling the thermocouples to this equipment.

#### *2.1.3 Test rig*

Two units of vehicles are used for testing the simplified engine split cooling system. One unit is used for baseline (benchmark) with no modification while the other one is installed with the proposed simplified split cooling engine system. Table 1 and table 2 show the specification of the engine and vehicle used in this study. All unit was dedicated with thermocouples installed at certain targeted point as in table 3. By having this test rig, the changes and the characteristic of the enhanced integrated mechanical development of the system, can be evaluated closely based on its original condition (baseline).

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**Table 1**: Engine specifications

| **Engine Model** | Charge Fuel Efficient (CFE) turbo-charged spark ignition internal combustion engine |
|---|---|
| **Displacement Volume** | 1561 cc |
| **Induction System** | Single scroll turbocharger |
| **Fuel Injection System** | Gasoline Port Fuel Injection |
| **Stroke** | 86mm |
| **Bore** | 76mm |
| **Compression ratio** | 8.9:1 |
| **Coolant** | 20% Ethylene Glycol and 70% water |
| **Engine Oil** | PETRONAS Mach 5 10W30 |
| **Maximum Torque** | 205 Nm at 2000-4000 rpm |
| **Maximum Power** | 103 kW at 5000 rpm |

**Table 2**: Vehicle specification used for the test rig

| **Model** | **Proton Exora Bold** |
|---|---|
| **Type** | 7 Seater Multi-purpose vehicle |
| **Kerb Weight** | 1466 kg |
| **Transmission** | Punch CVT |
| **CVT heat exchanger** | Oil-to-radiator |
| **Intercooler** | Air-to-air |
| **Power Steering** | Hydraulic |
| **Maximum Speed** | 185 km/h |

**Table 3**: Thermocouple points of installation

| **Channel** | **Point of Installation** |
|---|---|
| **1** | Ambient |
| **2** | Engine Coolant |
| **3** | Engine Oil Sump |
| **4** | Transmission Oil Sump |

### *2.2 Modifications*

Integrated mechanical developments of the engine would be the key of this study. Comparing to other works, this strategy utilizes mechanical approaches rather than complicated electrical and electronic development within the engine compartments. Among the elements of consideration in the modifications are as follows;

#### *2.2.1 Arrangement of engine cooling system, transmission cooling system and turbocharger*

Compared to the conventional cooling system, the transmission cooling system and turbocharger cooling system has been arranged in series, which are right after the engine cooling system. This strategy was made to improve heat recovery and thermal distribution during cold start and engine warm up. Heat from the turbocharger and engine cylinder head can heat up the coolant and raise the coolant circuit temperature to optimal temperature. After the coolant reached its optimal temperature, this serial cooling configuration helps the turbocharger and transmission temperature to maintain their optimal temperature and thus avoid the engine, turbocharger and transmission oil from overheat or overcool.

Based on the idea of split cooling, having a separate flow of coolant circuit for the engine cylinder head and cylinder block would contribute in the improvement of engine performance [12]. Believing on every part of the engine have their own needs in temperature, such engine improvement could be achieved by introducing parallel flow which by splitting the normal flow which work in series. By having such “parallel-like” circuit for engine cylindrical head and engine block would improve the internal engine cooling by allowing better flow rate (can reach higher flow rate) and flow rate control (better coolant flow rate range and better feedback control) for the coolant inside the engine itself.

#### *2.2.2 Coolant flow*

Coolant flow has been modified as in figure 2. By introducing separate flow of coolant in engine head and engine block, better engine thermal management would be obtained. Some mechanical development has been done along with this coolant flow modification. The proposed system introduced dual exit point (due to dual parallel cooling circuit; cylinder head cooling circuit and cylinder block cooling circuit). This strategy improves the coolant flow rate by reducing pressure drop as well as the internal engine coolant flow restriction is reduced. The permanent bypass is shifted to the cylindrical block. As the cylindrical block has lower flow rate, therefore it is possible to have a bypass line without overcooling the engine block.

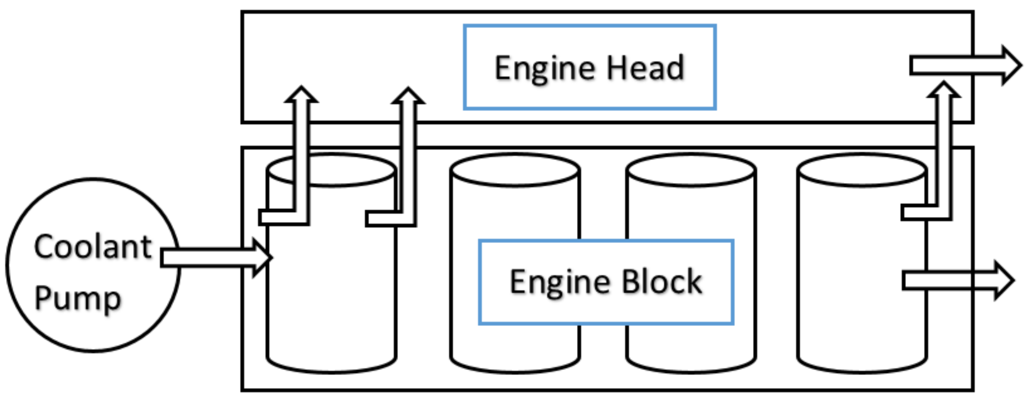


**Figure 2.** Proposed coolant flow layout

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### *2.2.3 Cooling pack (radiator and fan)*

Smaller cooling pack was introduced which is half of the original size. Smaller cooling pack gives lower coolant volume needed for heat exchanging as well as lower thermal inertia. Additionally, it will come with an extra advantage which lower in cost.

### *2.2.4 Single thermostat opening*

The introduction of a mechanically simpler cooling mechanism requires faster response in regulating the coolant temperature. Due to this concern, the opening temperature of the thermostat is modified by lowering the temperature for opening set point. In this study, the thermostat opening temperature is shifted from 72 °C to 67 °C, whereas 60 °C was the lower boundary of the optimum temperature range.

## *2.3 Test method*

The test is separated into two parts which are idle test and NEDC test. The explanation regarding these tests are described below. Temperature changes of two different fluids were measured which are the coolant and transmission oil. Coolant was selected as it represents the relative temperature of the engine blocks and warmed transmission oil was found to contribute in the reduction of the overall fuel consumption [20]. The warm up time is considered as the time taken for the coolant temperature to reach the minimum coolant temperature of a well-functioning engine, which is around 60 °C.

### *2.3.1 Idle Test*

The idle test is conducted in cold-start condition to have extra information on warm up and fuel consumption of a non-moving vehicle. The test is conducted by having “soaking time” with the minimum of 6 hours in control ambient condition (about 25°C). The vehicle’s engine is then started with cold-start condition for 600 seconds. The coolant and transmission oil temperature reading is recorded using INCA software that connected to engine calibration unit (ECU) and Graphtec Data Logger.

### *2.3.2 New European Driving Cycle (NEDC) test*

New European Driving Cycle (NEDC) test is used to simulate the driving conditions. NEDC is Driving Cycle pattern consist of idle state, transient state (acceleration and deceleration) and also the steady state (constant velocity). These types of driving pattern will show and trace the behaviour of vehicle performance based on the driving states. NEDC was divided into two sections, Urban Driving Cycle which simulate the relatively common cycle in the city driving, and Extra-Urban Driving Cycle which likely to simulates the common driving style on highway driving styles. During this test, the vehicle act as test subject is equipped with Engine Calibration Unit (ECU) channelled to INCA software and also Graphtec Data Logger are used to determine and record the reading of coolant and transmission oil temperature.

## 3. Results and Discussion

*Part 1 - Idle test*

It is posited that the minimum coolant temperature of a well-functioning engine is 60 °C. From figure 3, it can be observed that the baseline (unmodified) engine reached the optimum temperature of 60 °C after 199.96s while the engine with the proposed modification only took around 117.41s for the coolant temperature to reach the optimum point, an improvement of about 41.28%. At the end of the test (after 600s), the coolant in the modified engine reached a higher temperature point when compared to the baseline engine (106.35 °C compared to 80.25 °C). In terms of transmission oil, it can be observed in figure 4 that the modified configuration heat up the transmission oil around 4 times faster, of which the transmission oil in the modified engine reached higher temperature point than the baseline engine (54.40 °C than 30.00 °C) after 600 s.

Looking only at the warm up duration perspective, it can be assumed that the modified engine will perform better than the baseline engine in terms of efficiency. This is because lesser fuel will be burned in order to get the engine to the optimum temperature. The catalytic converter also will reach its optimum temperature condition in shorter time, causing less harmful gases to be emitted. Since the modified engine reached the temperature region of 100 – 110 °C in shorter time, there will be less frictional losses due to better lubrication properties of the engine oil in this temperature range [21]. However, it should be noted that the coolant temperature of 106.65 °C is considered quite high, therefore suggesting that the coolant layout can be further improved for a better cooling system in idle condition.

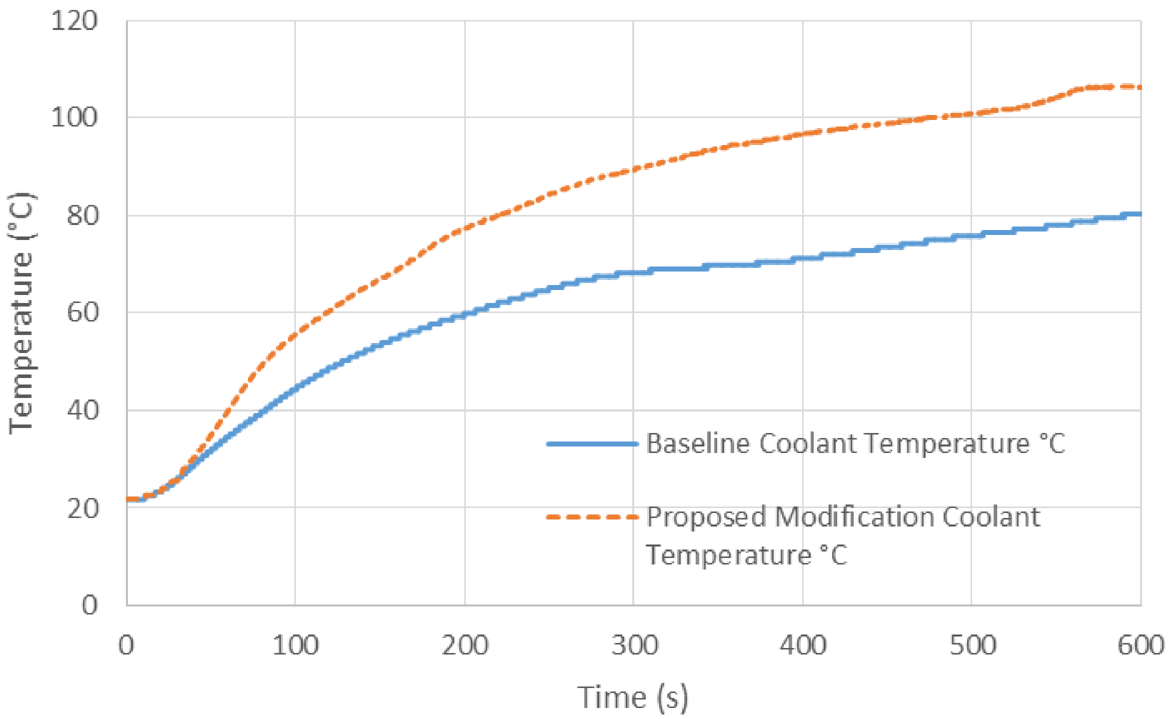


**Figure 3.** Coolant temperature comparison for idle test

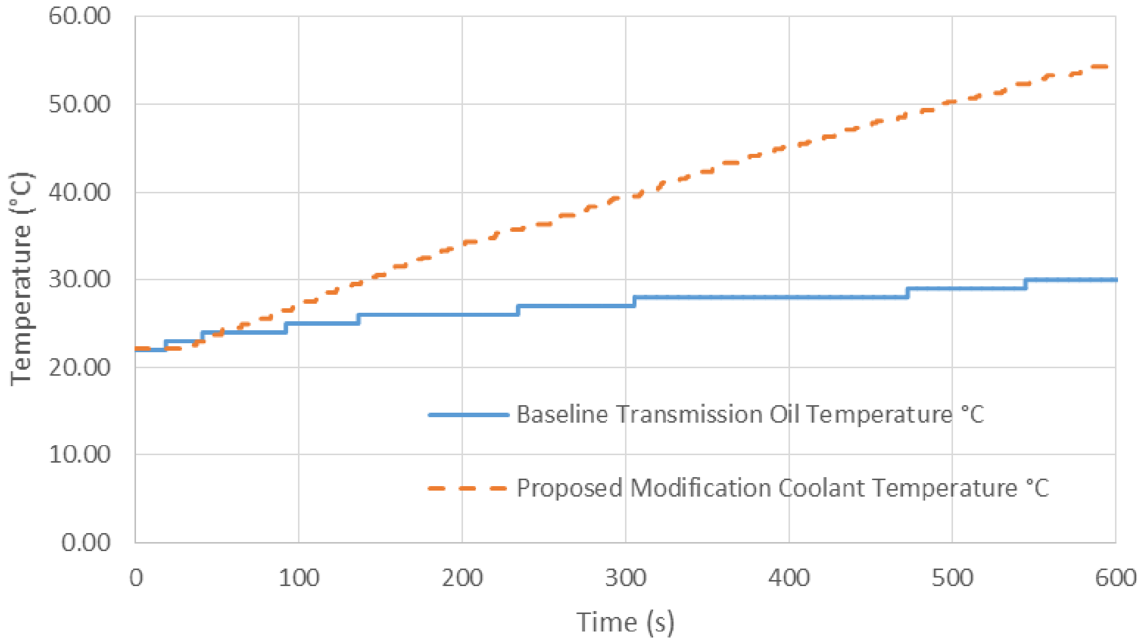


**Figure 4.** Transmission oil temperature comparison for idle test

*Part 2 - NEDC test*

Figure 5 shows that the coolant of the modified vehicle reached the temperature point of 60 °C after 114.78 s, which is 28.26% faster when compared to the baseline vehicle (159.99 s). Both vehicles reached 60 °C in the first UDC. After four UDC, the coolant temperature of the baseline and the modified vehicle were 81.00 °C and 84.60 °C respectively. The fluctuations in coolant temperature suggested that the engine of the modified cooling configuration operated at higher temperature compared to the one in baseline vehicle. At the end of the NEDC test, the coolant temperature of the baseline and modified vehicle were 76.50 °C and 83.25 °C respectively.

It should be highlighted that the difference in maximum coolant temperature between idle test (106.65 °C) and NEDC test (95.35 °C) were due to difference in test set up. Idle test was carried out in typical cold-start condition environment, while NEDC test was carried out using the designated test rig. There was no air flow through the heat exchanger (radiator) during idle test as the vehicle was in steady state (non-moving) condition. The presence of air flow into radiator in order to simulate real driving condition at particular speed during NEDC test caused more heat transfer out from the coolant, resulting in lower coolant temperature. From the results obtained, it can be said that the engine using the proposed cooling system operated at higher temperature condition than the one using conventional cooling system almost the entire time, but still within the safe temperature range.

For transmission oil, it can be deduced from the difference in line steepness in figure 6 that the modified configuration heat up the transmission oil by 107.49%, around two times faster. The temperature of the transmission oil within the modified cooling configuration was relatively higher than the baseline configuration almost the entire time. This suggests that the proposed cooling systems was doing a good job increasing the temperature of the transmission oil. Higher temperature of transmission oil is a necessity since its viscosity lower as the temperature increases. Transmission oil with high viscosity has higher intermolecular friction within the oil that can hinder the ability of which the engine can transmit the power through the transmission system efficiently. However, comparing only the line steepness (gradient) for the whole test duration still not good enough due to proposed modification already reached 60 °C (minimum of optimal operating temperature range) after around 500 s. Afterwards, it will increase at a slow rate and then start to maintain its temperature around the optimum range. This results in lower gradient steepness of the linear trend line of proposed cooling configuration. Plus, it was hard to compare the improvement of warm up time in terms of reaching the optimum temperature range as the transmission oil within the baseline configuration did not reached the optimum temperature of 60 °C during the entire NEDC test.

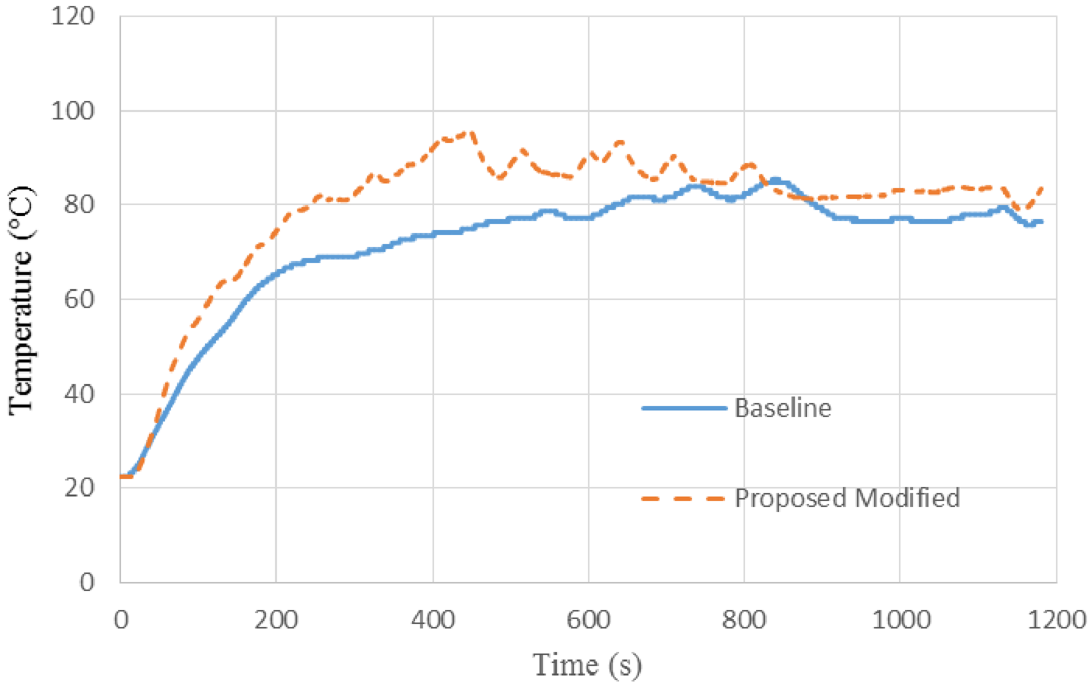


**Figure 5.** Coolant temperature comparison for NEDC test

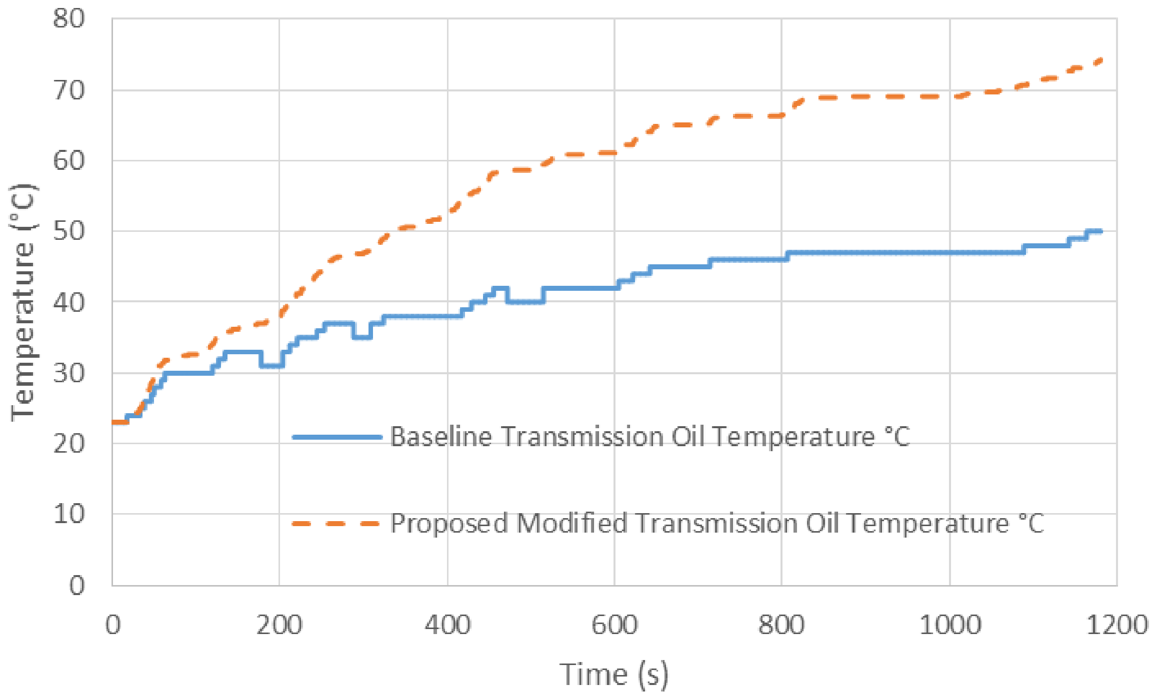


**Figure 6.** Transmission oil temperature comparison for NEDC test

## 4. Conclusion

In this study, a new coolant flow layout for replacing the conventional cooling system was proposed. This new cooling system was implemented into the modified vehicle and the performance of the modified vehicle was compared to the performance of the baseline vehicle, which is equipped with the conventional cooling system. The performance evaluation was done in terms of engine warm up time. Both vehicles undergo idle test in cold start condition and also the standard NEDC test using the designated dynamometer. The results suggested that the modified split cooling system performed better than the baseline vehicles. The warm up time of the modified configuration was 82.55 s and 45.21 s faster than the baseline configuration in idle test and standard NEDC test respectively. During the NEDC test, the coolant and the transmission oil of the modified vehicle were at a higher temperature point almost the entire time, implying that the engine operated at higher temperature.

From the test results, the proposed cooling circuit has shown promising attributes of a cost-effective solution, while meeting the future requirement. Nevertheless, the full potential of the proposed configuration is still ambiguous. In particular, the baseline engines which are widely produced today are optimized for the conventional serial cooling system. For future works, it is recommended that more thorough testing for further optimization are carried out which include engine performance and emission testing.

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