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Design Studies of Two Stage Cooling Loop for New Generation Vehicles

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Abstract

In this article, the design and integration of an intelligent refrigeration system that increases air conditioning and engine efficiency, reduces fuel consumption and emission levels in vehicles manufactured today will be examined. This design will include a two-stage cooling system. Two-stage cooling unit consist; high temperature radiator and low temperature radiator. The engine coolant will be cooled in the high temperature radiator. In the low temperature radiator, coolant of water cooled air charger and air conditioning condenser will be cooled. It is aimed to increase the engine efficiency by cooling more efficiently, thanks to the heat carrying capacity of the water which is high compared to air. With this project, it is aimed to cool the heated air after the turbocharging and air conditioning gas in the vehicle with water instead of air.

Key words: Cooling System, Turbocharge, Low Temperature Radiator, High Temperature Radiator, Dual Loop Cooling

1. Introduction

This study will be on the development of an innovative cooling system to be used in vehicles. In addition to the engine cooling cycle, it's considered another cooling cycle with low temperature cooling loop. With this low temperature loop, Cooling of the compressed air by turbocharge and air conditioning gas condensation will be done with cooled water instead of air.

In this way, both compressed air can be cooled to lower temperatures and volumetric efficiency in the engine can be increased, more efficient condensing of the air conditioning gas will be provided, and the amount of energy absorbed from the fan will be reduced. Consequently, fuel consumption and CO2 emissions will decrease without worsening engine performance.

Turbocharged engines are now widely produced by OEMs. Among with the downsizing current of the automotive sector, the use of turbochargers has become a necessity to get the same power and torque from these low engine volumes. Cooling of the compressed hot air coming out of the turbocharger compressor causes the air entering the cylinders to be cold and the engine's volumetric efficiency increases. In Figure 1, the relationship between the volumetric efficiency and the air temperature taken to the cylinders are shown. The heat exchanger that assumes this task in the cooling system is called intercooler [4].

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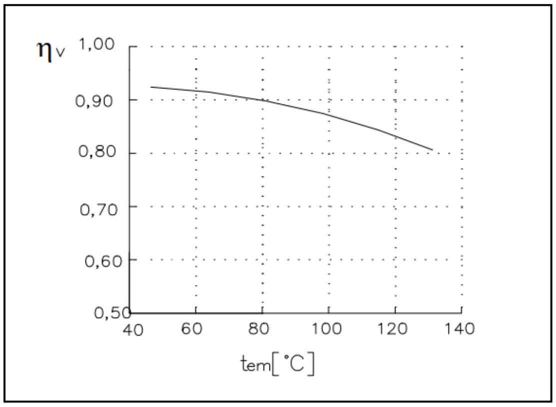

Figure 1: Diagram of volumetric efficiency vs. temperature

2. Description of The Dual Loop Cooling System

Traditionally; the engine oil, intercooler, condenser and radiator units in cars' cooling systems are packaged at the front of the vehicles.

In this project, with the dual loop cooling system, both the Intercooler which is a component of the turbo system, and the condenser, which is the component of the air conditioning system, will be cooled with water.

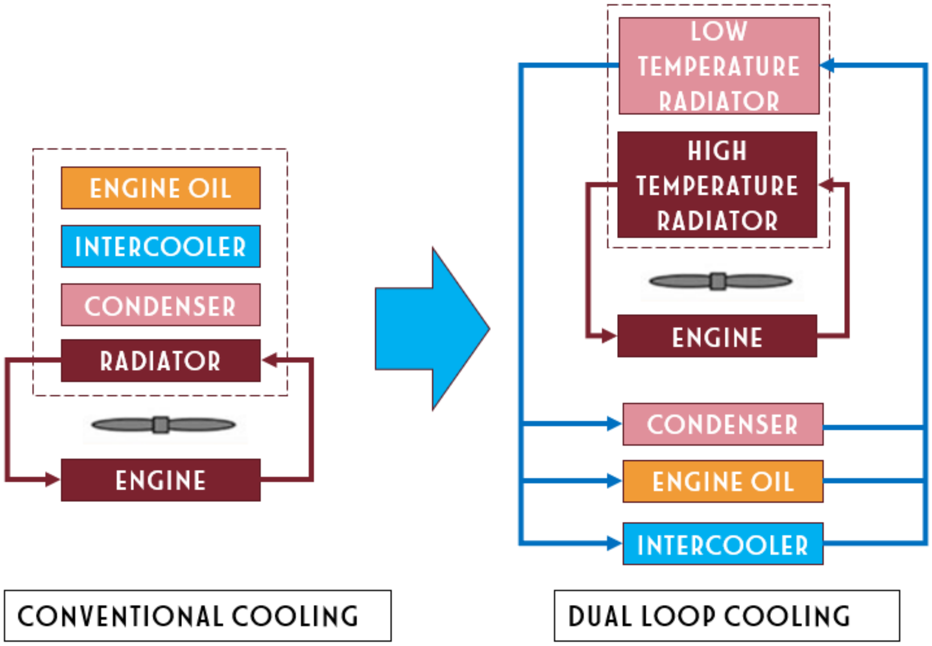

Figure 2: Conventional cooling system and dual loop cooling system

In the conventional system, each system cools its own liquid in the units in front of the vehicle, all using the same fan that demands high energy. Additional exchangers are required for integration with new electronic subsystems. In the innovative cooling system, the cycle containing the low temperature radiator is used for cooling all subsystems, while the cycle containing the high temperature radiator takes part in cooling the engine. Along with a compact structure in the innovative cooling system, a structure has been reached that allows standardization in the front radiator, better front engine area aerodynamics, less fan power demand, and easy addition of components such as electric motors and batteries.

On vehicles, the main heat exchangers of the cooling system are located on the front of the vehicle. The condenser, radiator and intercooler aim to increase heat transfer by forced transport of accelerated air provided by a single fan. Since the heat transfer coefficient of the air is much lower than that of water, the dimensions of the heat exchanger, which provides heat transfer with air, should be larger when an equal heat load is desired. In addition, substantial fan power should be used to guarantee the required air. This causes a considerable amount of noise to be produced and the electrical energy spent to increase.

Compact size heat exchangers, which will be provided in the innovative system, will be used to reduce the length of pipes carrying fluids. This will provide a reduction in pressure loss and a cooling system with more efficient heat transitions.

In the dual loop intelligent cooling system, the air-cooled intercooler will be replaced with the water-cooled intercooler (air charger). It will be replaced by a water-cooled and tubular heat exchanger in the upper area, closer to the intake manifold. Between the intercooler outlet and the intake manifold, the pipe length will be shortened, pressure losses and pipe losses will be seriously eliminated. The intercooler system will be connected to the low temperature radiator that will be added to the front.

In the air-conditioning part, the refrigerant cooled in the condenser in front of the vehicle is sent to the heat exchanger in the air conditioning module. The fact that the condenser is far from this heat exchanger in the conventional cooling system also brings some pressure loss. In the dual loop cooling solution, with the water-cooled and smaller condenser that will be positioned close to the air conditioner module, this pressure loss will be eliminated, and a more efficient air conditioning will be provided.

The path of the cooled air sent from the intercooler outlet to the intake manifold through the pipeline will be shortened. With the water-cooled intercooler, which will be placed closer to the intake manifold, this pipeline length will be significantly shortened, and pressure losses will be minimized.

With a more efficient cooling system, the efficiency of the engine will increase, and lower emission values will be provided with the increase in the quality of the air entering the cylinder.

2.1. Schematics of the system

Air conditioning and cooling systems are mainly affected by the solutions to be applied. As can be seen from the diagram shown as “Dual Loop Cooling” in Figure 3, two completely different cycles will be used.

The first cycle with a high temperature cycle, as the name suggests, will operate at higher temperatures and it will cool the engine itself. In this cycle, the engine coolant will be cooled in the high temperature radiator at the front and sent back to the engine.

The system called low temperature cycle is intercooler and air conditioning systems that will use low temperature radiator. These systems operate at relatively lower temperatures.

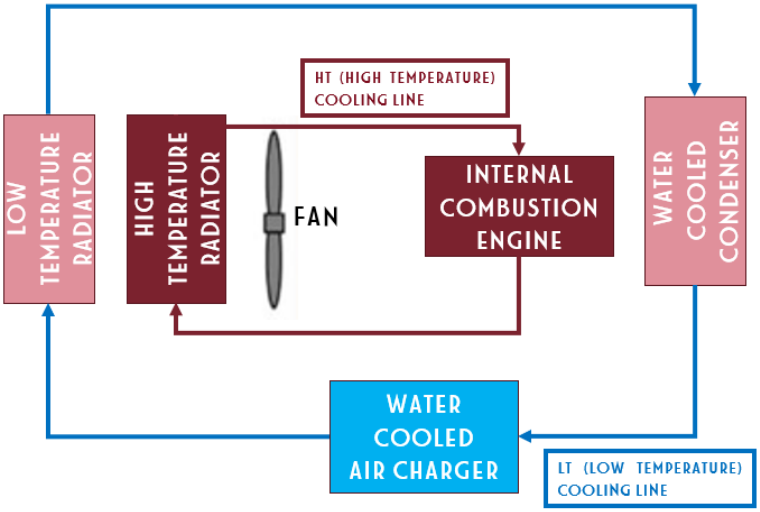

Figure 3: Schematics of the dual loop cooling system

3. 1D Cooling System Design of Current and Dual Loop Cooling System

As 1D modeling, system modeling, the information (geometry, technical data, etc.) of the 3D components that make up the system are integrated, and systems are created with these components. Within the scope of the project, 1D thermal models of existing/conventional and dual loop cooling systems were created.

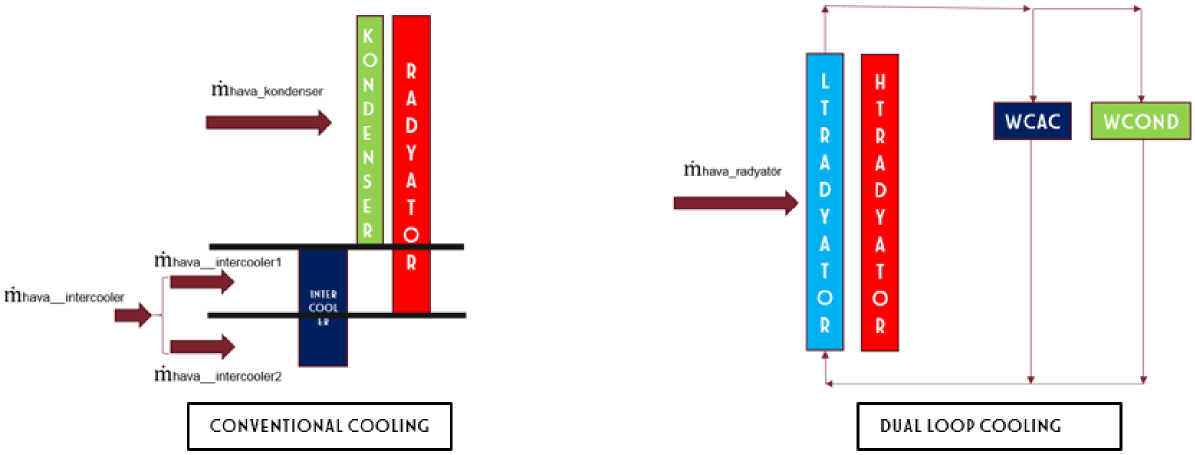

Figure 4: Air mass flow application approach on 1D model

The process of obtaining air flows entering the heat exchangers as the input conditions used when creating the 1D thermal system model was obtained as a result of a series of CFD analysis.

Averages and mass flow rates from the non-homogeneous velocity values on the surface were obtained and the values shown in Table 1 were obtained for each heat exchanger inlet flow rates and these values were applied as input to the 1D model. Porous media modeling, a widely used technique for modeling heat exchangers in CFD analysis, was used. Analyzes were carried out in the Star CCM + program with the K- ε turbulence model and polyhedral mesh for entry speeds of 20, 40 and 140 km / h.

Figure 5: Vehicle front grills and radiator module

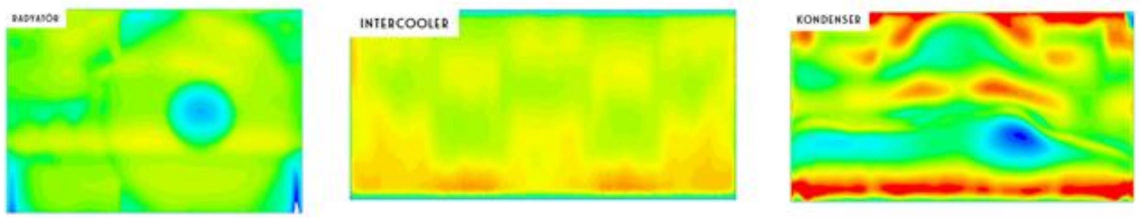

Figure 6: Vehicle speed contours on radiator, condenser and intercooler in CFD

As shown in Figure 6, the averages and mass flow rates from the non-homogeneous velocity values on the surface were obtained and the values shown in Table 1 were obtained for each heat exchanger inlet flow rates and these values were applied as inputs to the 1D model.

Table 1. Inputs for 1D cooling system

VELOCITY (KM/H)	CONDENSER (KG/S)	RADIATOR (KG/S)	INTERCOOLER (KG/S)
20	C1	R1	I1
40	C2	R2	I2
140	C3	R3	I3

3.1. Current system and dual loop cooling system

While creating the 1D model, the technical specifications, behavior and geometric information of all components must be embedded in the element that will belong to that component.
1D models of one of the current and double cycle cooling system alternatives are shown below figure7.

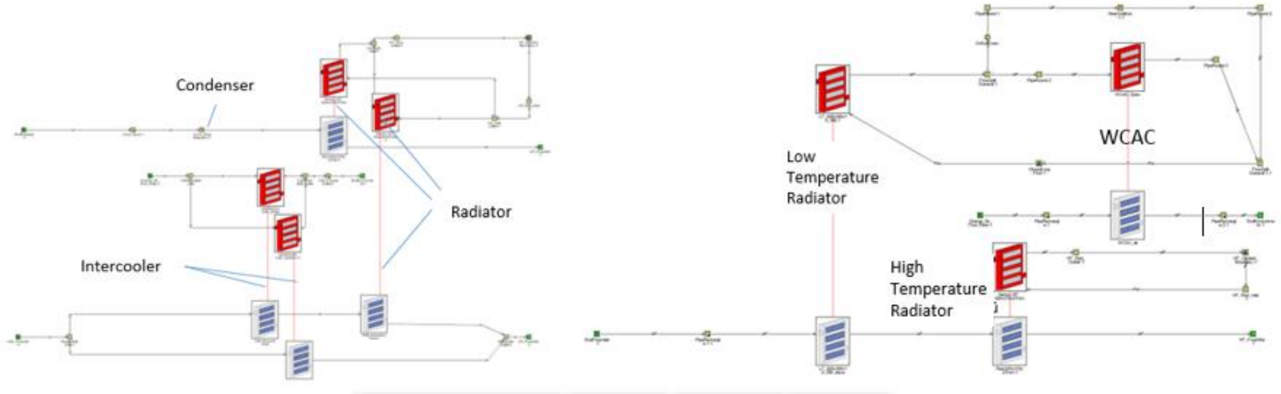

Figure 7: Current and dual loop cooling system

3.2. Correlation of 1D simulation method with the current system test results

As a result of the standard test for wind tunnel testing and thermal performance evaluation, the intercooler outlet temperatures of the air for the conventional system are shown in Table 2.

Table 2. Current system test results

	Case 2	Case 4	Case 7
Intercooler Outlet Temperature (°C)	IOT1	IOT2	IOT3

Firstly, conventional cooling system 1D model was analyzed. The temperatures of the critical points obtained as a result of the analysis of this system shown in Table 3.

Table 3. Current system 1D simulation results

	Case 2	Case 4	Case 7
Radiator Inlet Temperature (°C)	RIT1	RIT2	RIT3
Radiator Outlet Temperature (°C)	ROT1	ROT2	ROT3
Intercooler Inlet Temperature (°C)	IOT4	IOT5	IOT6
Intercooler Outlet Temperature (°C)	IOT1 -%2,2	IOT2 -%2,8	IOT3-%3,1

When the conventional system 1D analysis results are compared with the standard test results over the air's intercooler outlet temperature, a maximum 3% deviation from the test results was observed. In the light of these results, the reliability of the model has been proved and it has been decided that this model can be used to determine different alternatives of the low temperature cycle.

3.3. Create setup for dual loop cooling

The value that will be taken as basis in determining the appropriate one among the low temperature cycle alternatives is the intercooler outlet temperature. As mentioned earlier, as much as decreased air inlet temperature, it will be benefited on volumetric efficiency, emission, etc. It has been decided that the focus will be intercooler outlet temperature as a principal parameter in this study.

Since the high temperature cycle is the cycle that cools the engine water, it will work with a high temperature radiator due to the higher temperature demand. Since the engine and the thermal load which is dis-charged, will be the same in the dual loop cooling system, the high temperature radiator has been determined as the same radiator used (27 mm thick radiator) in current system.

In the low temperature cycle, as a result of the use of water-cooled intercoolers and condensers, 2 different radiator (27 mm and 16 mm thick) alternatives are considered. And if necessary, 2 series of water-cooled air chargers (intercoolers) were also used in the model.

3.4. Alternative definition of the wcac (water cooled air charger) and low temperature radiator

The first of the low temperature cycle alternatives was made with minimum performance components. The model shown in Figure 8 was created with a 16 mm thick radiator and a single water-cooled intercooler. The results of 1D analysis of the first low temperature cycle alternative created with the minimum performance components approach are shown in Table 4.

As seen in Table 4, the air temperature at the intercooler outlet was obtained relatively high when compared to the conventional system. In the light of these results, it is not possible to use the first alternative.

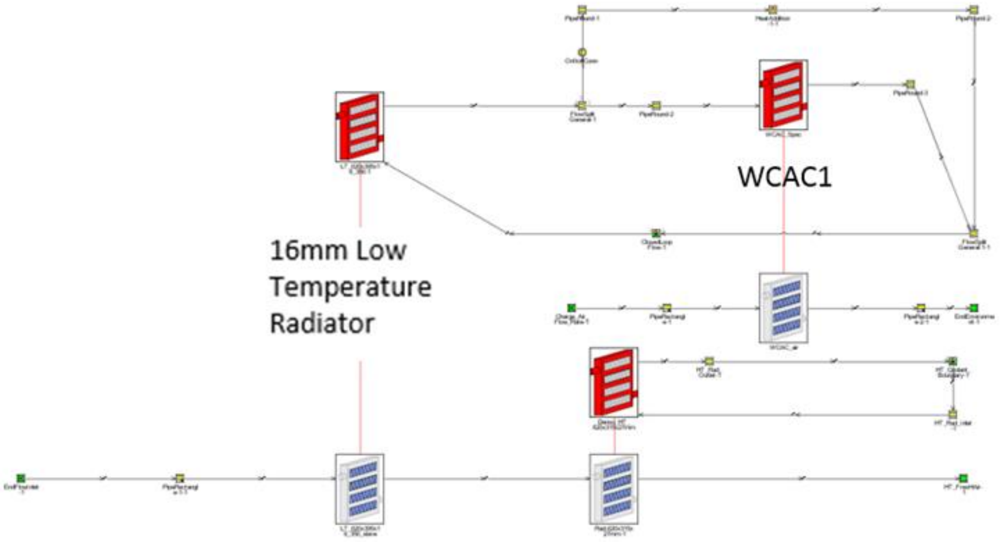

Figure 8: Low temperature cycle with 1st alternative – minimum dimension components

Table 4. 1D Analysis of the low temperature cycle with 1st alternative

	Case 2	**Case 4**	**Case 7**
Radiator Inlet Temperature (°C)	RIT4	RIT5	RIT6
Radiator Outlet Temperature (°C)	ROT4	ROT5	ROT6
LT Radiator Inlet Temperature (°C)	LTRIT1	LTRIT2	LTRIT3
LT Radiator Outlet Temperature (°C)	LTROT1	LTROT2	LTROT3
Intercooler Inlet Temperature (°C)	IOT7	IOT8	IOT9
Intercooler Outlet Temperature (°C)	IOT1 +%26	IOT2 +%33	IOT3+%43

As an alternative to the 2nd low temperature cycle, the study is continued 27 mm low temperature radiator. In this alternative, two series of water-cooled intercooler solutions were studied instead of single water-cooled intercooler. While the cooling water is distributed parallel to the two water-cooled heat exchangers, the reason for this connection is called the series: because the over-fed air will first go to the first heat exchanger and then the second heat exchanger and will continue in series between the water-cooled heat exchangers.

Figure 9 shows the 1D system model created for the 2nd alternative of the low temperature cycle. The results of this model are presented in Table 5.

When the results seen in Table 6 are evaluated, it is seen that better results are obtained with the 3rd alternative than the 1st and 2nd alternatives. However, when compared with the conventional situation results in Table 3, it is observed that there is improvement with the third alternative.

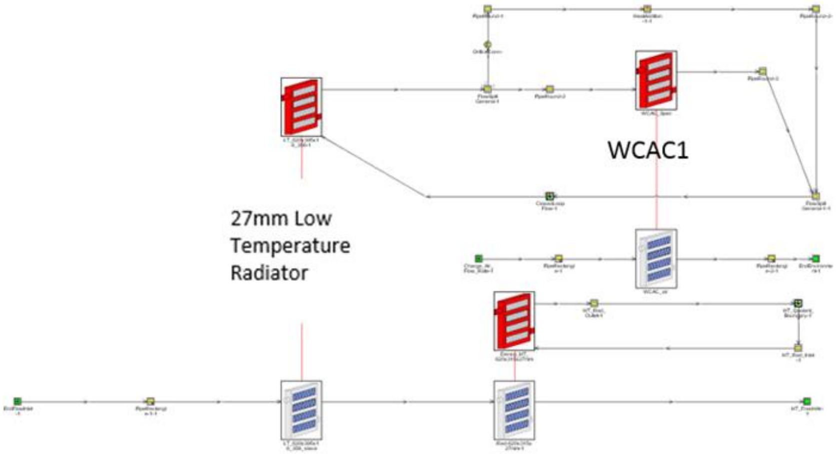

Figure 9: Low temperature cycle with 2nd alternative

Table 5. 1D Analysis of the low temperature cycle with 2nd alternative

	Case 2	**Case 4**	**Case 7**
Radiator Inlet Temperature (°C)	RIT7	RIT8	RIT9
Radiator Outlet Temperature (°C)	ROT7	ROT8	ROT9
LT Radiator Inlet Temperature (°C)	LTRIT4	LTRIT5	LTRIT6
LT Radiator Outlet Temperature (°C)	LTROT4	LTROT5	LTROT6
Intercooler Inlet Temperature (°C)	IOT10	IOT11	IOT12
Intercooler Outlet Temperature (°C)	IOT1 -%1,5	IOT2 -%2,4	IOT3-%2,6

Based on these results, the 27-mm high-performance radiator and two water-cooled intercoolers were used as an alternative to the 3rd low temperature cycle, with a maximum performance component approach. Figure 10 shows the third alternative system. The result of 1D analysis of this system is shared in Table 6.

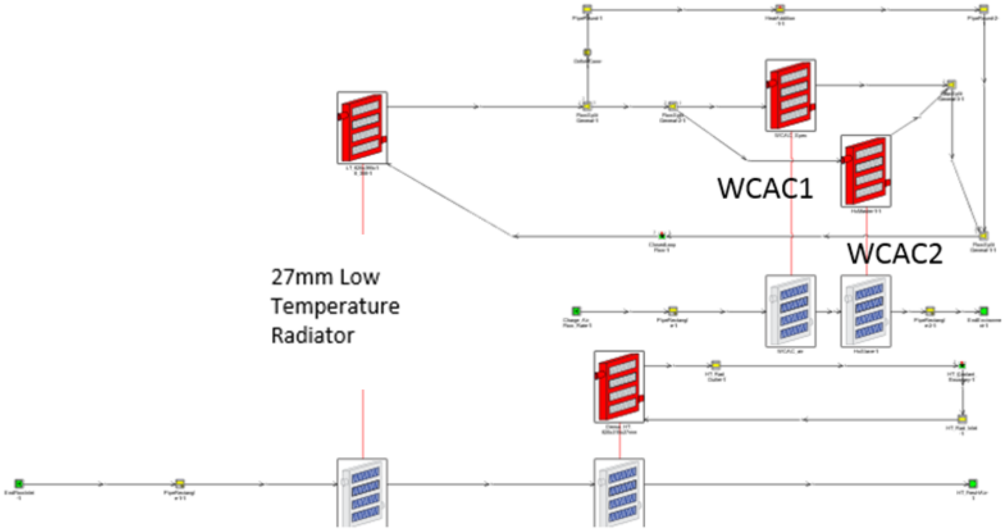

Figure 10: Low temperature cycle with 3rd alternative – maximum dimension components

Table 6. 1D Analysis of the low temperature cycle with 3rd alternative

	Case 2	Case 4	Case 7
Radiator Inlet Temperature (°C)	RIT10	RIT11	RIT12
Radiator Outlet Temperature (°C)	ROT10	ROT11	ROT12
LT Radiator Inlet Temperature (°C)	LTRIT7	LTRIT8	LTRIT9
LT Radiator Outlet Temperature (°C)	LTROT7	LTROT8	LTROT9
Intercooler Inlet Temperature (°C)	IOT113	IOT14	IOT15
Intercooler Outlet Temperature (°C)	IOT1 -%6,7	IOT2 -%8,5	IOT3-%19

4. Results and Discussion

When the results shared in Table 6 and Table 3 are compared, it is clear that a remarkable improvement has been achieved in the 3rd low temperature cycle alternative compared to the conventional situation. An improvement of 4%, 6% and 17% was achieved between the intercooler outlet temperatures for 3 conditions, respectively. Considering that other low temperature cycle alternatives have failed, it has been decided to continue design with the third alternative.

As a result of 1D Virtual analysis, 27 mm thick radiators will be used as low and high temperature radiators in the cooling system to be operated within the scope of two level smart cooling system, and two of these heat exchangers will be connected as water cooled intercooler. While cooling water is distributed parallel to these two heat exchangers, the overfeed air will use these heat exchangers in series and, as the results obtained in Table 7 show, will gradually reach the engine by reaching lower temperatures compared to the conventional situation.

5. References

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