Remodelling the Auxiliary Components of a Diesel and a Gasoline Engine

Modification of SISU 420 DWI diesel and an Opel Astra G 1.6 16V gasoline motors

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Abstract

In Technobothnia facilities there is a lack of a gasoline engine. At the moment, a diesel engine (SISU 420 DWI) is being run. The laboratory managers pretend to redesign three auxiliary parts of the engine installation. In addition, this thesis aims to achieve high compatibility between both engines (SISU 420 DWI diesel and Opel Astra G 1.6 16V) and possible future motors installed in the laboratory.

First, the actual diesel and gasoline engines were analysed to study their main components and realise which are very similar to know if adaptability between both motors can be achieved. Moreover, the different systems studied are explained in further detail to ease the comprehension of each device. Components selection for each system is made considering both, performance and cost. The studied auxiliary parts are the petrol injection system, the cooling unit, and the exhaust gas extraction. A gasoline injection system for providing petrol to the Opel engine is done. Also, research is being conducted to develop a portable cooling system unit that can work with both engines. Furthermore, the laboratory extractor operating in the engine bed where the SISU 420 DWI motor is, has been redesigned and converted into a configurable device that can adopt four different lengths with increments of 50 mm up to a maximum of 200 mm.

As a result, the SISU diesel auxiliary equipment mentioned has been well-adapted, increasing the overall efficiency of the whole engine. Also, the Opel gasoline engine can be properly installed. The chosen components are well-known in the industry and have a wide range of support, making equipment replacement easier when maintenance is needed. The selected components are fully documented with a total listed price of 7124€ (including VAT).

Language: English

Keywords: Sisudiesel, gasoline engine, petrol injection system, cooling system, exhaust gases, 3D design, modularity

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GLOSSARY

ICEs	Internal Combustion Engines
3D	Three Dimension
ECU	Electronic Control Unit
GHG	Greenhouse gases
VAT	Value Added Taxes
BEV	Battery Electric Vehicle
CO_2	Carbon dioxide
HVE	Hybrid Electric Vehicles
EV	Electric Vehicles
BSFC	Brake-Specific Fuel Consumption
CO	Carbon monoxide
No_x	Oxide of nitrogen
HC	Hydrocarbons
O_2	Oxygen
N_2	Nitrogen
H_2O	Water
EPDM	Ethylene Propylene Diene Monomer

1. Introduction

At present, internal combustion engines (ICEs) still account for 99.8% of global transportation, with petroleum-based liquid fuels providing 95 % of transportation energy (Leach et al., 2020). Various alternatives are being studied, such as battery-electric cars (BEVs) as well as a range of alternative fuels such as biofuels and hydrogen. However, all these options begin without a robust base and are still being developed as it is a new technology compared with ICEs. The actual resurgent of the electric car did not occur until the beginning of the twenty-first century. Moreover, it has faced considerable constraints to an indefinite expansion, like the high cost of acquiring an electric vehicle. Furthermore, its current immature range anxiety situation, makes that even by 2040, traditional liquid fuels powering combustion engines are estimated to account for 85–90% of transportation energy (International Energy Agency, 2021). Thus, it is clear that ICEs will be still used for the foreseeable future. Hybrid automobiles are a decent compromise between ICE and BEV vehicles due to battery technology limitations. In these types of automobiles internal combustion engine and an electric motor, which uses energy stored in batteries, power hybrid electric vehicles. The percentage of hybrid vehicles in 2019 was 2 % which had been considerably higher than the usage of BEVs automobiles with just 0.1 % (Transportation Energy Data Book, 2021).

Furthermore, BEVs CO_2 emissions are not always lower than ICEs engine ones (Kawamoto et al., 2019). Even if the operating stage of an electric vehicle has zero emissions, the comparison of carbon emissions should analyse the entire lifecycle, not just the usage phase. Then, carbon dioxide emissions through vehicle production and recovery must also be considered (Zhao et al., 2020). A recent study was undertaken in China (Lu et al., 2016) has evaluated the emissions of ICEs, Hybrid Electric Vehicles (HVE) and Electric Vehicles (EV). According to the findings, ICEs during the usage period emit the higher equivalent carbon emissions, 29.3 tonnes. On the other hand, Strong HEV and EV300 generate 19.6 and 17.8 tonnes respectively. However, during the manufacturer stage, the carbon emissions of electric vehicles are considerably higher than those of gasoline-diesel vehicles. For example, ICEs produce 6.5 tonnes of equivalent Carbon, and HEV and EV300 release 6.8 and 13.8 tonnes respectively (Hao et al., 2017). However, when considering all the life cycles, ICEs motors are indeed the most polluting ones, but the difference is lower than the one that is thought.

Thus, it is important that at Novia University of Applied Sciences (NOVIA UAS) the students can learn how diesel and gasoline engines work, and which are their important parameters while running them. Nowadays, in the Technobothnia laboratory, based in Vaasa (Finland), there is a SISU 420 DWI, 4-stroke diesel engine to make simulations analysing certain crucial metrics such as the engine's output torque, output power, brake-specific fuel consumption (BSFC), etc. Furthermore, because the engine is controlled by a computer programme, the various data required for a heat balance calculation may be recorded during the simulations. These are the temperature of the air, fuel, the time that the engine needs to reach the desired output power, the fuel consumption and so on. The monitoring of an engine is essential to make the students aware of which are the correct values for these parameters to have an idea in case they work with similar engines during their professional life.

However, currently, the laboratory lacks the equivalent test facilities for a gasoline car engine. Therefore, this thesis focuses on how this Opel Astra G 1.6 16V gasoline motor could be installed in the same laboratory. The main purpose of it is to have the possibility of making simulations with both engines and analysing the differences between each other. First, because they are used in different vehicles, the diesel engine is used in a tractor and the gasoline one in a car. Secondly, as the fuel is not the same, the combustion process and thus, its conditions are going to differ. So, a comparison of the different performances and efficiencies can be very useful for taking into consideration the advantages and disadvantages of diesel and gasoline engines.

1.1 Background

Diesel and gasoline motors are currently the most used engines in the world and one of the most studied by researchers. Both engines lack in the sustainability aspect as they are one of the main pollute components nowadays. Nonetheless, there are multiple devices used to reduce the contaminants exiting the car, for instance, the catalytic will convert the harmful exhaust gasses into carbon dioxide and water (which are by far less pollutant than the gasses created during the combustion process). So, the multiple improvements these motors could have and their popularity in the market are the key factors why these motors are so studied.

Technobothnia's facilities are known for their advanced laboratories which help students comprehend better the components that form the motors that are being taught during their lectures. One drawback in the laboratories was the lack of a proper gasoline engine to be analysed and studied. Therefore, the idea the team came up with was to install a gasoline motor next to the existing diesel engine. Or, installing it in the same bed where the actual SISU Diesel Engine is running. This will help the students to understand better the differences between both motors and will improve the capacity for future research in the Technobothnia laboratories.

The team members linked up with another group that is working on other aspects of the same engines and the thesis supervisors (who are the managers of the engine laboratory) to complete the installation of the gasoline engine. Furthermore, some components of the diesel engine were improved as well. The team focussed on the parts outside the engine block and centred on the fuel injection, cooling system and the exhaust gas system to ease the project. The supervisors will be in charge of the physical installation by considering using the material delivered from this thesis to use in the future to build the different designed parts. The other group that is working on the same engines, will improve the dynamometer of the diesel engine and will establish the gasoline engine is placed. Furthermore, they will analyse the existing mountings and couplings and they are in charge of the design of the engine bed.

The members came up with some ideas such as the cooling system module which will be mounted on a portable device. The idea is to create a component that could function on future engines and that could be stored anywhere when not being run. This is important since the area where is going to be installed is nowadays a zone where the people working there circulate and therefore, the idea is to do not cover it all the time. Furthermore, the laboratory exhaust system is improved as well, gaining some mobility for the actual extractor to run another engine in the same bed and have the capacity as well to remove the exhaust gases.

1.2 Aims and Objectives

The work assigned is to remodel some parts of the existing diesel engine in Technobothnia laboratory in Vaasa, Finland. Moreover, there is the need to add a gasoline engine to the same bed. Thus, simulations with both motors could be carried out to compare the operating processes of the two engines. Currently, there is a SISU 420 DWI, 4-stroke diesel engine.

Ergo, this project aims to study the compatibility of some of the auxiliary parts of diesel and gasoline engines. These are the fuel injection system, the cooling system, and the exhaust gas design to adapt and make more versatile the actual extractor.

To achieve this, the following objectives are mentioned below:

- Devise a new fuel injection system in the Technobothnia laboratory for the gasoline engine

- Explore and design a remote cooling system that is compatible with both, diesel and gasoline engines.

- Analyse the current exhaust gas structure and develop some modifications to the actual extractor placed in the laboratory. These will be used to integrate into the existing exhaust gas extraction some other engines that can be run in the actual engine bed.

1.3 Document structure

The first section (Study background) provides a deep look at the working principles of the systems studied, furthermore, some pieces of the system are explained individually to gain more knowledge on the researched field. Section 2 (Current state of the engine different parts to be analysed) guides the reader through an explanation of the studied engine systems. These reviewed systems may vary from the explained logical concepts due to their antiquity. The third section, Methodology, is where all the components for an optimal installation are selected, moreover, a study is made to achieve better compatibility among both engines. Also, in this section, a study on the placement of the systems is displayed. Following the Methodology is the Results section, where all the components selected are shown discussing the pros and the cons of these. An economic study is made as well. A 3D model of the cooling system and the new extractor design are included. Moreover, a final 2D overview of how is going to be the laboratory after developing the objectives that this thesis has will be as well included. The last sections are Discussion and Conclusion where the team members will write their thoughts about the project and the objectives planned.

2. Study Background

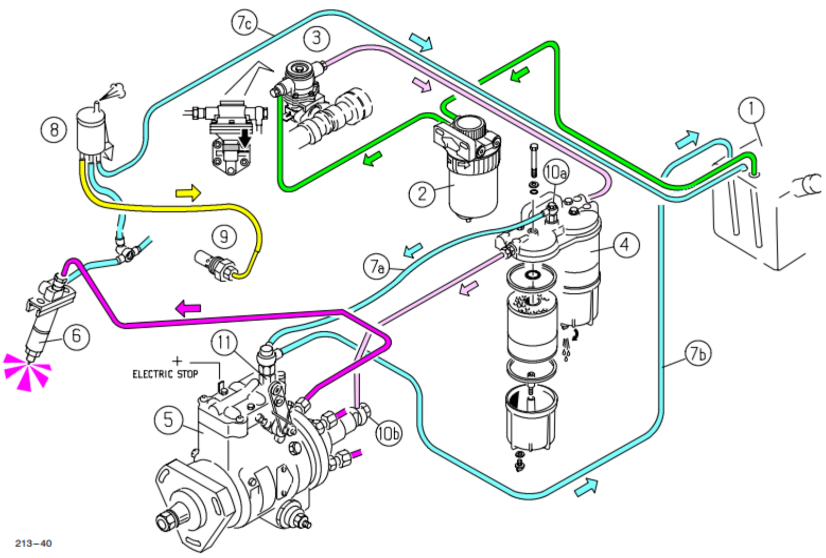
This section explains the basic concepts which will be employed throughout this thesis, with the cooling system being the most practical element of the project. The fuel injection system for a gasoline engine that might be used in the laboratory is also examined, as well as a new design to the current extractor pipe to have the capacity to make its length variable to run more engines in the same bed.

2.1 Fuel injection system

One of the parts studied in the project is the fuel injection system. This part is common in every type of vehicle or device that uses an engine, whether it is a gas engine, diesel engine, etc. Thus, two types of fuel injection systems are studied: a gasoline injection system and a diesel injection system. The objective is to design an injection system regarding the outboard part of the engine, in order words, the goal is to make the fuel arrive in the engine inlet pipe and make it return to the fuel tank. However, as a theoretical background, it is important to know how the injection system works inside the engine and which are its most important components.

2.1.1 Diesel injection general overview

The actual system is a Diesel fuel injection for the SISU 420 DWI engine which is designed with the following elements presented in Figure 1.



FUEL INJECTION SYSTEM COMPONENTS
1. Fuel tank
2. Prefilter
3. Fuel feed pump
4. Fuel filter
5. Distributor pump
6. Injector
7 a, b, c. Return fuel to the tank.
8. Thermostart reservoir
9. Glow plug
10. a,b Bleeding screws
11. Valve of reverse backflow

Figure 1. *Fuel system with distributor pump for a Sisu Diesel engine (SisuDiesel, 2002).*

Diesel from the fuel tank (1) firstly passes through the prefilter (2). It has the function to remove the majority of water and contaminant particles from the fuel. Then, it arrives at the fuel feed pump (3) which has to pull the fuel from the tank and drive it through the mentioned prefilter and to a second filter (4). Thanks to this filter, impurities that should not be in the fuel are cleaned out of the solution. These are, for example, small dirt and rust particles that are separated from the fuel as they do not fit in the fuel and water. If these particles are not eliminated, they may cause harm to the engine and cause it to underperform. Getting out of the filter, the fuel is ready to go to the distributor or injection pump (5). This is the element of the engine that pumps the diesel and increases the pressure to high rates to pass it as a thin mist to the injectors (6). The fuel feed pump provides more fuel than the injection pump requires. The surplus fuel is returned to the fuel tank via the overflow valve (7b). This extra fuel absorbs the heat and thus, cools the injection pump. It also absorbs unwanted air bubbles into the tank (SisuDiesel, 2002).

In cold weather, the thermostart (8) device is frequently installed in the fuel system. It has a device similar to a cigarette lighter as a heating element. The small reservoir contains diesel. This element heats up and diesel drops on it, generating a little fire that warms the air in the intake collector and makes it simpler to start, as said during cold conditions, normally when starting to operate the engine (Hayburner, 2010). The extra fuel is returned to the fuel tank via the overflow valve (7c). Similar to the thermostart the system is provided with a glow plug (9). It is a warming device that helps diesel engines start. The generated heat is directly supplied to the cylinders to increase the temperature of the engine block that surrounds the cylinders. The thermostart device's separate reservoir (8) provides fuel for the glow plug (9).

2.1.2 Gasoline fuel injection system

The actual fuel injection system for the Opel Astra G 1.6 16V gasoline motor is made of 2 pumps, a fuel tank, and a fuel consumption measurement device.

The first pump will take the fuel from the barrel and carry it to the tank. The pump is not required to be a high-pressure pump because it will be used as a transportation pump to a low-pressure tank. The second pump, known as the fuel feed pump, is responsible for transporting fuel from the tank to the engine and must be a high-pressure pump to compress the fuel to a pressure of between 2.8 and 3.2 bar (Spectrapremium.com, 2022).

When the engine is turned off, the fuel is stored in the tank. This component of the fuel injection system is in the centre of both pumps and is connected to various pipes. One pipe feeds the fuel into the tank, while another returns the fuel to the barrel in case the tank is overfilled with gasoline. The following two pipes will inject and pressurize the fuel into the engine, as well as return any excess fuel from the combustion process to the tank. In addition, there is a measurement mechanism that indicates the level of fuel in the tank.

Once the engine is operating, the fuel drawn from the tank has to previously pass a filter and a fuel consumption device before getting into the fuel distributor pump. In the gasoline engine, the filter and the fuel feed pump are separated from the engine as the filter, placed after the tank, removes all the impurities from the fuel. Moreover, the connection between the pipes where the fuel is entering the engine and the pipes of the motor are made with quick connections.

2.1.3 Main fuel injection components

The most important components of the fuel injection system are the fuel feeding pump, the injector, and the distributor pump which are explained in the following sections. These components can be found in every diesel and gasoline engine and work equally in both engines. These are the components that are inside the engine.

2.1.3.1 Fuel feed pump

The fuel feed pump for the SISU 420 DWI, 4-stroke diesel engine, is the Bosch FP/KEG 24 AD 504. The fuel feed pressure of the entering diesel is between 0.7 and 1.2 bar (70 and 120 kPa). Moreover, when the fuel leaves this pump, its pressure is 2.7 bar (270 kPa) (SisuDiesel, 2002).

Figure 2. *Bosch FP/KEG 24 AD 504 fuel feed pump (Eurodiesel, 2022).*

This element has the function to take the diesel from the tank and drive it all through the prefilter and to the second filter (4).

Fuel is transferred from the tank to the fuel injection system via the lift pump. The three common types of lift pumps in use are the diaphragm, plunger, and vane A diaphragm pump is employed in this instance.

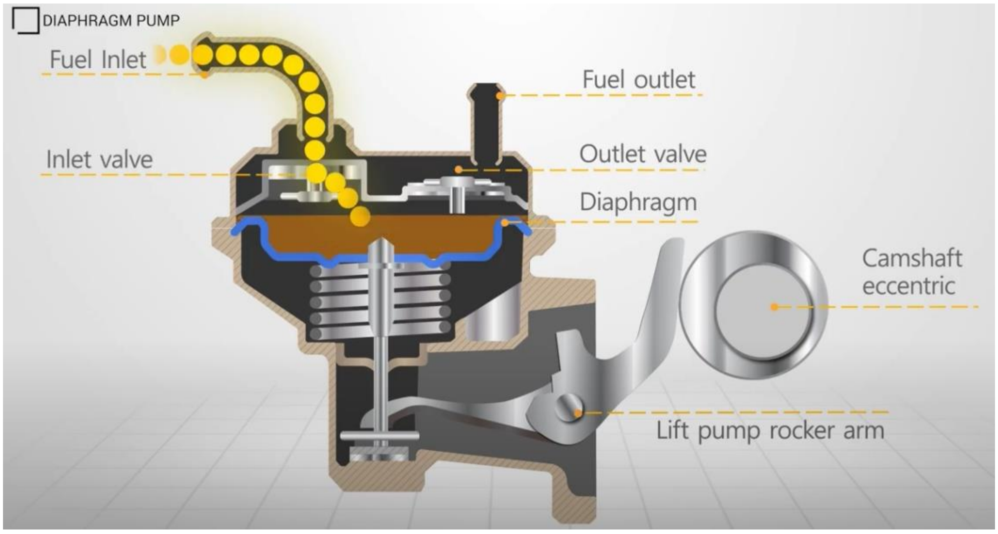


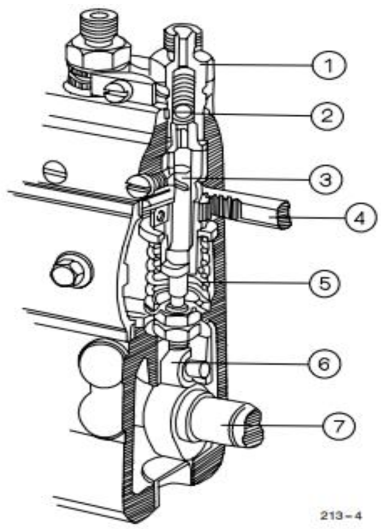
Figure 3. *Scheme of a diaphragm pump with its principal components (Park and Lee, 2014).*

The rocker's arm pivots and pulls the diaphragm down due to a revolving eccentric camshaft. The return spring is squeezed, creating a low-pressure area in the pumping chamber of the diaphragms. The inlet check valve then allows gasoline to flow into the pumping chamber. The diaphragm moves in the opposite direction as the cam rotates, decompressing the spring and raising the pressure of the fuel. Through the exit check valve, the high-pressure fuel is eventually expelled (Park and Lee, 2014). If the injected pump does not require extra fuel due to low engine speed, the outlet pressure rises until it equals the pumping chamber pressure, at which point no fuel can enter through the intake valve. The cam will continue to revolve at this point, but the rocker arm will collapse and the engine will shut down (Denson, Galad and Malamug, 2016).

2.1.3.2 Injector

Injectors are one of the most important parts of the fuel injection system. The main function of an injector is to control the quantity of fuel given to the engine to maximize its efficiency. Without them, the dose of the fuel entering into the cylinder could be incorrect and excessive for a diesel engine, damaging and reducing the efficiency of all cylinders and therefore, all the engine. Previously to the injector, the fuel mixture has to flow over the distributor pump, which will increase the pressure of the diesel fuel to convert it from a liquid phase into a misty state. The transformation of the fuel is of important relevance because, within a gas state form, the combustion of the fuel mixture can be achieved much faster.

An injector is composed of multiple parts as shown in Figure 4, and each one of them has a very specific function within the working system.



1. Pressure valve holder
2. Pressure valve
3. Pump element
4. Control rod
5. Return spring for pump plunger
6. Roller tappet
7. Camshaft

Figure 4. *Diesel fuel injector schematic view for a Sisu Diesel engine (SisuDiesel, 2002).*

Fuel is entered into the injector part which is between the pumping element (3) and the pressure valve (2). Here, the fuel pressure increases, and therefore, the applied force to the pressure valve increases as well as Figure 5, step A shows. The force from the fuel applied over the pressure valve is bigger than the force of the spring that keeps the injection gate (pressure valve) closed. Thus, the difference in forces will make the pressure valve move back, and let the fuel enter the piston as Figure 5, step B samples.

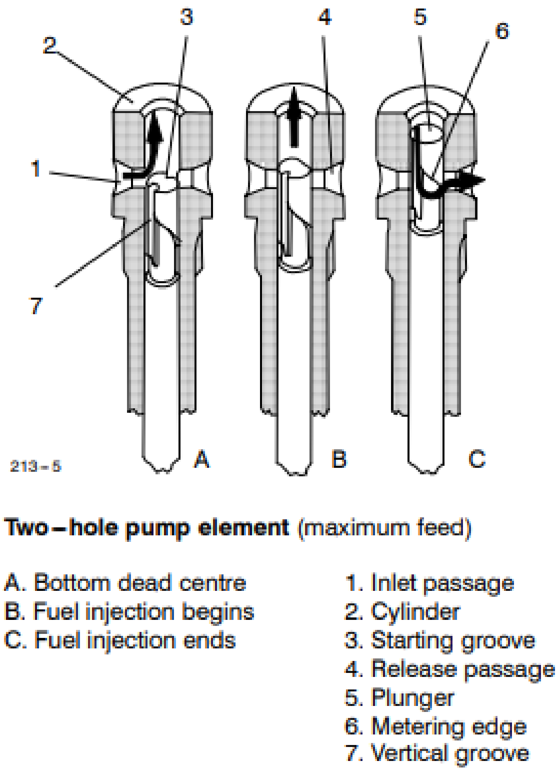


Figure 5. *Two-hole pump element is used for the injector for a Sisu Diesel engine (SisuDiesel, 2002).*

As the fuel enters the piston, the pressure of the mixture reduces, decreasing the force applied over the pressure valve. Once the spring force surpasses the force made by the fuel mixture, the gate will close, and the remaining fuel escapes the chamber through the vertical groove and metering edge as Figure 5, step C shows.

The up and down movement of the pump element is done through the camshaft, which is directly connected to the crankshaft. The movement of the crankshaft will synchronize both, cylinders and injector, and will lead to the movement of the fuel injection pump element. As both elements are in sync, the quantity of fuel introduced to the piston will be the perfect amount and will increase its efficiency.

2.1.3.3 Distributor pump

The distributor pump comes before the injectors and is the most important part of the fuel injection system since it works as the engine's heart and stomach meaning that it is the component that pumps fuel through the engine and tries to convert it into energy (torque).

The distributor pump is composed of a variety of pieces that work together to transport and give the right quantity of fuel to the injectors as Figure 6 represents.

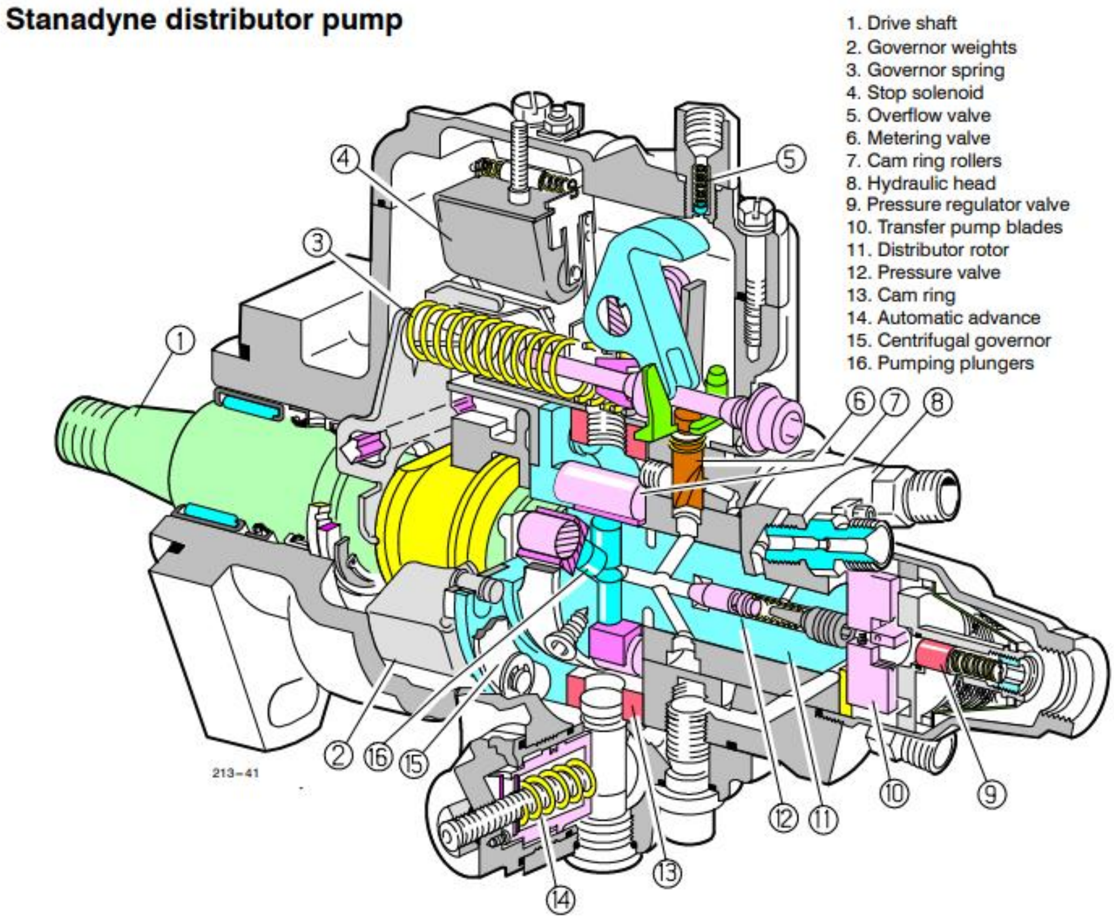


Figure 6. *Distributor pump schematic representation for a Sisu Diesel engine (SisuDiesel, 2002).*

Among all the parts of a Stanadyne distributor pump, four components surpass the importance of the others. These components are; the drive shaft (1), the governor weights (2), the hydraulic head (8), the metering valve (6), the distributor rotor (11), and the governor spring (3).

The working principle of the device is the next. The governor weight retainer rotates in tandem with the drive shaft. Due to the centrifugal force, the governor's weight pushes the petal-like pieces and presses the governor's arm. Therefore, the metering valve moves and closes the gallery inside the head (linking the rotor pump and metering valve) as the governor's arm travels towards the head, cutting or limiting the fuel flow. The fuel flows to the injectors since they are connected to the internal galleries of the metering valves.

The fuel demand is co-related with the accelerator pedal, as the throttle shaft, is attached to it. When the driver presses the accelerator pedal, fuel consumption increases, and when it releases the pedal, fuel does no longer enter the hydraulic head. As a result of pushing the throttle shaft, the governor's arm is pushed backwards by the throttle lever, and the metering valve moves as a result because it is coupled to the governor's arm. This causes the internal port metering valve to open, allowing fuel to flow to the rotor. In conclusion, the gas pedal is the part that controls the fuel demand as when it is more pressed, bigger is the opening of the fuel entrance in the hydraulic head, and when the driver releases the accelerator, the opening is closed, stopping the fuel demand into the distributor pump.

2.2 Cooling system

The cooling system is one of the most important parts of the engine and prevents the motor from self-damage due to its high temperatures. Even if the goal of the thesis is to design a new remote cooling module, this section, is going to explain why is it important, the different types that exist nowadays and their key components.

2.2.1 Importance of cooling systems

A portion of the energy created while combustion is not transformed into mechanical energy and is lost as heat. Based on the engine, roughly 33% of the fuel's potential energy is turned into mechanical work, while the remainder is released as heat that must be dissipated to prevent the engine's mechanical integrity from being damaged (Denso, 2016).

To avoid engine problems, the system must somehow control the maximum engine temperature and maintain the optimal operating temperature, which varies by engine design but is typically between 80 and 100°C (Cooling in internal combustion engines, 2020). The engine's thermal efficiency is highly dependent on its optimal operation.

Because most automobile engines are composed of steel or comparable materials, high temperatures may cause some of the motor's components to deform. As a result, if a deformation in one or more sections occurs, the entire motor will ground to a stop, causing significant damage to the engine. Furthermore, operating the engine above its optimal temperature increases the danger of lower oil viscosity, higher engine wear, part overheating, and increased friction between them. Detonation can also happen if the fuel mixture ignites too soon. A bigger problem would be when the pistons are essentially fused to the inside of the cylinders if the heat cannot be evacuated from the engine. Then the only solution is to dispose of the engine and replace it with a new one. As a result, it is very important to maintain and understand the engine's cooling system (Gimeno, 2021).

2.2.2 Types of cooling units: air-cooled or water-cooled system

One significant factor of the cooling system is that an engine can be refrigerated in two ways: with an air-cooled system or with a water-cooled technology.

On the one hand, air-cooled engines are more common in small engines with lower power output compared to heavy engines (Hemmings, 2018). They are commonly seen in motorbikes, miniature tractors, scooters, and aeroplanes with very small engines and propellers. These engines are less expensive, easier to build, and less in weight. Above all, they require far less monitoring and maintenance, and they are unaffected by temperature differences or temperatures below zero. In fact, due to water shortages and sub-zero temperatures, these engines are chosen above others in the arctic region (ShipFever, 2018).

The effects of air velocity and surface area on heat transmission between two mediums or bodies are the basis for air-cooled engine cooling systems. Heat is transferred from the cylinder to its walls before being carried away by air via natural convection. The surrounding air is heated by the cylinder's walls; hot air rises, making room for cool air to fill in and continue the process.

Thus, the natural convection cooling system of an air-cooled engine works to lower the majority of its waste heat via convection, while some manage to escape via radiation. Even a modest engine, such as that found in a motorcycle, cannot provide adequate cooling for a lengthy period.

On the other hand, water-cooled engines make up a substantial portion of the engines found in autos and businesses. They are in our buses, cars, trucks, tractors, alternators, industrial engines, and even ships, where they are found in marine diesel engines.

The radiator, expansion tank, cooling fan, water pump, thermostat, bypass valve, cylinder jacket, and pressure cap are all immediately identifiable parts of a water-cooled engine that we will be discussed hereafter. However, instead of using a radiator, a heat exchanger can be used. This is the case of the actual cooling system that the SISU 420 DWI diesel and an Opel Astra G 1.6 16V engines use.

The working principle is that coolant flows from the bottom to the top of the cylinder liner in these water-cooled engines, with coolant running in series to the cylinder head. This means that after cooling the cylinder, some of the hot refrigerants are directed through the exit pipe.

A water-cooled engine can be classed into three groups based on its design: closed loop, open loop, and semi-closed engine cooling systems. In this case, only a closed loop is going to be analysed as it is the one used in both engines before changing the system and the one that is going to be implemented with the remote cooling system module.

2.2.3 Main components of the cooling system

Both, the diesel and the gasoline engine use the same cooling elements except the coolant type, which may be different for the diesel motors. That is because the diesel cooling systems are more corrosive than the gasoline ones, therefore, a special coolant and frequent maintenance of the equipment have to be done every 2 years approximately. However, this project is aimed to find a solution and search for a compatible coolant for both engines.

The typical components of a cooling system are a radiator (with or without fan included), coolant pump, expansion tank and thermostat.

2.2.3.1 Radiator and fan

The heat exchanger, also known as a radiator, is one key element in the design of a cooling system. Radiators are made of parallel tubes with some fins attached to them. The main function is to cool down the refrigerant that absorbs the heat produced from the engine, therefore, it is very important to implement fins, as it will increase the capacity to dissipate heat from the refrigerant (more surface to deliver heat in convection form). Furthermore, on some occasions, the tubes previous to the radiator, incorporate some fins to generate a turbulent flow and maximize the heat transfer (Yadav and Bharat, 2015).

The installation of the radiator can be made with a fan next to it as can be appreciated in Figure 7.

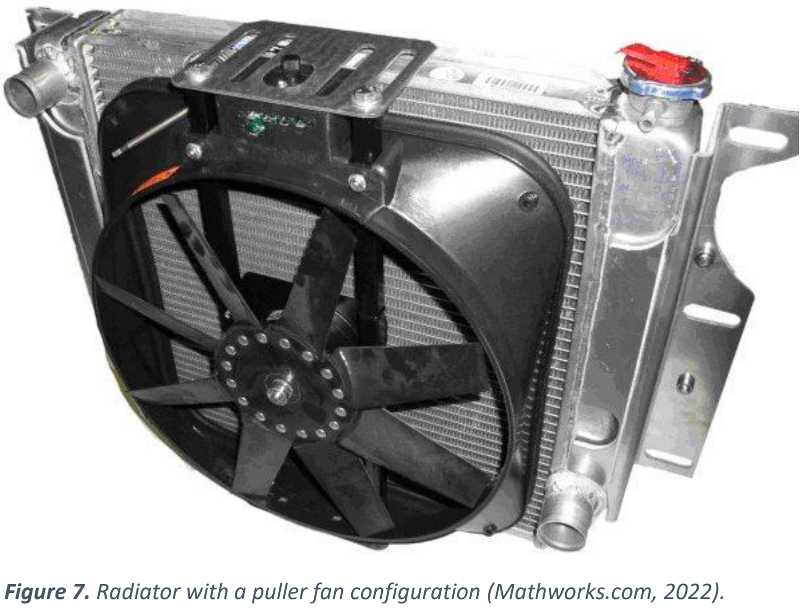


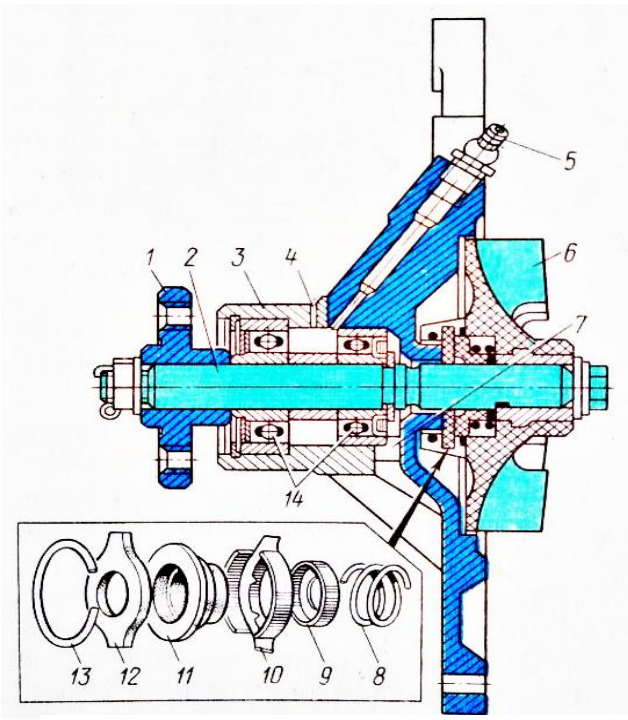
Figure 7. *Radiator with a puller fan configuration (Mathworks.com, 2022).*

The fan will provide the power (in case the radiator does not have the capacity) to cool down the refrigerant to normal working temperatures (Nice, 2000). Depending on the installation the fan can be in front of the radiator (pusher configuration) or behind the radiator (puller configuration). The pusher configuration is not the most suitable election in most of the cars available on the market, furthermore, they disturb the airflow that will cool down the radiator, concluding in a downgrade of the cooling capacity of the system (Holley.com, 2017). Therefore, a puller solution is more used nowadays (used configuration in Figure 7). The puller fan is located behind the radiator, leaving the air entry without any obstacle, which will correlate to an increase of dissipated heat in the radiator and with the fan rejecting heat from the back of the heat exchanger, it is the most suitable and used configuration in most of the manufacturers (Staff, 2015).

2.2.3.2 Water pump

The cooling system's heart is the water pump. It circulates coolant through the engine, radiator and heater core. These days, certain vehicles (such as some SUVs, pickup trucks and most hybrids) often have more than one water pump, and the auxiliary pumps are usually powered by electric motors and controlled by a computer (MACS, 2010). While the pump incorporated within the engine is belt-driven as it rotates due to the spinning of the crankshaft.

The assembly of the device has to be very precise, if not, there will be a lack of efficiency and can make some troubles for the engine (affect to the cavitation effect, overheating the fluid, etc.). The construction components of the engine water pump are visible in Figure 8.



COMPONENTS OF A WATER PUMP
1. Fan and pulley hub
2. Shaft
3. Housing
4. Inspection hole for the release of lubricant
5. Lubricator
6. Water pump impeller
7. Control aperture for an exit of a cooling liquid at the stuffing box leak.
8. Spring.
9, 10 and 11. Stuffing box cuff.
12. Stuffing box washer.
13. Stuffing box locking rings.
14. Ball bearings.

Figure 8. *Typical water pump with the different parts indicated and referenced on the table next to the figure (Car Construction, 2019).*

At one end of the shaft, a pump pulley, a fan hub, and a generator pulley are pressed on. With a washer and a precisely split toothed nut, the hub protects against axial displacement (Car Construction, 2019). On the second shaft end, a water pump impeller (6) is installed.

The washer and bolt prevent the water pump's impeller from being displaced. A self-locking stuffing box, consisting of a graphitic-textolite washer (12), rubber sleeve (11), two cages (9 and 10), and a spring (8), seals the shaft in the housing. A spring (8) forces the washer to the plane of the housing (3) through a rubber sleeve (12), preventing fluid from leaking from the pump. Furthermore, fluid leakage through the control hole (7) implies a self-locking stuffing box problem. You must remove and fix the pump in this case (InnovationDiscoveries, 2020).

2.2.3.3 Thermostat

A traditional thermostat is a simple temperature-controlled two-way valve that opens when the temperature reaches a certain level (Samarin, 2022). A thermostat is usually located on the engine and connected to the upper or lower radiator hose in most autos.

The thermostat (primary valve) is closed when the engine is started cold, therefore there is no flow through the radiator. Because the smaller by-pass valve is open, coolant only circulates within the engine and through the car heating system. The thermostat gradually opens up when the engine warms up to operational temperature, allowing coolant to flow through the radiator. If the engine temperature falls below the lower limit of the operational range (90°C) in cold weather, the thermostat closes again (Nice, 2000). This process can be seen in Figure 9.

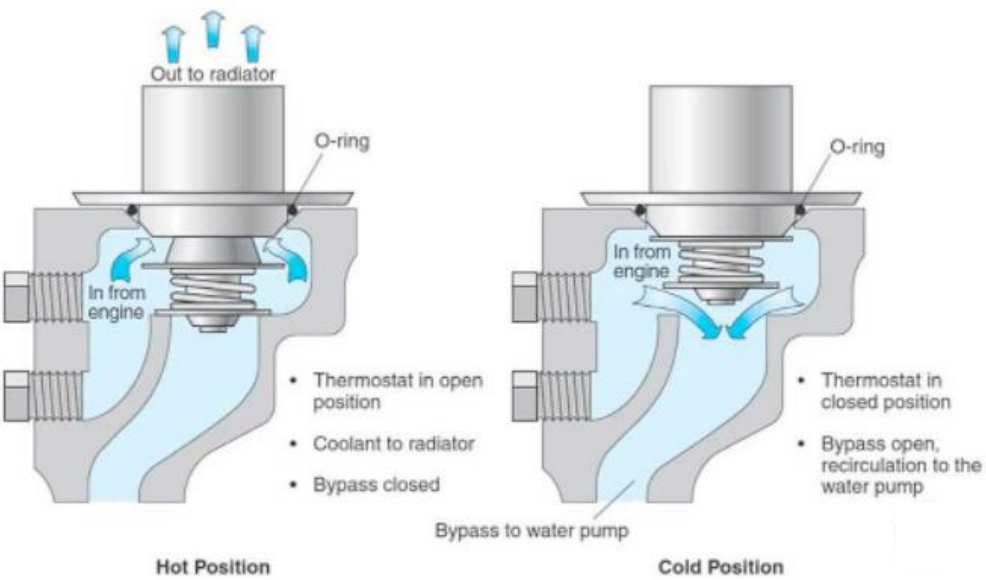


***Figure** 9. Working principle of a car's cooling system thermostat (InnovationDiscoveries, 2020).*

The working principle of the thermostat resides in the melting of the wax inside the cylinder. Inside the thermostat, there is a connecting rod attached to the spring that can be appreciated in Figure 9. The thermostat is in contact with the refrigerant fluid that comes out of the engine, so when starting the motor, the coolant will yet be cold and this will lead to the inactivation of the thermostat as the wax will remain in a solid-state (Studentlesson, 2020). Once the refrigerant starts to heat up, the wax will melt. The state transformation of the wax will lead to an expansion of the same, and therefore, will apply a force to the rod which will start to move and plug the conduct that redirects the refrigerant to the engine. When the by-pass valve is closed, the refrigerant is forced to pass through the radiator. Finally, when the engine is switched off, the inverse procedure occurs, solidifying the wax and unclogging the conduct that sends the coolant to the engine.

2.2.3.4 Expansion tank

An expansion tank is an important component of a car's cooling system. The primary purpose of the expansion tank is to permit the coolant to expand thermally (Naveen *et al.*, 2015).

The cooling system of an engine's main purpose is to remove excess heat and pressure from the engine and keep it running at its most efficient temperature. The cooling system should, in theory, keep the engine running at its most efficient temperature regardless of the operating conditions (Sci-hub, 2015).

The coolant inside the engine expands as it heats up. When the coolant is hot, the expansion tank stores it and then releases it when it cools down. Therefore, coolant can flow between the system and the expansion tank as it expands and contracts since a cooling system with an expansion tank is a closed system (Arthanari, Sundaram and Sathish Kumar, 2015). If the system is working properly, no coolant will be lost. Furthermore, the expansion tank is also used to remove air bubbles that had been made during the cooling down of the liquid.

Expansion tanks work by balancing the pressure in the system. An expansion tank is a small tank with a rubber diaphragm that divides it into two pieces. The water is contained on one side, which is connected to the heating system's pipes. The other side is completely dry and contains pressurized air at a pressure of around 0.8 bar (Boyle, 2014). The pressure in the heating system rises when hot water enters the system. The expansion tank's diaphragm is pushed down as pressure rises. As a result, the air in the tank is compressed, allowing more water to enter. This reduces the system's excess pressure and protects the system's pipes from harm (Jones et al., 2008).

To maintain the pressure, there is the radiator pressure cap, which consists of a spring-loaded valve mechanism which will respond to higher pressure. When the pressure is above 1 bar, it will push the pressure cap valve and the coolant is going to flow to the expansion tank until the pressure goes down to operation level. As soon as the system cools down, the system sucks back the coolant from the expansion tank. In case there is too much pressure build-up in the system due to trapped air or other failures, the coolant in the expansion tank will be pushed out through the overflow hose (Autotechlabs, 2015).

To achieve this balance between the expansion tank and the system a few tubes are involved. These tubes have different functions and can be appreciated in Figure 10.

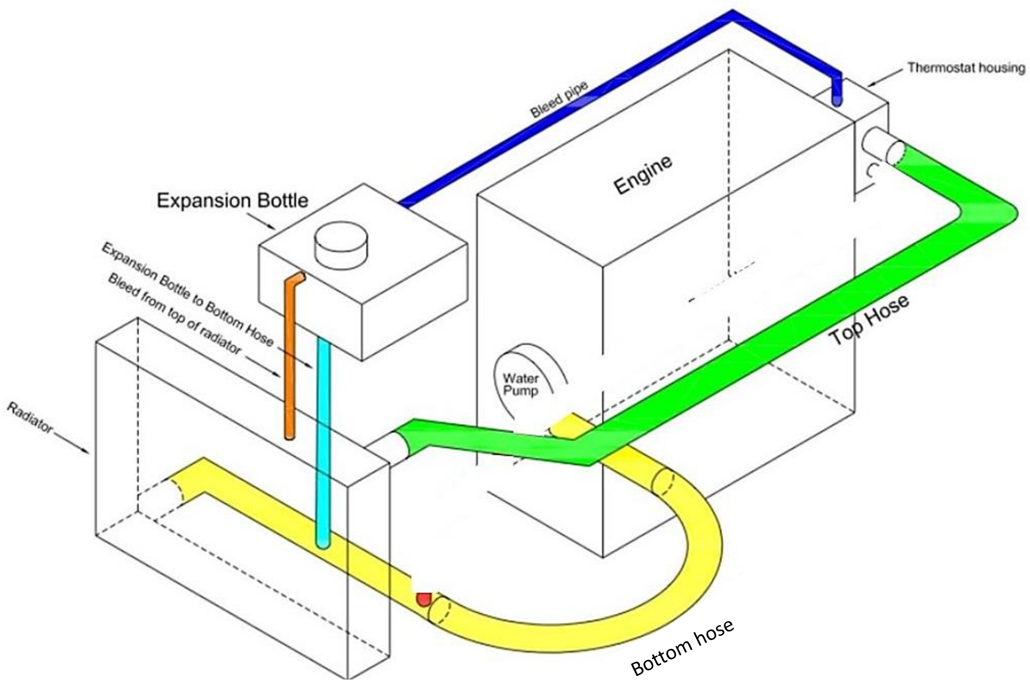


Figure 10. *Cooling system scheme with the expansion tank pipes integrated (Locostbuilders, 2022).*

The liquid enters the expansion tank through the orange tube that exits from the radiator as seen in Figure 10. If the liquid is more heated, more fluid will flow through this hose and fuller will be the expansion tank. Moreover, it is of vital importance the assembly of this tube inside the expansion tank as it has to be positioned at a deeper level than the coolant. This configuration minimized the apparition of bubbles inside the expansion tank that could damage the engine (Locostbuilders, 2022). If the tank is overfilled, the liquid escapes through the light blue hose and is returned at the beginning of the radiator. The dark blue pipe is where the fuel exits the expansion tank and is directed into the entrance of the engine. So basically, the fuel enters the expansion tank through the orange pipe and exits through the dark blue pipe, but in case the tank is with too much coolant, then it escapes the system through both blue pipes.

2.3 Exhaust gas system

As in the other sections, the goal of the project is to design a new extractor for the laboratory by modifying the one that is being used nowadays. However, it is considered important to know how the exhaust gas system works and the main exhaust system parts.

2.3.1 Importance of the exhaust gas unit and operating process

The combustion process made in the cylinders generates harmful gasses such as carbon monoxide (CO), oxide of nitrogen (No_x) and unburned hydrocarbons (HC) (Automotive System, 2013). These gasses are very harmful to the ecosystem and they travel along with sound waves that generate an enormous quantity of noise, therefore, the sound level and the gasses generated must be treated before they are released into the atmosphere.

The fuel enters the cylinder mixed with air and experiences a combustion process due to the increase of pressure. This process will create exhaust gasses and sound waves. The generated gasses exit the cylinder through the exhaust manifold which is mainly a series of pipes that are connected to the cylinders that act as an exit pipe for the gasses (Galindo et al., 2004). Once the gasses escape the combustion chamber and pass through the exhaust manifold, they are directed to the catalytic. The catalytic converter has the function to create chemical reactions within the gasses released during the combustion process. These reactions will transform the harmful gasses into eco-friendlier substances that can be released into the atmosphere (Amatayakul and Ramnäs, 2001).

The sound waves are treated in the next exhaust system device, which is the muffler. The muffler has the unique function of reducing the noise created by the engine. This reduction of sound is achieved by the friction of multiple sound waves which will eventually destroy themselves, nonetheless, the most powerful sound waves may reach the end of the exhaust system (Daniel, 2005).

The ultimate part of the system is the exhaust pipe (also named tailpipe) and the exhaust exit. These parts will conduct the sound waves and the gasses to a safe place where can be released to be non-harmful to the passengers of the vehicle.

2.3.2 Main exhaust system parts

Both gasoline and diesel engine, share the same components for the exhaust system. The principal parts of the exhaust system are the exhaust manifold, the catalytic converter, the muffler and the tailpipe. Further details of each component can be found hereafter.

2.3.1.1 Exhaust manifold

The exhaust manifold is the initial section of the exhaust system of your car. It is attached to the vehicle's engine and gathers the emissions produced by it. The exhaust manifold receives the air/fuel mixture from the cylinders of your vehicle's engine. Not only does the exhaust manifold absorb all of the burned engine gases, but it also uses its extremely high temperature to burn any unused or incompletely burned gases (Brodie's Tire & Automotive, 2022). Moreover, the first oxygen sensor in your exhaust system is located in the manifold, and it monitors the amount of oxygen entering the system.

Also, the manifold helps the engine with the gas flow through the cylinder. When the gasses exit the cylinder, they flow to the manifold where they will be conducted to the catalytic, but the tubes of the device are made in such a manner that the first wave of gasses exiting the cylinder is at high pressure, while the last remaining of the gas' outlet is at low pressure (Club Lexus, 2012). This phenomenon can be seen in Figure 11.

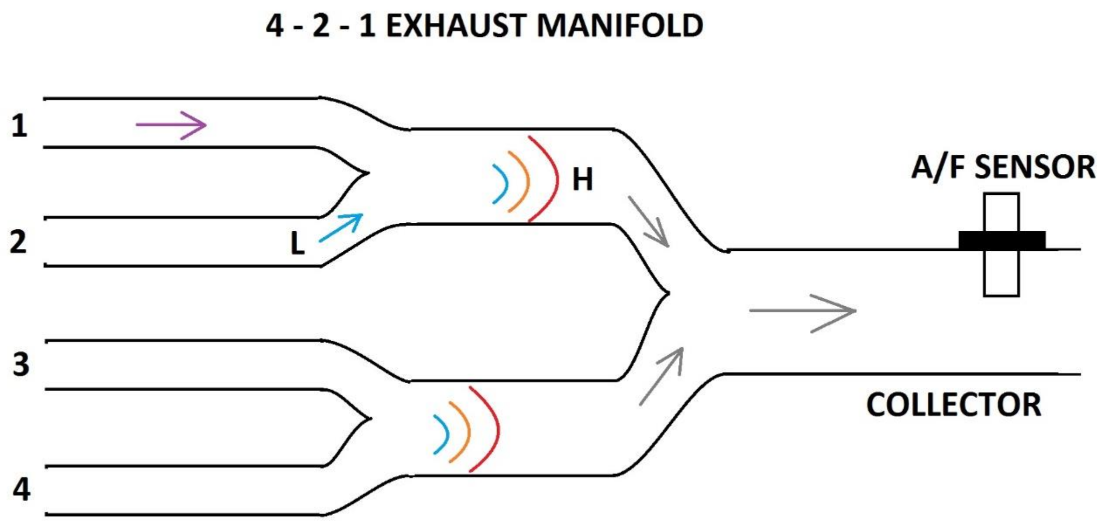


Figure 11. *High pressure (H) and low-pressure(L) gas waves phenomenon picturized (Club Lexus, 2012).*

The three blue orange and red refer to high-pressure gas (H) and the blue arrows reference low-pressure gasses (L). As seen, the front part of the exhaust gasses is at a higher pressure than the end. By doing this, the manifold has the power to pull the gas from the cylinder and help the intake manifold fulfil the cylinder (Figure 12).

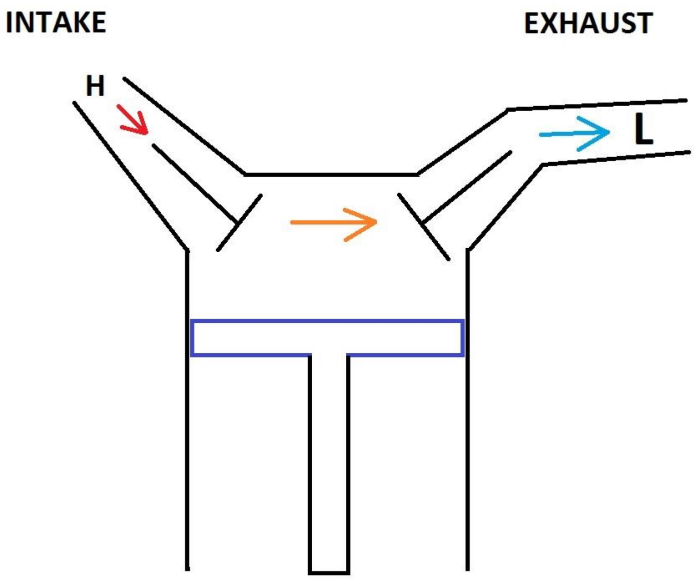


***Figure 12**. Scavenging effect due to the low-pressure gasses of the exhaust manifold (Club Lexus, 2012).*

The low pressure (L) will drag the gasses that are at a higher pressure (H) and will make the exhaust gasses come out of the cylinder once the combustion process has been made (How a car works, 2019). Moreover, when pulling the gasses out of the engine, the flow generated by the pressures will help the inlet gasses as they are at a higher pressure than the exhaust gasses.

Finally, an air/fuel ratio sensor is installed within the exhaust manifold to control the amount of fuel entering the cylinder (Michael, 2016).

2.3.1.2 Catalytic converter

The catalytic has the function to reduce car emissions by transforming the gasses exiting the engine. The catalytic is the previous element to the exhaust manifold and receives all the high-temperature gasses that come from the cylinder. Whether it is a diesel engine or a gasoline engine, the exhaust gasses from the combustion process are carbon monoxide (CO), oxide of nitrogen (NO_x) and unburned hydrocarbons (HC) (Automotive System, 2013).

These gasses cannot be released into the atmosphere because of their toxicity. Moreover, all the cars around the world require the instalment of a catalytic to reduce the pollution these gasses cause (Chrzanów, 2018).

A catalytic is a filter that will cause the exhaust gasses to react into less-harmful gasses. The reaction process is made due to the materials of the catalytic. Figure 13 represents an inside view of the catalytic converter design. The cylinders inside the catalytic are made from platinum, gold, rhodium or palladium, depending on the manufacturer.

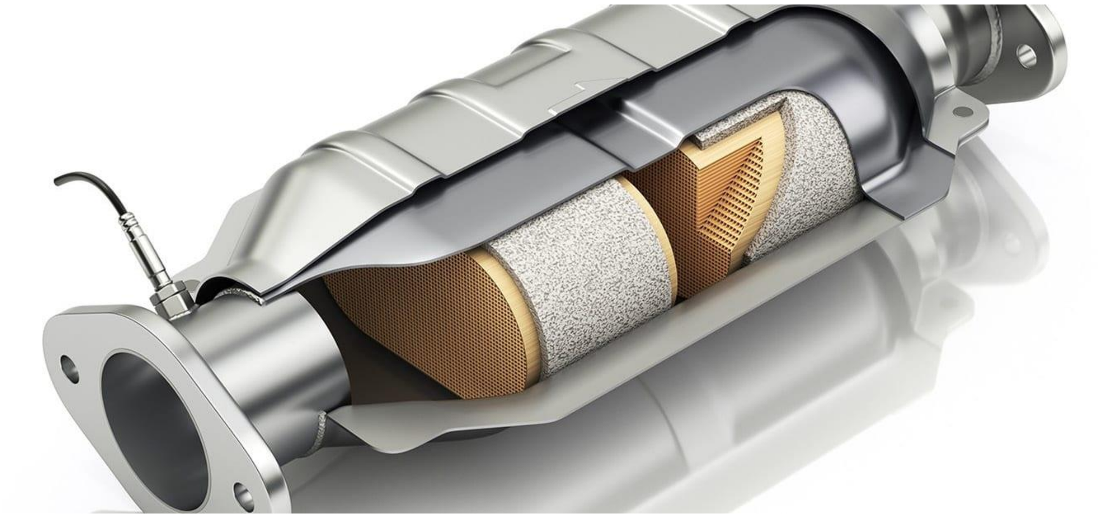


Figure 13. *View of the inside of a catalytic converter (Which Car, 2019).*

Sometimes the cylinders are from different materials as they will exercise different functions and in some cases inside the catalytic, there is only one big cylinder that makes the same function as the two displayed in Figure 13 (UTI Corporate, 2021).

The materials of the catalytic cylinders will cause the oxide of nitrogen to reduce into oxygen (O_2) and nitrogen (N_2) and they will oxidize the carbon monoxide (CO) and the oxygen (O_2) into carbon dioxide (CO_2). Furthermore, it will make react to the hydrocarbons with the oxygen leading to the formation of water (H_2O) and carbon dioxide (CO_2) (Automotive System, 2013).

One drawback of the device is that it only operates at high temperatures, meaning that the engine's starting will not be as effective as it should be. Moreover, the catalytic is placed as close as possible to the exhaust manifold because the gasses will be more heated (Michael, 2016).

At the end of the catalytic converter is installed the second air/fuel ratio sensor. This serves as a measurement device to control the correct operation of the catalytic.

2.3.1.3 Exhaust Muffler

Mufflers are part of the exhaust system and are located near the bottom of the vehicle. They aid in the reduction of vehicle emissions and noise. They are built of steel with an aluminium coating to protect them from the heat and chemicals emitted by the engine (Dieselnet, 2022).

Mufflers are primarily employed to disperse the loud noises produced by the pistons and valves of an engine. A significant burst of the burnt gases consumed throughout your engine's combustion is expelled into the exhaust system every time your outlet valve opens. The expulsion of gases produces extremely loud sound waves. Sound is a vibration-induced pressure wave. These vibrations are caused by air pressure pulses that alternate between high and low pressure (Singh and Katra, 1978). As a result, once your exhaust valve opens, a large amount of high-pressure gas enters the exhaust system. These high-pressure gases will interact with low-pressure molecules, resulting in pressure waves (sound), which will move down the exhaust system (Sullivan, 1979).

It is possible to cancel out sound if you can add a pressure wave that is the polar opposite of the initial sound wave, meaning their wavelengths, or high- and low-pressure points, are the same, they cancel each other out and no sound is produced (Rothemund *et al*., 2018). Another way to put it is that when one sound wave reaches its greatest pressure, the other reaches its minimum pressure, cancelling each other out. This is what happens within your muffler and is known as destructive interference.

The design of a muffler is both basic and accurate. There are pipes with apertures inside a muffler that route sound waves through the muffler and out the end. Sound waves will enter the middle chamber through a central tube, hit the back wall and travel through a gap. The sound wave will next pass through a second hole and enter the resonator chamber, which is located towards the front of the muffler where the sound waves first entered. The sound wave will now reflect off the wall of the centre chamber, while the rest will flow through the hole and into the resonator chamber. To produce sound waves that cancel out other waves, the resonator chamber must be a specified length. The length of the resonator chamber is constructed so that when a sound wave strikes the rear wall and returns through the hole through which it came, it will collide with the next sound wave exactly as it hits the centre chamber's wall (Fu *et al*., 2021). As a result, the high-pressure sound wave that passed through the resonator will cancel out the low-pressure sound wave that was reflected off the middle chamber's wall. The whole chamber design is presented in Figure 14.

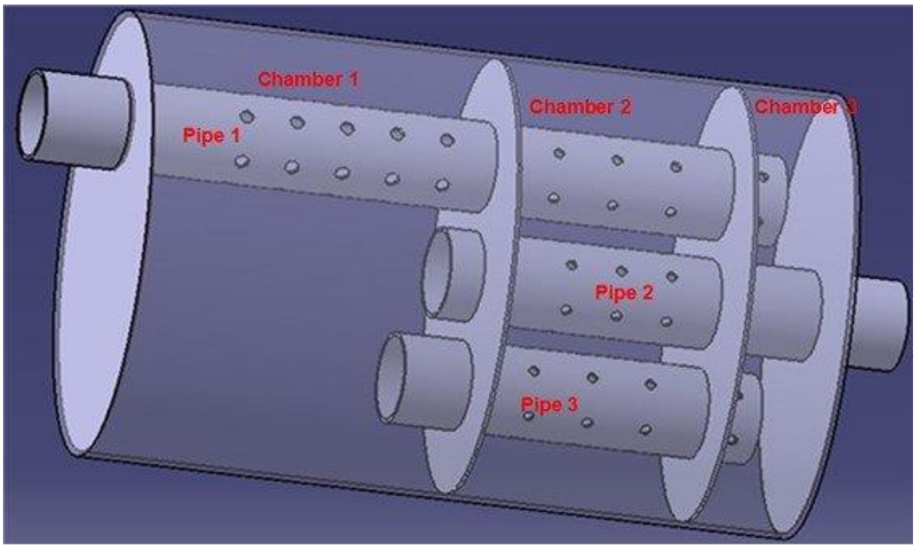


Figure 14. *3D model of the inside of a muffler (Tianjun Z, 2017).*

Every feature of the muffler is designed to help reduce noise (holes, pipes, etc.). Even the walls of a muffler are custom-made, and they can absorb some of the pressure waves (Mishra *et al.*, 2016). Returning to the perforated tubes, these perforations allow thousands of little pressure waves to enter the middle chamber, bouncing walls, and cancel each other out. A muffler is essentially a device that is designed to manage the way sound waves bounce off its walls so that they cancel each other out.

2.3.1.4 Tailpipe

The tailpipe has the direct function of releasing the treated exhaust gasses in a safe place where they cannot be harmful to the passengers of the vehicle. They are often located on the rear end of the car as it is the best possible place to not interfere with the people inside the vehicle (Figure 15 illustrates where the tailpipe is commonly located).

Figure 15. *Tailpipe next to the muffler component in the back part of a car (Park Muffler, 2019).*

Tailpipes start at the end of the muffler (Present in Figure 15) and they can vary in size depending on the manufacturer. The tailpipes are made of steel but they can be made of a different material at the end of the pipe (Journal of the Air & Waste Management Association, 2012). The switch of materials is a mere design aspect as it is the only part of the exhaust system that can be visible from the outside of the car.

Moreover, the tailpipes are also supported in the car with rubbers. The selection of rubber as a supporting material is a question of vibrations. The rubber can handle the heat of the exhaust system well and will reduce the vibrations produced by the muffler, that way, the whole car is not under vibration forces due to the cancellation of the sound of the muffler (Abu-Allaban et al., 2003).

3. Current state of the engine different parts to be analysed

This section analyses the actual equipment available in the laboratory previous to the thesis modifications. It will explain which are the existing problems and how will be handled in the Methodology section.

3.1 Fuel injection system

In this section, only the diesel engine will be explained. The gasoline engine is not installed in the laboratory and the petrol injection system cannot be explained as it is non-existent at the moment. Thus, the fuel injection system design outside the engine that ensures that the Diesel arriving at the SISU engine will be explained accompanied by photos to clarify the function of each part of the system.

3.1.1 Analysis of the actual SISU fuel injection system

Within the fuel injection system, there are two visible parts, the first one is the pieces that are assembled into the wall (fuel tank, pre-filter, fuel consumption device, etc.) and the other one is all the components already incorporated into the engine (filters, fuel feed pump, etc.). This section will focus on the components assembled into the wall.

The first part is composed of the fuel feeding pump that conducts the diesel into the tank, the fuel tank, the pre-filter, the distributor pump and the fuel consumption measurement device (all the devices can be observed in Figure 16 on the right-hand side of the image)

Figure 16. Diesel injection system. From down to up, the fuel consumption device (blue and grey box), the pre-filter (left-hand side of the fuel measurement item and the fuel tank (grey box) (Author's own).

The fuel enters the tank by the white pipes located on the right-down side of the fuel consumption device (blue and grey box). As seen in Figure 17, there are two pipes (enclosed in red) that emerge from the diesel barrel. One of these pipes serves as a conductor to get fuel into the tank. The other pipe is used to redirect the diesel to the barrel in case of over-filling the tank.

***Figure 17**. Actual fuel injection equipment signalizing the fuel tank inlet fuel white pipes - enclosed in red (Author's own).*

These pipes pass behind the fuel consumption device and connect to the fuel tank that is located on the upper part of the fuel consumption device (Figure 18 a). The white pipes can be seen on the left hand of the diesel tank.

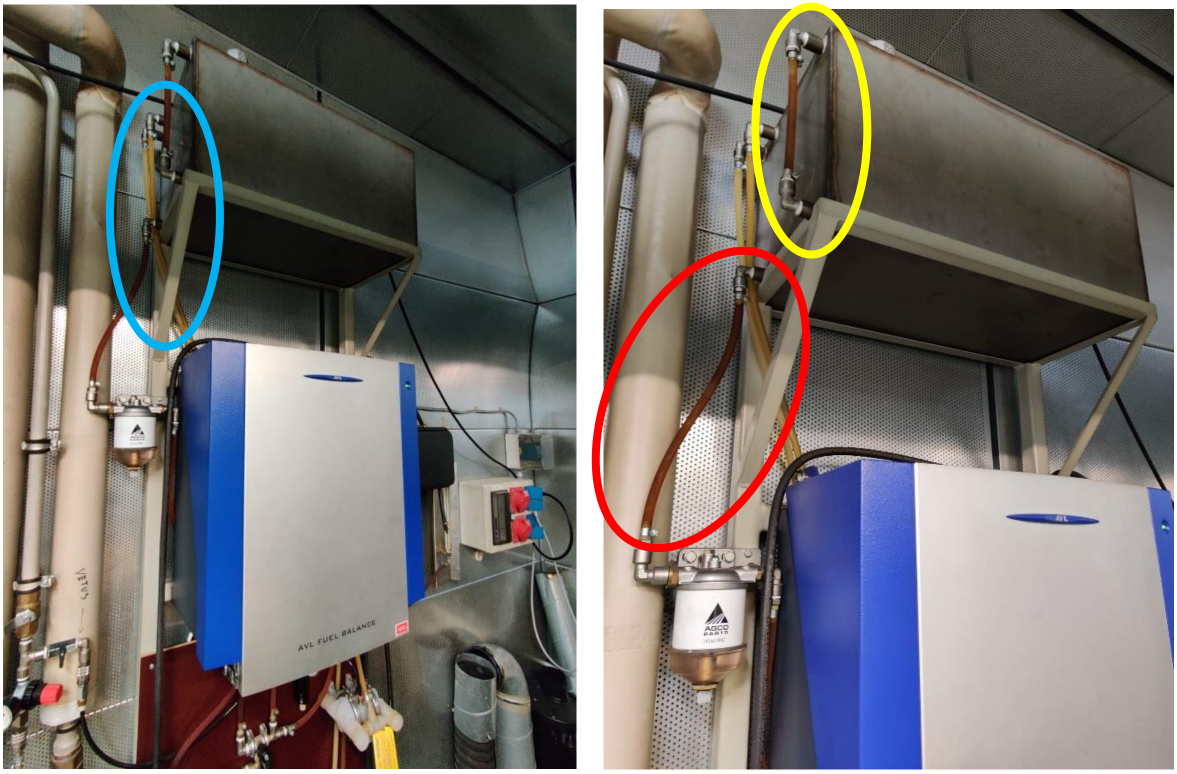


Figure 18 a) and b). *Fuel tank used on the studied motor with indicators of the inlet (blue) and outlet pipes (red) (Author's own).*

Furthermore, in Figure 18 b, can be appreciated that more pipes are connected to the tank. These pipes have a different function than the white pipes (enclosed in blue). The blue circled pipes provide fuel to the tank. Moreover, there is another pipe that serves as a measurement device that displays the level of fuel inside the tank (yellow circle in Figure 18 b). While the red exiting pipe that comes out of the bottom of the fuel tank is the inlet fuel pipe that gets fuel to the measurement box after passing through the fuel filter (red circle in Figure 18 b). A scheme of an inside view of the tank is presented in Appendix I as it is of vital importance to the configuration of these tubes to avoid the cavitation effect. The trickiest tubes (blue ones in Appendix I) are both tubes that provide fuel into the tank (returning from the engine and entering from the barrel) as they have to be positioned very deep inside the tank. This is due to the possibility of the apparition of bubbles when the fuel is deposited in the tank. If the pipes are very high inside the fuel tank and the fuel level is low, the diesel will splash inside the tank and will lead to the creation of bubbles that will decrease the engine’s efficiency.

In the following Figure, the diesel filter is shown.

Figure 19. Pre-filter used on the SISU engine – annotated with a red circle (Author's own).

Here, the diesel is filtered for the first time before going through the injector. Once the fuel has passed the pre-filter (red circle in Figure 19) it is directed into the fuel measurement consumption device (blue and grey box in Figure 20). This machine's function is to regulate the fuel entering the engine, delivering a perfect amount of fuel to improve the engine's efficiency.

Figure 20. *Picture of the fuel consumption device and the inlet (blue) and outlet (red) fuel pipes of the system (Author's own).*

The returning fuel of the engine enters the fuel consumption device through the black pipes below it. As indicated in Figure 20 the fuel enters the engine through the right pipe (blue arrow) and comes back to the measurement device through the left pipe (red arrow). Then, with the amount of fuel returning from the motor, the computer inside the fuel consumption device makes an approximation of the quantity of new fuel from the tank required to achieve the highest efficiency of the combustion process.

3.2 Cooling system

The actual cooling system differs from the explained in the technological concepts as it is not installed in a vehicle, therefore, some modifications can be done to achieve a high-level efficiency much more economically than a standard cooling system. The SISU engine and the Opel engine use the same cooling method, with minor differences in the design. These differences will be explained hereafter.

3.2.1 Analysis of the actual cooling equipment for the SISU Diesel engine

Car cooling systems are typically closed-loop systems with a radiator, however, because the researched diesel motor is not installed in a car, a closed-loop system with a water heat exchanger is employed instead. This method uses a pump to circulate water through the cooling system, lowering the temperature of the refrigerant, which absorbs the heat from the motor. Freshwater will be cold when it enters the heat exchanger and will absorb the heat from the heated refrigerant. Previously, the water would heat up and be flushed down the drain. Once the refrigerant has cooled, it will travel through the crankshaft, pistons, and other parts of the motor before exiting through a pipe with a temperature sensor that will tell the user what temperature range the motor is in.

SISU engine cooling system has 4 main pipes. 2 are designated for the flow of the coolant while the other 2 are made for the entry and exit of freshwater.

Freshwater is obtained through the general water grid, and the pipe goes from the wall up to the cooling system. The inlet water is controlled with an opening valve which remains open when the engine is running and remains closed the rest of the time. The inlet freshwater pipe is indicated in Figure 21 with a light blue arrow.

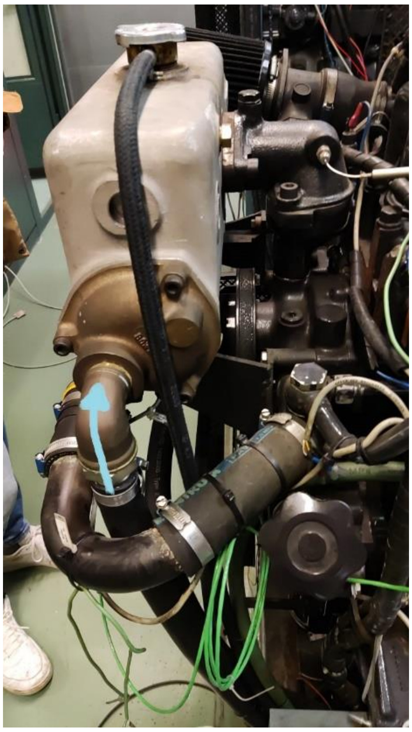


Figure 21. Inlet freshwater pipe of the studied SISU engine (Author's own).

Once the freshwater is inside the cooling module, it goes through a heat exchanger where it will absorb the heat from the refrigerant. The variation in temperature of the water is much lower than the variation of temperature of the coolant the freshwater is running through the heat exchanger with a fast flow, while the refrigerant is flowing at a much slower pace. The fast flow of the water provokes a relatively small increase in temperatures in the liquid, without achieving the high temperature of the inlet refrigerant. Thus, when the operation is done, the heated freshwater exits the cooling system through the pipe on the other side of the module (Figure 22) and ends up in the sewage.

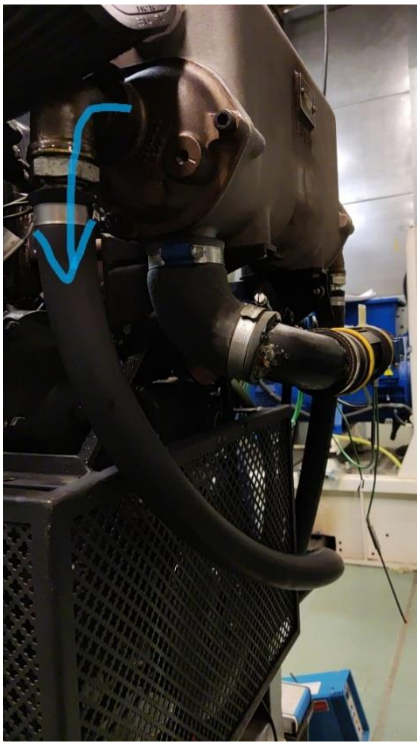


Figure 22. *Outlet freshwater pipe of the studied SISU engine (Author's own).*

The other 2 pipes are reserved for the refrigerant closed-loop system. The hot coolant enters the cooling system for the pipe with the red arrow and exits through the pipe with the blue arrow (Figure 23). The refrigerant enters the cooling system and is cooled down by the running water obtained from the water grid.

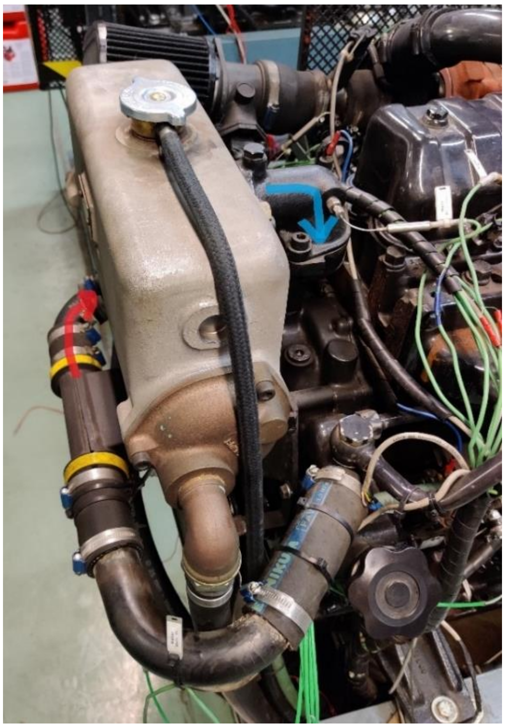


Figure 23. *Inlet and outlet pipes of the refrigerant closed-loop cooling system of the studied SISU engine (Author's own).*

To keep the circuit operating a water pump is needed. In the SISU engine, a low-pressure pump is used to run the refrigerant. It can be found next to the inlet pipe of cold coolant to the engine block, pumping the cooled down refrigerant to the motor (Figure 24).

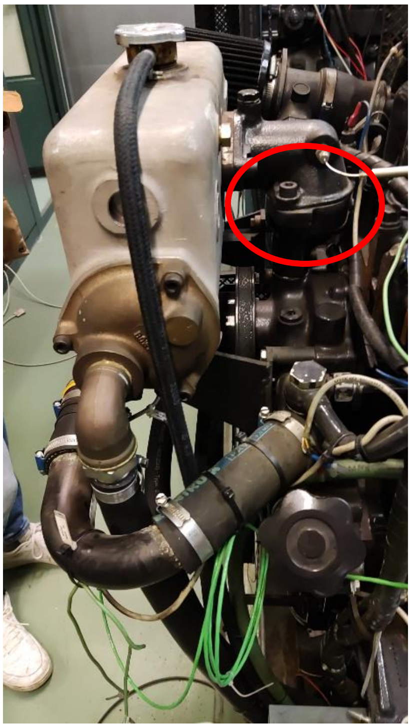


Figure 24. *The water pump of the studied SISU engine is circled in red (Author's own).*

Moreover, the inlet refrigerant pipe is using a temperature sensor that will display the range of temperatures of the engine on the computer.

Figure 25. *The temperature sensor of the cooling system of the SISU 420 DWI Diesel Engine (Author's own).*

3.2.2 Analysis of the actual cooling equipment for the Opel Gasoline engine

The actual technology for removing heat that this engine has is similar to a simple closed-loop cooling system. The engine has a heat exchanger where the refrigerant loses heat. It is the device presented in Figure 26.

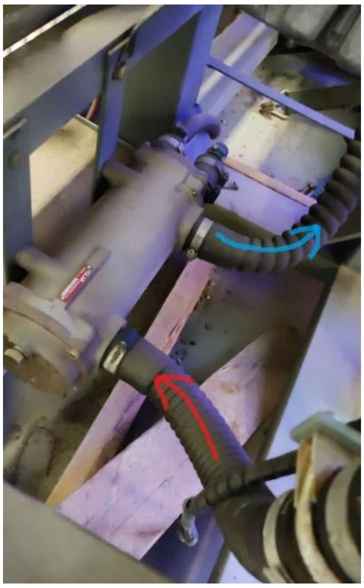


Figure 26. *Heat exchanger for the Opel Engine with the inlet (red) and outlet (blue) pipes to the heat exchanger (Author's own).*

Thus, as the fluids go through the heat exchanger it gets cooled down and can return to the engine through the blue pipe placed on the left of the image. Then the coolant is going to have the capacity to decrease the temperature of the motor again. On the one hand, the pipe with the blue arrow is the tube through which the coolant is going back to the engine block once its temperature has been decreased thanks to the heat exchanger. On the other hand, the pipe with the red arrows is for letting the hot coolant that leaves the motor enter the heat exchanger.

It also has a water pump to make the coolant pass through the different parts of the system enclosed in red in Figure 27.

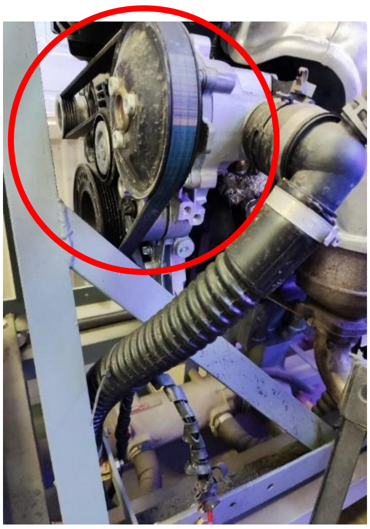


Figure 27. *Water pump for making the coolant able to circulate (Author's own).*

In the engine, there is a thermostat. The thermostat controls what occurs to the liquid based on the temperature. It is placed as Figure 28 shows next to the inlet pipe through which the cold coolant enters the engine block.

Figure 28. *Inlet port of the coolant to the engine block where the thermostat is placed (Author's own).*

This valve is in charge of keeping the temperature of a vehicle's engine in check. As a result, the thermostat's function is to maintain a comfortable temperature range between these sides, allowing for optimal driving by managing the flow of coolant through the engine. The thermostat valve keeps the engine cool by allowing coolant to flow.

Pressure can start building up and need to be released before the hose or gasket can deflate. Excess pressure and fluid are accumulated in the expansion tank presented in Figure 29.

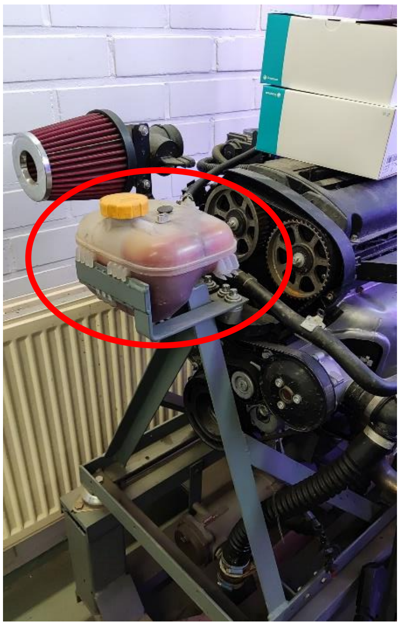


Figure 29. *Expansion tank component of the cooling system for the Opel engine (Author's own).*

The liquid in the storage tank is returned to the cooling system for re-circulation after it has cooled to an acceptable degree (Gimeno, 2021).

Identifying the inlet pipe through which the cold coolant is going to enter the engine block, it can be done knowing that it is in a higher position than the outlet pipe of the engine.

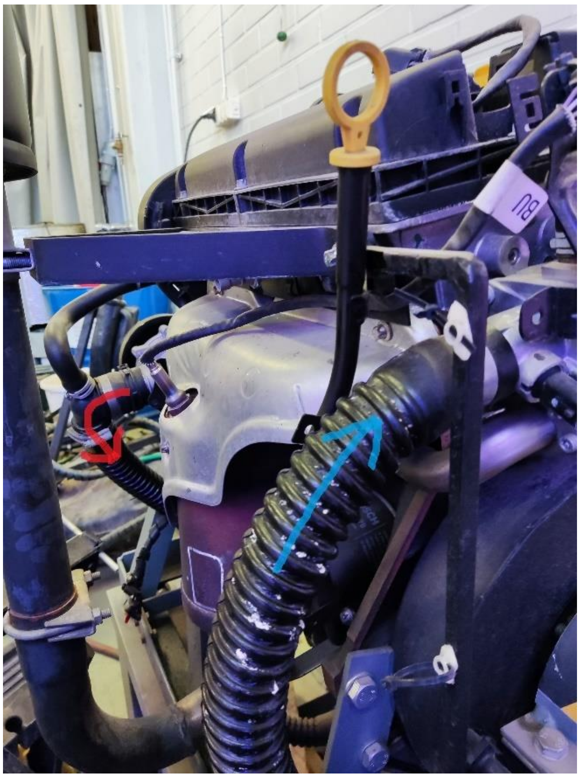


Figure 30. *Inlet and outlet pipes for the coolant entering and leaving the engine block of the Opel motor (Author's own).*

As Figure 30 shows, the right pipe (blue arrow) is for letting the cold coolant enter the engine block to reduce its temperature. Moreover, at the left part of the engine, there is the outlet pipe (red arrow). This tube allows the hot coolant to leave the engine block and enter the heat exchanger. As mentioned, to identify which was the inlet and outlet pipe, its altitude was measured. In most cooling systems, the low-temperature coolant flows through a pipe that is usually located at a higher position and will be exiting the cooling system for a pipe at a lower position of the engine block (Moviecultists, 2022).

There are other elements such as a freeze plug, which is a steel plug used to seal gaps generated during the casting process in the cylinder block and cylinder heads. If there is no frost protection, they can burst out in cold weather. For critical sealings engine elements, timing head and cover gasket are used. It prevents oil, antifreeze, and cylinder pressure from combining (Kevin, 2019). Finally, the system has the necessary hoses to make the coolant circulate and arrive in the different components. The coolant is transported from the radiator to the engine via a system of rubber hoses. These hoses may begin to leak after years of use, so maintenance is as well very important.

3.3 Exhaust gas system

The studied exhaust systems contain most of the parts explained in the study background, nonetheless, the Opel engine contains parts non-included in the SISU engine. This is mainly because the Opel engine is extracted from a car and therefore includes all the parts of the exhaust system. On the other hand, the SISU engine was assembled in the laboratory, therefore, all the parts are customized and do not proceed from the same manufacturer. Moreover, the SISU engine exhaust system will not be able to work in a functional car for the fact of not including components that are illegal to drive without.

3.3.1 Analysis of the SISU engine exhaust system

The actual SISU engine is composed of an exhaust manifold, a turbo muffler and a tailpipe. There is an absence of a catalytic converter to filter the particles of the combustion process. Therefore, to be mounted in a car, a catalytic must be installed to be legal to drive, but, as the motor is only focused on laboratory experiments, the filtering device is not required.

The first component of the exhaust system is the exhaust manifold which is connected directed to the cylinders where the combustion process takes place. Once the fuel is combusted, the exit valve is open and the gasses are released through the exhaust manifold. The device is presented circled in red in Figure 31.

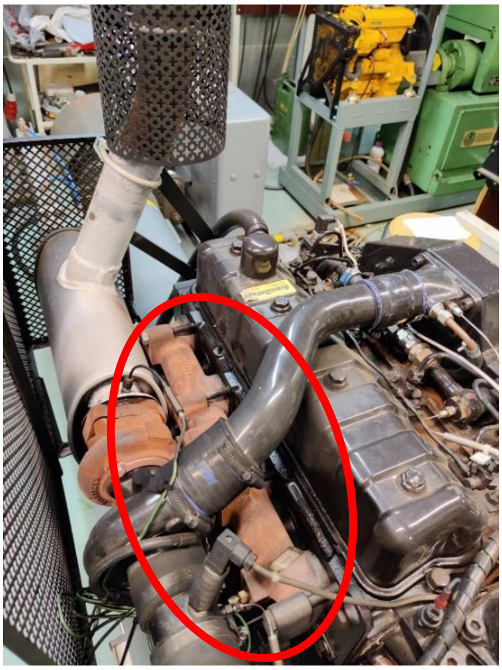


Figure 31. *View of the exhaust manifold, turbo and muffler of the SISU engine with signalization of the exhaust manifold (Author's own).*

Once the gasses are recollected from the exhaust manifold, the gases, are directed to a turbo (Figure 32). The turbo has the function to recollect more ambient air to make the combustion process more efficient. Nowadays it is not required to assemble a turbo into the exhaust gas system, nonetheless, the device is incorporated into the engine to increase its efficiency.

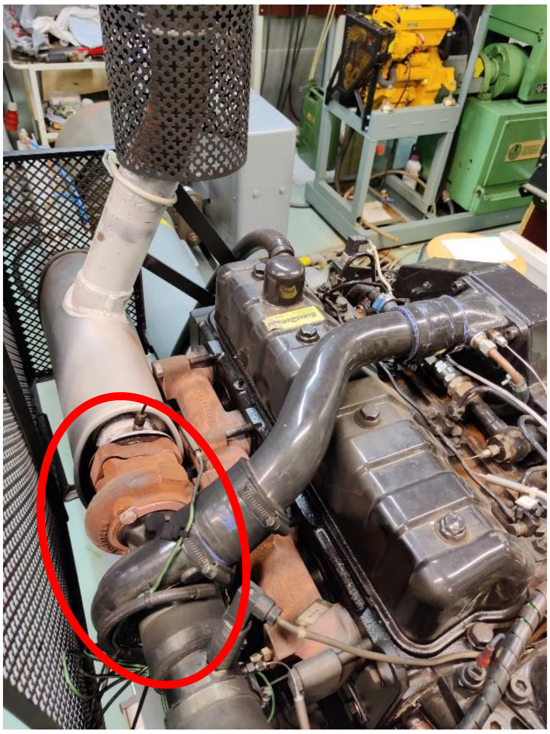


Figure 32*. View of the exhaust manifold, turbo and muffler of the SISU engine with annotation of the turbo in red (Author's own).*

The turbo device is activated by the exhaust gasses. These gasses enter the turbo device and spin a turbine wheel at high RPM. The turbine wheel is connected by a shaft to another turbine wheel that will suck ambient air into the engine. The inlet ambient air is denser than the average, and therefore, will make a better ignition of the combustible increasing the efficiency of the SISU engine (Garrett Motion, 2020).

Once the exhaust gasses pass through the turbo, they are directed into the exhaust muffler, which has the function of reducing the sound waves released by the engine. In some vehicles, there might be two mufflers, one bigger than the other, but in this case, there is only one muffler. The muffler is circled in Figure 33.

Figure 33. View of the exhaust manifold, turbo and muffler of the SISU engine with signalization of the muffler (Author's own).

Once the sound waves are partially destructed and the noise is highly reduced the engine's exhaust gasses are released through the tailpipe (smaller tube of Figure 34). These gasses are not liberated directly into the laboratory as they are collected by the laboratory exhaust gas system which collects the exhaust gasses from all the engines. The laboratory exhaust system will be the part discussed hereafter and it can be seen in Figure 34 (bigger tube).

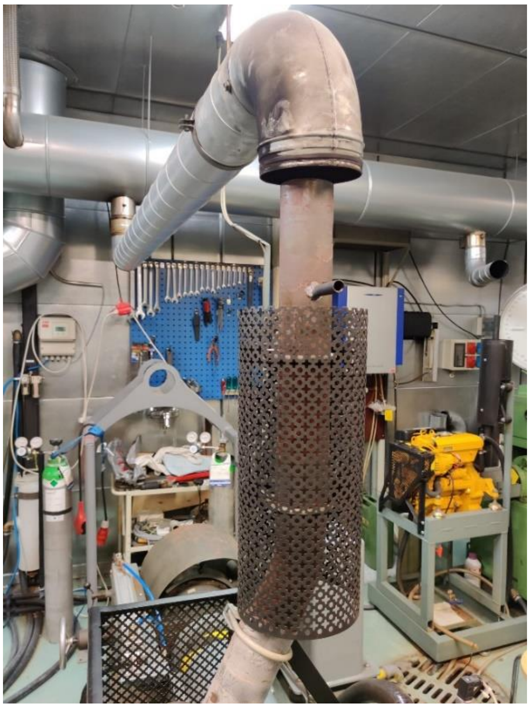


Figure 34. View of the SISU tailpipe and laboratory exhaust system pipe (Author's own).

3.3.2 Analysis of the Opel engine exhaust system

The Opel engine exhaust system is composed of the basic components of an exhaust car system. The system was extracted from a car, therefore, all the components mentioned in the technological concepts needed to be assembled into the system to be legal to drive. The Opel exhaust gas system is mainly composed of the exhaust manifold, a catalytic converter, an exhaust muffler, and a tailpipe.

The system starts with the collection of exhaust gasses through the exhaust manifold. The device is not viewable without extracting pieces from the engine, therefore a signalization of where is located can be seen in Figure 35.

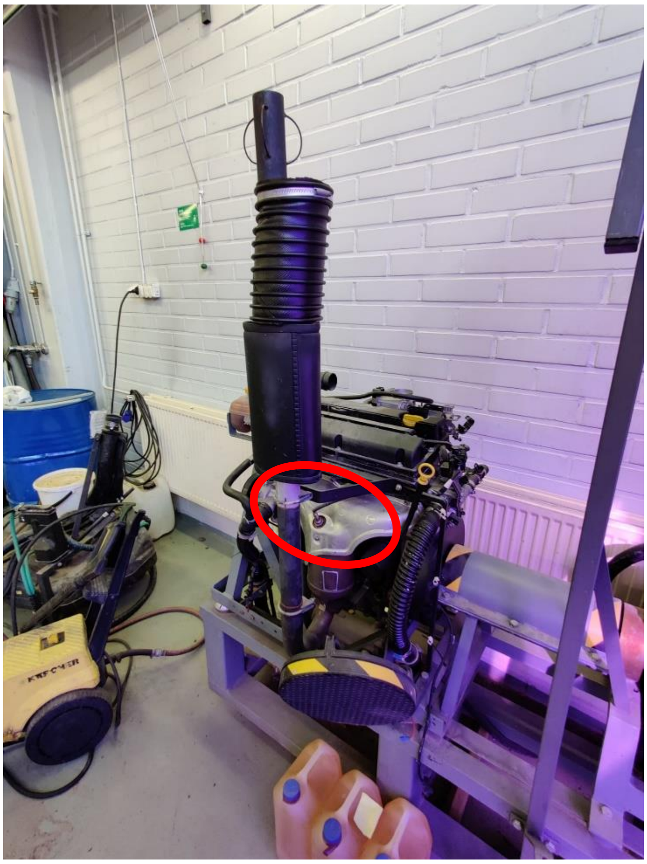


Figure 35. *View of the exhaust manifold in the Opel engine (Author's own).*

The grey metal sheet acts as a shield for the manifold and the combustion system. Under the metal sheet, the manifold can be found. The design of the exhaust manifold is similar to the SISU engine manifold and makes the same function.

Under the exhaust manifold is the next component of the exhaust system, the catalytic converter (Figure 36). In contrast to the SISU engine, the Opel engine has a catalytic installed. The installation of the catalytic is due to legal requirements of the car, moreover, nowadays is illegal to drive without a catalytic.

Figure 36. View of the catalytic converter of the Opel engine (Author's own).

The catalytic is located very close to the exhaust manifold to achieve a high temperature faster. In some vehicles the catalytic is separated from the engine due to design difficulties, nonetheless, the Opel engine solves the structural problem and fits it near the manifold, achieving higher efficiency of the chemical process.

Once the exhaust gasses pass through the catalytic and are converted into CO_2 and water the gasses pass through the muffler, which is another legal requirement in every car. The muffler has the function to reduce the engine noise destructing the sound waves created by the combustion process and is located after the catalytic converter (Figure 37).

Figure 37*.Display of the Opel's engine exhaust muffler (Author's own).*

The exhaust muffler, displayed in Figure 37, is the previous step before the gas release. The gasses are conducted from the muffler to the atmosphere through the tailpipe, that is the pipe directed in the upwards direction that comes from the muffler. In this case, the engine is not incorporated into the laboratory exhaust system and if used will pollute the room highly.

3.3.3 Extractor actual design

The main function of the extractor is to redirect the exhaust gases of the SISU engine outside of the laboratory. As Figure 38 illustrates the starting point of the extractor is located very close to the tailpipe of the motor. As the gases are heated up, they will flow upwards into the extractor pipe. No sealing between these two pipes is needed due to the physical phenomenon of the heated gases (if the gasses are hot, they tend to go upwards, while the cold gasses tend to go down because they have more weight).

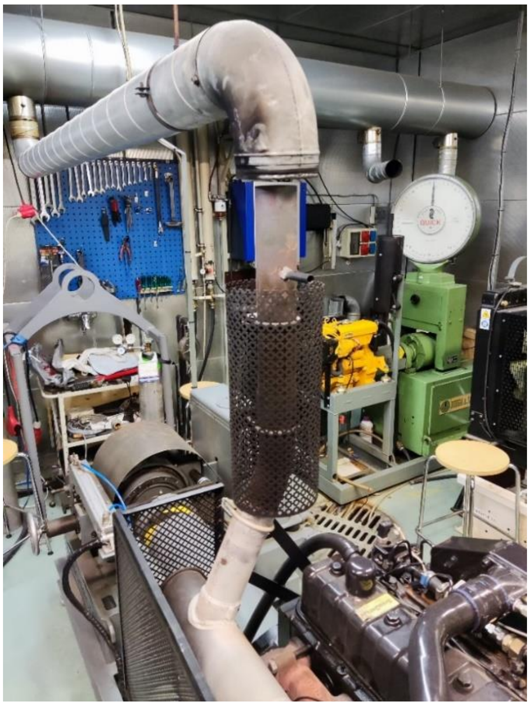


Figure 38. Extractor pipe and tailpipe photo of the laboratory exhaust gas system (Author's own).

Once the gasses enter the extractor pipe they are directed to the common channel (bigger pipe at the end of Figure 39) where the gases from all the pipes from the different engines that are being run in the laboratory are collected (Figure 39). This common pipe has a connection with another pipe (pipe on the left of Figure 39 going into the ceiling) that will recirculate the gasses to the outside of the building, providing a safe exhaust system.

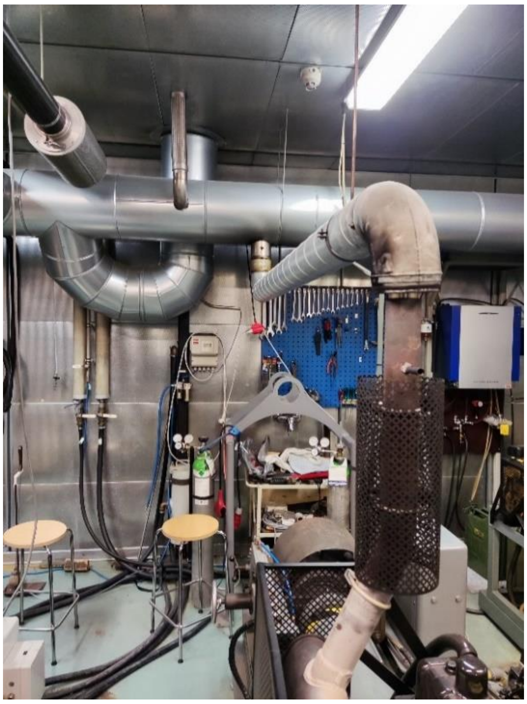


Figure 39. Extractor pipe and laboratory exhaust gas system with the common channel pipe and exit pipe in the background (Author's own).

4. Methodology

This section summarizes the selection of components to create in the laboratory, a functional fuel injection system for the gasoline engine. Furthermore, a study on the cooling system is made to develop a remote cooling module that could be compatible with both engines. As this has been noticed to be possible, a study for selecting the optimal components for the remote cooling system module is as well done. Finally, it also includes the selection of the needed components to adapt the actual exhaust gas extractor in case other engines have to be run in the engine bed that the SISU Diesel motor uses currently. All the prices for the different analysed components have the Value Added Tax (VAT) included.

4.1 Gasoline fuel injection system design

In this section, only the gasoline system will be studied as the diesel injection system is already installed in the laboratory. The possibility to design a gasoline injection system with quick connectors is studied for having the capacity to install other engines in the laboratory in the future.

4.1.1 Selection of gasoline injection system components

A discussion about different models for each part of the gasoline injection system is made below. The components for the diesel engine are not discussed hereafter as they are already incorporated into the actual SISU engine as mentioned before.

4.1.1.1 Fuel tank

The gasoline fuel tank is going to be placed in the upper part of the wall in the lab. It is going to have the shape of a rectangular cuboid. The requirements for this tank are to have a storage capacity of approximately 35 litres (L). It also has to include a pipe that shows the level of fuel in the tank to be always aware of the quantity that it has when refilling it with a pump. A return pipe to the jug where the gasoline is obtained must also be provided in case the tank is overfilled.

The tank models that can be useful to solve the need of this project are the following ones: Murray Motorsport Fuel Tank 7.7 Gallon - 35 L and the AH Fabrications 8 Gallon Racing / Competition / Track Alloy Fuel Tank – 028.

The Murray Motorsport Fuel Tank 7.7 Gallon - 35 L is shown in Figure 40 and the technical specifications of the tank are explained hereunder.

Figure 40*. Murray Motorsport Fuel Tank 7.7 Gallon - 35 Litre (Murraymotorsportm, 2022).*

Table 1. *Technical data of Murray Motorsport Fuel Tank 7.7 Gallon - 35 Litre.*

Technical data	
Volume (L)	35
Dimensions (mm)	435 x 280 x 280
Fittings	6/8

Source: Murraymotorsportm, 2022

This tank, as can be seen, has the needed volume capacity (35L). It includes the inlet and outlet port when filling it from the jug. Furthermore, it has a transparent pipe (the right part of the tank). This is the part that allows measuring the quantity of petrol that is in the tank. Thus, depending on the rate that it has, the pump that is used to move the gasoline from a lower pressure area to a higher-pressure area is going to be activated or not. There is also the port from which the fluid is going to leave and go to the fuel filter. From this orifice, the extra fuel that leaves the engine is going to enter this tank as well. The price of this tank is 322.42 €.

Another option for the fuel tank is presented in the following Figure 41.

Figure 41. A H Fabrications 8 Gallon Racing / Competition / Track Alloy Fuel Tank - 028 (eBay, 2021).

It has the following specifications shown in the following table.

Table 2. A H Fabrications 8 Gallon Racing / Competition / Track Alloy Fuel Tank – 028.

Technical data	
Fuel filler diameter (mm)	38
Fuel outlet diameter (mm)	8
Sight gauge diameter (mm)	6
Volume (L)	30.2
Dimensions (mm)	480 x 250 x 300

Source: Racingfueltank, 2018.

This is a precision-made alloy tank. The interior diameter of the fuel filler is 38mm, and it has a knurled screw-on lid with a seal. The outside diameter of standard gasoline outlets is 8 mm, and the outside diameter of sight gauge outlets is 6 mm.

This tank also has a port to fill it with the petrol and for transporting it into the filter. What is lacking is the tube that shows the current fuel that it contains. The capacity is a little bit lower than required as it has a volume of 30 Litres. It costs 507 €.

After analysing both types of fuel tanks, the one that fits most of the requirements is the Murray Motorsport Fuel Tank 7.7 Gallon - 35 L.

First of all, it has the exact capacity that is needed, and all the precise valves and measurement components for being conscient of the quantity of gasoline that we have in the tank. What is more, because it is smaller than the second provided choice (in the horizontal direction), its shape can fill the lab better. Finally, it is cheaper than the AH Fabrications 8 Gallon Racing Fuel Tank, so as money and cost are important aspects to take into consideration, the fuel tank that is going to be used is the mentioned.

4.1.1.2 Feeding tank pump

To raise the fuel from the barrel to the tank, a low-pressure pump is required. Its principal requirements are to be able to work with petrol and to have the capacity to lift 5 meters. Moreover, the minimum flow that it has to be able to carry is about 1.6 l/min. Related to the pressure it is enough with 3 bars.

Thus, an option is the one presented in Figure 42.

Figure 42. *Fuel lab low-pressure in-tank lift pump (Nebhub, 2018).*

The technical data is presented in the following Table.

Table 3. *Fuel lab low-pressure in-tank lift pump.*

Technical data	
Type	Low-pressure pump
Outlet diameter (mm)	9
Flow rate (lph) (litter per hour)	160

Source: Nebhub, 2018.

The pump is compatible with gasoline and ethanol, with a low current draw, ring terminal power connection and straining filter included. It also can raise the fuel by at least 5 metres which is more than the needed height. Its price is 75.2 €.

Another option is the one presented in Figure 43.

Figure 43. *WALBRO GSL393 Fuel Pump 160LPH external fuel pump (Walbrofuelpumps, 2022).*

It has the specifications presented in the following Table.

Table 4. *WALBRO GSL393 Fuel Pump 160LPH external fuel pump.*

Technical data	
Flow rate (lph)	160
Weight (kg)	17.4
Outside materials	Aluminium
Terminals (inlet) (mm)	4.76
Inlet fittings diameter (mm)	10
Outlet fittings diameter (mm)	10
Temperature range (ºC)	-40 to 65
Vibration	9 G’s @ 10-55 Hz for 6 hours
Shocks	25 g’s
Contamination	8 grams per 378,5 L, 80-micron dust contaminate
Corrosion resistance	96-hour salt spray per ASTM B117
Safe dry operation	5 minutes
Mounting	In-tank or in-line

Source: Walbro, 2022.

The principal curves of this pump model comparing the flow with its pressure are analysed in the following graph.

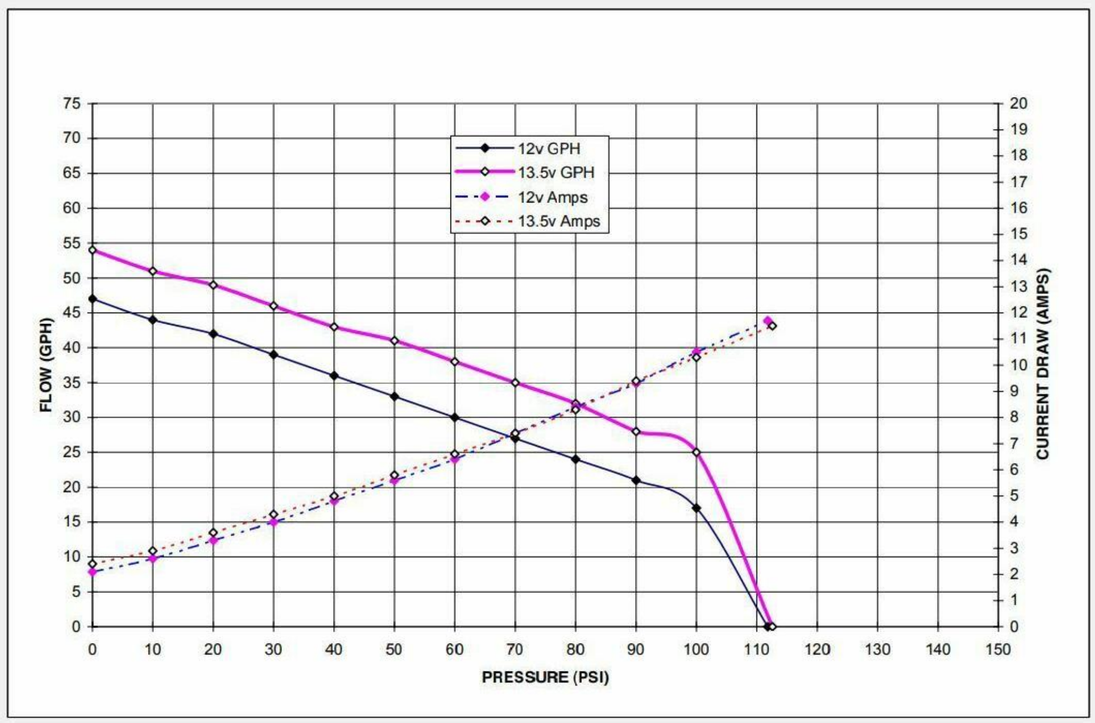


Figure 44. *Flow vs. Pressure 12 and 13.5 VDC in WALBRO GSL393 Typical Performance. (Walbro, 2022).*

As the main requirement, it is to accomplish a flow rate of 1.6 litres per min (LPM) and a pressure of 3 bar. Figure 44, demonstrates that the WALBRO GSL393 pump is enough for accomplishing these requirements. Moreover, this pump, as can be seen in Figure 44 has a good operating point. It can provide a pressure of 90 psi ≈ 6.2 bar at a flow rate of approximately 28 GPH ≈105 LPH≈ 1.75 l/min. However, if a higher flow rate is required, the pressure can be decreased as it is considerably high. Finally, the need to rising the gasoline 5 metres from the barrel to the fuel tank would be achieved with this pump. It costs 240.2 € (Jdtracing, 2022).

As the second pump presented in Figure 43, the WALBRO GSL393 Fuel Pump 160LPH, has further analysis on its specifications and includes the graph presented in Figure 44, it will be the selected option in the installation. Pumps are one of the most important parts of the fuel filter injection systems, therefore, the pump with more information is selected to ensure the correct functioning of the motor. The price is one of its drawbacks as it triples the price of the first option. Nevertheless, the lack of specifications of the Fuel lab low-pressure in-tank lift pump makes the difference when choosing a fuel feeding pump.

4.1.1.3 Fuel filter

A fuel filter is a device that screens impurities out of the fuel system and therefore, prevents damage to the engine (Mzwmotor, 2019).

Contaminants can enter the fuel in a variety of ways, but the majority of the time, it happens during transportation, storage, or replenishing the fuel tank. Not every impurity comes with the fuel, there can be some contaminants made by the fuel injection system itself, for example, particles such as corrosion and paint chips may be produced by the fuel tank. These detach from the walls and contaminate the fuel. Soot, dirt, sand, and mineral particles are examples of other types of contaminants also found in fuel.

An advantage of gasoline engines is the requirement of only a single filter (Holley, 2022). The main reason is that gasoline is a cleaner type of fuel and does not require to be depurated in that much detail. On the other hand, diesel engines need a prefilter and a filter as the combustible contains more impurities.

The most common filters used in gasoline cars are the in-tank and the in-line filter, with their respective advantages and disadvantages. While modern cars stick to the in-tank filters, old vehicles preferred using in-line filters. In-tank fuel filters are incorporated inside of the fuel tank or next to it. On the other hand, the in-line filters are located somewhere between the fuel tank and the injectors (Van Kessel *et al.,* 2011).

In-tank filters have higher efficiency when compared with the in-line and are frequently used nowadays in gasoline engines. These filters have the disadvantage of being difficult to service due to their inaccessibility. Moreover, in-tank fuel filters cannot be removed individually because they are part of the fuel tank. When there is the need to replace a clogged or damaged filter, it will be a more expensive replacement.

When selecting a filter, accessibility was a key factor. Researchers and teachers in the laboratory want to have everything under control and if possible easy to remove if an incident occurs, all these ideas contributed to the selection of the in-line filter as the filter to use in the gasoline engine.

When choosing a fuel filter, it is needed to look for some specific aspects to review which filter will suit better the engine. The first thing to look at is the micron rating, which, when applied to a fuel filter, refers to the filter's ability to capture impurities of a given size. A micron value of 10 microns indicates that the filter removes particles larger than 10 microns, whereas a micron rating of 5 microns indicates that the filter traps contaminants larger than 5 microns (Noria Corporation, 2017). The micron rating of a filter is simply the size of the pores in the filter medium. The greater the micron rating score, the larger the apertures.

The second aspect to look for is the efficiency of the filter. This is the particle retention level of a filter. It is a comparison of the particles caught versus the particles left in the fuel. The efficiency value is frequently used in conjunction with the micron rating value. A filter with a 98 per cent efficiency and a micron rating of 5 microns eliminates 98 per cent of particles 5 microns and larger (Mzwmotor, 2019).

Another key aspect is the pressure that the filter can handle. The fuel pump will compress the gasoline to 3 bars approximately so the fuel will flow in a high-pressure state, therefore, the filter needed has to handle high pressures or at least the 3 bars achieved in the transportation process.

A range of problems appeared when deciding which filter will suit better the engine. The main idea was to look for the efficiency and the micron rating different models had and select the one that was more suitable for the project whether it was economically or efficiently. When starting the search most of the filters did not indicate which was its micron rate or its efficiency which impossibilities the idea of selecting a filter for its technical parameters. With the unexpected issue, another selection method was used. It consisted in look for the most common filters in Opel Astra cars or similar types of engines to know which filters could be used for the selected engine. One priority while searching for a filter was the diameter of the inlet and outlet pipes, as it was decided to use a 10 mm diameter pipe for the fuel injection system.

The first discussed model is the KAMOKA F322501 Fuel filter which can be seen in Figure 45.

Figure 45. *KAMOKA F322501 fuel filter (Autoteiledirekt.de, 2022).*

Table 5. *Technical data of KAMOKA F322501 fuel filter.*

Technical data	
Inlet diameter (mm)	10
Outer diameter (mm)	99
Outlet diameter (mm)	10
Height (mm)	120

Source: Trodo, 2018.

It can be found in some models of Opel cars and a variety of cars in the automotive industry. The inlet and outer diameter are 10 mm and it can be found on the market for 27.55 € (Buycarparts, 2022).

The second option studied is the FILTRON PE 946/6 fuel filter which technical data can be seen hereunder (Table 6).

Figure 46. *FILTRON PE 946/6 fuel filter (Piezas de vehículos, 2022).*

Table 6. *Technical specs of FILTRON PE 946/6 fuel filter.*

Technical data	
Height (H) (mm)	83
Outer diameter (A) (mm)	66
Outer diameter (D) (mm)	76
Inner diameter (mm)	10

Source: Trodo, 2018

It is found in a big range of Opel cars and is used by other car manufacturers. The inlet and outlet diameter measures are 10 mm and it is sold for a price of 54 € (Autodoc, 2022).

Finally, the KAMOKA F322501 fuel filter is chosen for the gasoline engine. The filter is used in a wider range of cars whether it is from Opel or other manufacturers than the FILTRON PE 946/6 fuel filter. In the final decision, the price was not a priority to look for as both models were considered cheap as it is a very important component and the price difference was about 30 €.

4.1.1.4 Fuel Balance and Fuel Temperature Control

The measuring system which is going to analyse the different consumption gasoline parameters and the temperature of it is going to be from the AVL enterprise. AVL is the world's biggest independent company for powertrain system development, simulation, and testing, as well as vehicle integration and new disciplines like ADAS/AD and Data Intelligence (AVL, 2021).

The AVL Fuel Balance is the most widely used system for measuring discontinuous fuel usage. The AVL Fuel Balance is primarily utilized in applications demanding large measuring levels of accuracy and gravimetric measurements. The system can be calibrated under real-world testbed conditions thanks to the built-in calibration device. The AVL Fuel Balance is based on the gravimetric measurement technique. The amount of gasoline consumed is immediately calculated by using a capacitive sensor to measure the time-related weight loss of the measurement vessel. The optimum ease of use is provided through convenient calibration and simple maintenance.

It is good to have this type of system in the laboratory to analyse in deepest detail the different parameters that are important to control when talking about the fuel injection system. These are the intake air temperature, the charge air temperature before and after the internal combustion, the engine oil temperature, the time and finally the fuel consumption (AVL, 2021).

The technical operation process of this measuring system is as follows:

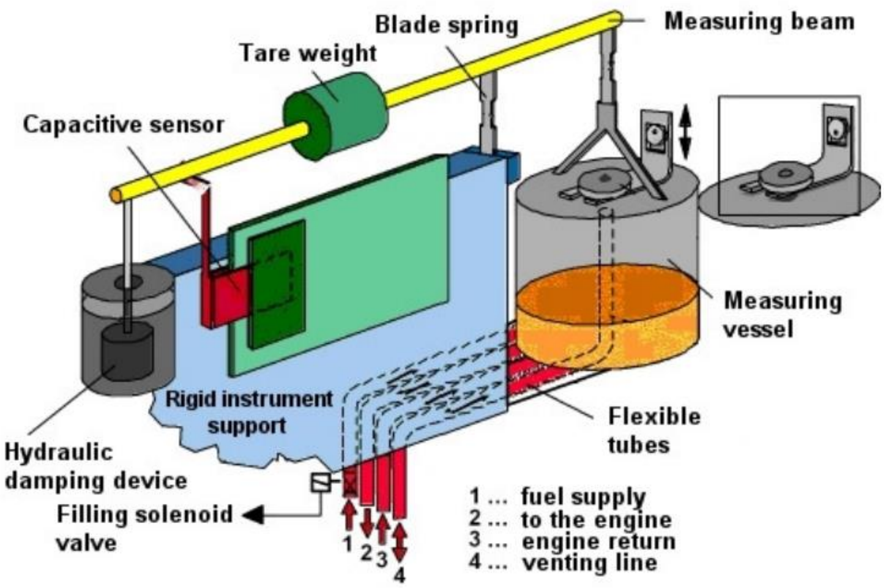


Figure 47. *Technical insight of the AVL fuel balance measurement (AVL, 2021).*

The fuel consumption is calculated using an adequate measuring vessel connected to a capacitive displacement sensor via a bending beam. This is a discontinuous measurement principle since the weighted vessel must be replenished after each measurement.

As a result, the mass of fuel consumed is calculated gravimetrically, eliminating the need to calculate density separately. Fuel usage may thus be calculated with a precision of 0.12% (AVL, 2021).

Moreover, getting one of these devices not only consists of an AVL fuel balance, connecting cable and operating instructions but also a PC-software to obtain all the data.

The AVL Fuel Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C can be used for a wide range of engine capacities, from single-cylinder to 600 kW large-scale engines, as well as cutting-edge injection systems and inspection cycles. As mentioned, it has a precision of 0.12 % (AVL, 2021). The technical data is shown in the following table:

Table 7. *Technical data Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C.*

TECHNICAL DETAILS	
Type	AVL 735S/753C
Measurement principle	Mass flow
Measurement ranges (Mass flow) (kg/h)	0…125
Measurement uncertainty (Mass)	≤0.12% (acc. to DIN 1319)
Interfaces / output signal	RS232, analog I/O, 0…10 V, digital I/O
Measurement frequency (Hz)	20 (analogue)
Response time (ms)	<125
Fuel types	Standard* and 100% biofuels
Engine feed pressure (kPa)	max. 600 rel.
Fuel circulation quantities (l/h)	Optionally 240 / 450 / 540
Control range (ºC)	10…80
Stability (ºC)	better than 0.02
Heating/ cooling (kW)	1.6 /1.6
Power supply (v, Hz)	230, 50 ; 220 , 60 ; 100 , 50 - 60; 115 , 60
Power consumption (kW)	0.4 (without heating)
Ambient temperature (ºC)	5…50
Dimensions (W×H×D) (mm)	770 × 1,630 × 345

Source: AVL, 2021.

An image of the model can be seen in the following Figure.

Figure 48. *Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C (AVL, 2021).*

The cost of the Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C is 2438.50 €. Even though it is quite expensive it is a very important component of the fuel injection installation (AVL, 2021).

4.1.1.5 Distributor pump

There are several options for the distributor pump which is the one that is going to transfer the gasoline to the engine. For example, it can be an electric battery or a battery from the car industry. What is sure is that it has to be a High-Pressure pump. However, as we have the idea to make it usable in the future with other engines that can be installed in the laboratory, it is better to choose an electric battery with its switch. If a battery is picked up from the automotive engine, then it will be only able to be used with the Opel engine which will reduce its usage with other motors.

The pump has the requirement to support a pressure of 2.8 – 3.2 bar so an optimal pressure for the pump will be 5 – 8 bar. The minimum flow that it has to be able to carry is 1.6 L/min.

The first option is to use the AEM's 400 lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009). It is presented in Figure 49.

Figure 49. *AEM's 400lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009) (Aemelectronics, 2022).*

Technical specifications of the pump are shown in the table below:

Table 8. *Specifications of the AEM's 400lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009).*

TECHNICAL SPECS	
Weight (grams):	1015
Outside Diameter (mm):	60
Inlet Fitting:	M18X1.5 female
Outlet Fitting:	M12x1.5 male
Pressure Relief Valve (PRV) Activation (bar):	10.34
VOLTAGE SPECS	
Connector Terminal	6 mm stud positive, 5 mm stud negative
Flow rate (L/min) at 5 bars:	5.6
Min Voltage Input (V):	10

Max Voltage Input (V):	18
Current Draw (2.75 bar):	9.73 amps no check valve, 10.68 amps with check valve (13.5 V)
Current Draw (8.3 bar):	16.07 amps no check valve, 17.13 amps with check valve (13.5 V)
Fuse:	25 amps (13.5 V)

Source: Aemelectronics, 2022.

Another possible pump to use is the one presented in Figure 50. As the pump presented in the previous Figure 49, the STARK SKFP-0160089 Fuel Pump has also the capacity to operate with the Opel Astra G 1.6 16V motor.

Figure 50. *STARK SKFP-0160089 Fuel Pump (Car parts, 2019).*

The specifications of the STARK SKFP-0160089 Fuel Pump are presented in Table 9.

Table 9. *Specifications of the STARK SKFP-0160089 Fuel Pump.*

TECHNICAL SPECS	
Length (mm):	197
Height (mm):	54
Width (mm):	52
VOLTAGE SPECS	
Operating Mode	Electric
Flow rate (L/min):	2.17
Voltage (V):	12

Operating Pressure (bar):	3
Number of connectors:	2

Source: Car parts, 2019.

After comparing and analysing the specifications of both fuel pumps, and considering the requirements of the installation that is being designed, it can be stated that the best option is the AEM's 400lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009) presented in Figure 49. It has a cost of 55 € (Autodoc, 2022) which compared with the 180 € of the first option makes it seem like the best economic option (Jegs, 2022).

It comfortably meets the requirement of having a pressure between 5 and 8 bar as it has a Pressure Relief Valve (PRV) of 10.34 bar. Moreover, the flow rate that the pump has to provide is at least 1.6 l/min. So, after analysing the specs presented in Table 8, it can be seen that can provide fuel with a flow rate of 5.6 L/min at 5 bars which is a considerably high-pressure value for the necessities of the installation.

For knowing more information about the pump, the following graph can be analysed.

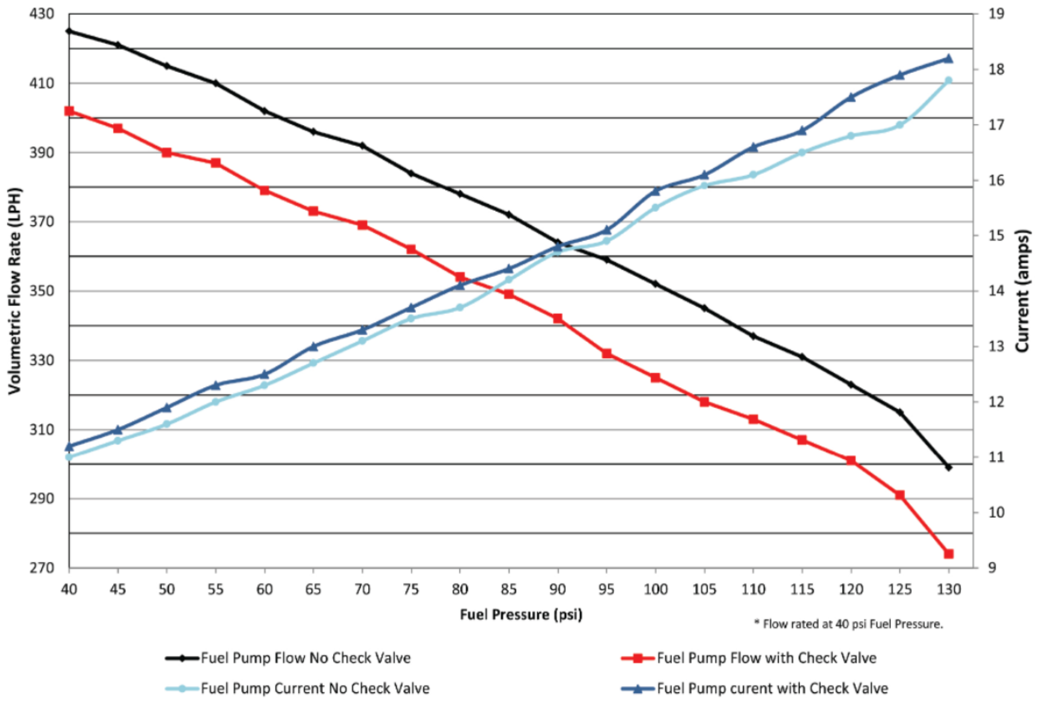


Figure 51. *Volumetric Flow Rate (lph) and Current (amps) in the function of the pressure (psi) AEM 400 LPH (Aemelectronics, 2022).*

First of all, for analysing the graph presented in Figure 51, it is important to know what a check valve is. Gravity wants the water in the discharge pipe to collapse into the pit when the pump is turned off. The check valve is meant to make sure that does not happen. The check valve avoids the pump from having to re-pump that water out, resulting in shorter cycling times (McEwen, 2022). So, as the check valve is used to make its life cycle longer and make the battery more durable, the curves that are going to be analysed are the ones considering that the Fuel Pump has the Check Valve.

First of all, it can be seen that the Volumetric Flow Rate is inversely proportional to the Fuel Pressure. Indeed, as the Fuel Pressure increases, the Flow Rate decreases. A good operating point is 120 psi ≈ 8 bar and 300 LPH $\approx$ 5 L/min. Thus, the installation's requirements have been met in full. Then, considering the current (amps) it has to be about 17 amps at 120 psi. Thus, the power supplier has to provide a current of 17 amps.

4.1.1.6 Power supplier

To adapt the voltage of the grid which is 240 V in the laboratory, a power adapter with a voltage of 12 V and a current of 17 amps is necessary.

Figure 52. *Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply (Single, 2018).*

This 12-volt power supply has a 17-amp rating. It is a 200-watt power supply. In a slim enclosure with a single output. At full load, the burn-in was tested. At a modest cost, it is quite dependable. The warranty is for one year. It is priced at 37.18 € (Circuitspecialists, 2022).

Table 10. *Hengfu HF200W-FSM-12 12 Volt 17 Amp specifications.*

TECHNICAL SPECS	
DC Output (V)	12 @ 17 Amps
Rated Power (W)	200
Load Regulation (%)	2
Voltage Tolerance (%)	±1
Ripple & Noise (max) (mVp-p)	150

Efficiency (%)	85
Input Voltage (VAC)	90~132 / 180~264 selected by switch
Input Current (A)	<4.0 / 115VAC <2.0 / 230VAC
Operating Temperature (ºC)	-30 ~ + 70
Storage Temperature(ºC)	-40 ~ + 85

Source: Single, 2018.

After analysing the most common characteristics of this power adapter, it seems to fit the requirements of the AEM's 400lph Metric High Flow, high-pressure Inline Fuel Pump.

4.1.1.7 Pipe adapters

As the pump has an inlet diameter pipe of 12 mm and an outlet diameter pipe of 18 mm, diameter adapters of 18 to 10 mm and 12 to 10 mm are needed to connect the pump to the installation chosen hose that has a diameter of 10 mm. This diameter of 10 mm for the hoses of the fuel injection installation is enough to carry sufficient fuel to the engine.

Figure 53. *Straight Barbed 18mm to 10mm Hose Pipe Connector Tube Fitting Fuel (eBay, 2022).*

Figure 54. Straight Barbed 12mm to 10mm Hose Pipe Connector Tubing Fitting Fuel (eBay, 2022).

The cost of the adapter from 18 mm to 10 mm presented in Figure 53 is 3.2 € and the price for the adapter from 12 mm to 10 presented in Figure 54 mm is 4 € (eBay, 2022).

4.1.1.8 Quick connectors

Quick-connect couplings are connectors or fittings that are used to attach fluid lines to machinery that needs to be connected and disconnected often. Their main advantage is providing a fast and easy union (Maxson, Logan and O'Brien, 2001). They are employed in hydraulic and pneumatic applications, and they are designed for simple hand control with suitable attachments on mobile equipment. These components are going to be employed to connect the hoses of the engine that is going to be placed in the bed (Opel Astra G 1.6 16 V), with the ending pipes injection system that is being designed in this project. Thus, in case another gasoline engine is analysed in the lab, adding quick connectors to this new engine allows it to be able to use the designed fuel injection system.

It is very important a good connection to ensure that no mistakes are done while establishing the union. To reach it, the best option is to put for example, in the part of the engine, in the inlet pipe the male connector and, in the outlet, pipe the female connector. In consequence, regarding the injection system hoses, there have to be in the outlet pipe the female connector to be able to connect it with the male put in the inlet hose of the engine part as mentioned before. Finally, in the inlet pipe of the fuel injection system, there has to be a male connector.

Figure 55. Quick connectors bearing type scheme (Pro-lift-montagetechnik.com, 2022).

As seen in Figure 55, their construction is straightforward: a male end (or plug) is put into a female end (or socket) to form a tight seal. They are sometimes referred to as "push-to-connect" as they only necessitate a fast push to join.

Once the coupling is clamp attached, they normally have a one-way sleeve to enable for break-away with a tool. One-handed disconnection is possible with two-way sleeves.

Several designs are used to make these locking seal quick-connect couplings, but the one that fits better for the necessities of the project is the ball or bearing type (Figure 56). There, spring-loaded balls are housed in cavities to form the coupling. Since they can be unplugged with one hand, this is the most frequent variety. They have a spring-loaded ball locking mechanism that, when pressed together, mechanically locks the two halves of the fitting together. The sleeve is drawn back to disengage the connection, and the balls are emptied to free the connection (Gannon, 2016).

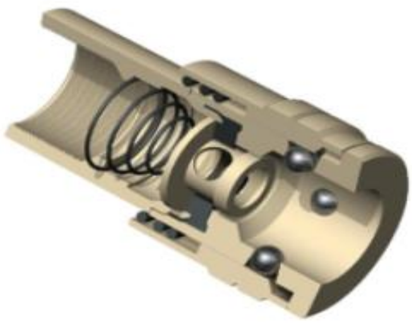


Figure 56. *Ball or bearing type quick connector (Hartford Technologies, 2020).*

In this type of quick connector, the precision of the balls is critical for ensuring a consistent connection across all of the balls in the head unit. Generally, balls with a rating of 100 or higher will be used (Walker, 2006). Material testing is crucial since this material must be compatible with the fluid or air passing through the connection. Stainless steel and brass are widely used materials (Hartford Technologies, 2020).

A good option is the following quick connectors.

Figure 57. *1/4" quick coupling with ball bearing: Female (left) and spout (right) for 10mm hose, 112C31S, 01995 (Pro-lift-montagetechnik, 2022).*

The presented quick connectors have the following specifications.

Table 11. Technical data of 1/4" quick coupling with ball bearing: Female and spout for 10mm hose, 112C31S, 01995.

Technical data	
Total length (mm)	63,5
Total diameter (mm)	23
Outer diameter spot (mm)	11.4
Length spout (mm)	20
Hex key	Size 19
Inlet diameter (mm)	10

Source: Pro lift montagetechnik., 2022.

Ten units of this gasoline quick connector (five male and five female) cost 42.90 €. So, the cost of one male and one female is 8.58 €.

There are other options such as the following one:

Figure 58. *Female (left) and male (right) quick connectors Parker Steel Hydraulic Quick Connect Coupling (Steel, 2021).*

Table 12. Technical data of Parker Steel Hydraulic Quick Connect Coupling.

Technical data	
Thread Size (mm)	19
Inner diameter (mm)	10
Seal material	Nitrile rubber
Material	Steel
Maximum pressure (bars)	175
Temperature range (ºC)	-40 to 110

Source: Steel, 2021.

The problem with this model is its price. Each female unit costs 53.2 € and each male 104.5 € which is much more expensive than the quick connectors presented in Figure 57. This is the main reason why the team has decided to use the quick connectors presented in Figure 57 as they are also ensuring a good performance.

4.1.1.9 Pipes

The pipes are going to be used for passing the gasoline from the tank to the engine and for returning the extra petrol that the engine has not used. The diameter of the pipe can variate but, in this case, 10 mm diameter pipes are the ones that are going to be used. The length of the pipeline shall be 10 meters for the feeding part and 10 meters more for the returning fuel to the tank. Moreover, for passing fuel to the tank from the barrel 4 meters are going to be needed and 4 more for returning the excess fuel from the tank to the barrel. Finally, to ensure the connection with the filter and the Fuel Balance and Fuel Temperature Control system, 7 more meters are going to be used. Thus, the total amount of pipeline that is going to be used is 35 meters.

The model that is going to be used is FUEL HOSE 10MM from Biltema. This type of fuel hose is having a Nitrile rubber hose NBR inner layer, PET reinforcement, and NBR and PVC exterior protection. Outside of the tank, the hose can be used for both gasoline and diesel. The maximum pressure is 80 bar. The temperatures range from -40 to +125 ºC. It is produced by DIN 73379 (Biltema, 2020).

Figure 59. *FUEL HOSE 10 mm from Biltema (Biltema, 2020).*

As 35 meters are needed, the most economic option could be to buy two 15-metre pieces plus one 5-meter piece. However, as the pipes are not the most valuable part of the installation, the best option is to buy 3 15-metre pieces to ensure that all the connections are going to be achieved and then if there are metres of pipe left over, they can be used in case some reparations have to be done in the future. The cost of the pipe is 64.80 € (Biltema, 2000).

4.1.2 Schematic view of the gasoline injection system installation

To clarify the installation in the laboratory, a schematic design with the software AutoCAD of the room has been made.

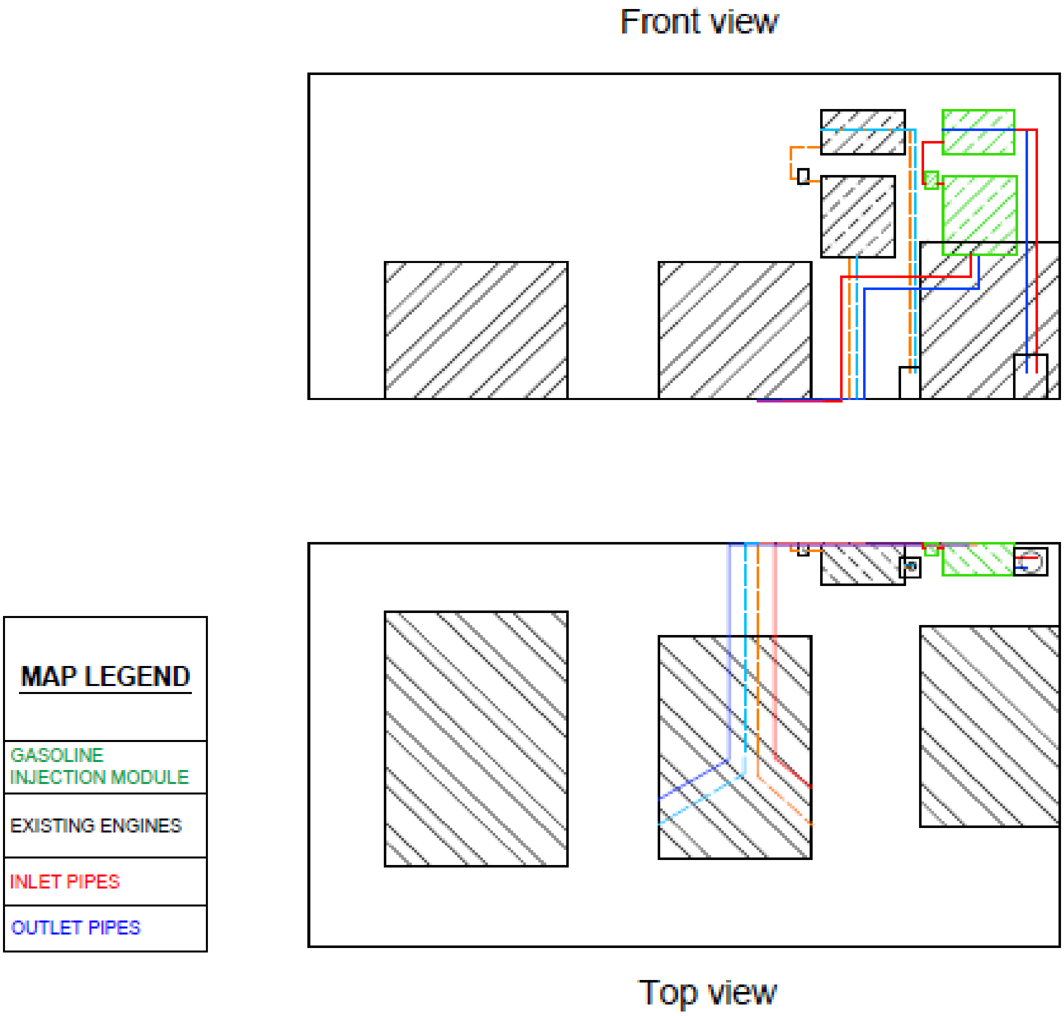


Figure 60. *Schematic representation of the fuel injection system in the laboratory with AutoCAD (Author's own).*

The representation has a front view and a top view of the room as Figure 60 shows. The existing engines and diesel injection system has been made in black colour. The new gasoline injection module (Tank, filter, and fuel consumption device) is indicated with green colours and is decided to be incorporated on the right of the diesel injection system as there is a space with no utilization at the moment. The discontinuous blue and orange lines are used to represent the actual diesel pipes, being the orange one the inlet pipe and the blue the outlet, while the continuous lines represent the pipes from the gasoline injection system (inlet is with red colour and outlet is represented with dark blue colour). This space was selected because on the left side of the diesel injection system (behind the SISU engine) there were water pumps and valves that could not be taken out and cancelled every type of possibility of installation. Furthermore, if the installation was made on the left side of the laboratory the pump will require more power to transport the fuel into the engine as it should be placed next to the left wall due to the high number of components (pipes, tools, etc) assembled into the wall. Therefore, the blank space on the right side of the diesel injection system seemed optimal to assemble the gasoline injection system.

4.2 Cooling system design

The idea is to redesign the cooling system of both engines. As seen before, diesel and gasoline engines use a semi-open loop system that uses water to cool down the refrigerant. The desired update is to use the same closed-loop cooling system for both engines and study the behaviour with bigger engines as it achieves a high multi-functionality degree.

The study of the possibility to incorporate an equal cooling system for the two engines studied is explained hereunder.

4.2.1 Study of the possibility of a remote cooling system compatible with both engines

The main objective of this part of the project is to design a remote cooling system. It consists in developing a module with the radiator, electrical fan, thermostat, expansion tank, water pump, temperature sensor, pressure cap for the expansion tank and all the needed hoses and adapters.

Then, the idea is to connect this module with quick connectors to the engine that is running in the bed at that moment. Thus, each engine placed in the bed needs its internal hoses where the refrigerant has to pass through to cool the engine when it reaches very high temperatures that can damage the motor.

So, the cooling unit has a radiator, made up of many small channels armed with a matrix of fins. The radiator should not be placed too high because the pump will need a lot of power to transfer the coolant to this point. Unwanted heat is transferred from the radiator to the room where it is placed, and the cooled liquid flows back into the channels through an intake at the bottom of the block. Rubber hoses connect the radiator to the engine, and it has a top and bottom tank connected by a core, which is a bank of numerous fine tubes. The tubes travel through perforations in a stack of thin sheet-metal fins, resulting in a huge surface area in the core that may quickly lose heat to the cooler air passing across it. The radiator cap, which has a pressure valve in it, limits the additional pressure. When the valve is opened by too much pressure, the coolant pours out through an overflow pipe (Muir A., 2022).

A centrifugal-type water pump is as well needed. It has the main function to distribute and make the coolant able to circulate. When hot water expands, becomes lighter, and rises above cool water when heated, the pump usually transports coolant up through the engine and down through the radiator. It has a natural propensity to flow upwards, and the pump helps circulate it. However, as in this case, both engines have each water pump, and the module is going to have a low flow pump. This pump is needed in case the radiator is placed between 1 and 2 (or more) meters away from the engine to avoid cavitation in the water pump of each engine (Wagner et al., 2002). This low flow pump is placed next to the inlet pipe through which the hot coolant enters the radiator. It is going to be operated with a valve to use it in case the radiator, as said before is placed from 1 to 2 or more meters away from the motor block.

Moreover, a thermostat regulates the temperature of the coolant adjusting the quantity of it that goes to the radiator. When the temperature of the coolant and the engine is not too high, the refrigerant does not pass through the radiator.

There is also a fan that passes cold air to the radiator. Later cars have a sealed system in which any overflow is drawn back into the engine as the remaining liquid cools. The electric fan is planned to have 12 V and to work with the following principle. If the temperature of the coolant circulating in the system is between 88-92 ºC, a transmitter that connects the electric fan to a battery will make contact and thus, make the fan operate (Puqi Ning *et al.*, 2008).

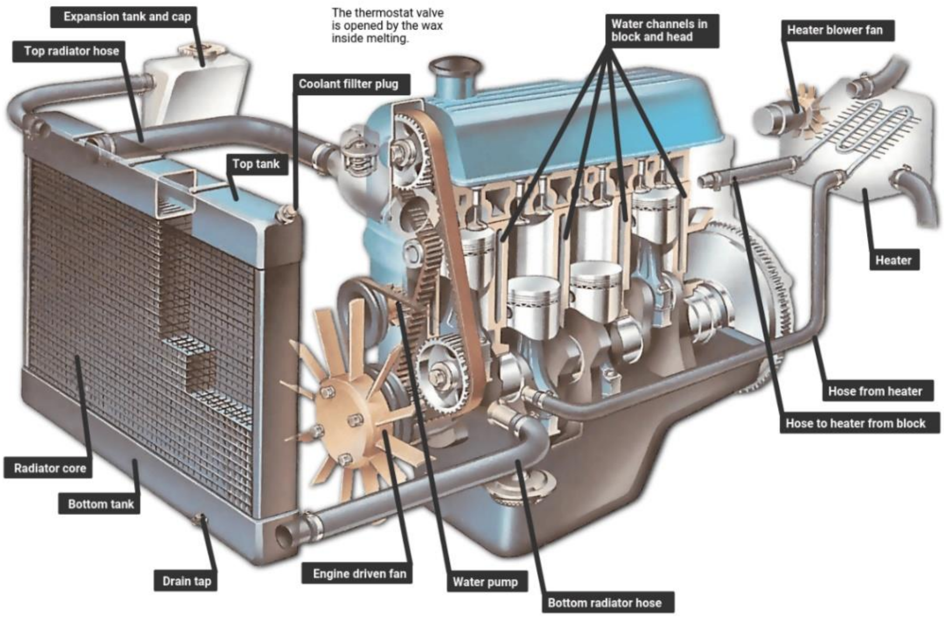


Figure 61. *A typical water-cooling system with an engine-driven fan module (Muir A., 2022).*

The used coolant liquid, usually it is water mixed with an antifreeze solution. Antifreeze is frequently considered one of the biggest components of a coolant mixture, which is usually a 50-50 combination of antifreeze and water (HELLA, 2018). Antifreeze (more particularly, the major constituent ethylene glycol) is used to reduce the freezing point of the liquid that circulates a vehicle's engine. This prevents the liquid from freezing in cold temperatures and raises the boiling point of the liquid, preventing it from evaporating. Another way is by increasing the pressure in the system, which raises the boiling point and then the risk of boiling is reduced. The coolant also maintains the engine's interior parts lubricated, allowing them to function properly (K-Seal, 2021). Furthermore, the compounds that prevent the cooling system from corrosion, rust, pitting, electrolysis, gelling, and foaming must be renewed every 2 -3 years (4 - 5 years for vehicles with long life coolants). It can be used for both, diesel and gasoline engines if it is kept in maintenance and changed properly (Waynesgarage, 2022).

This remote module has to be designed so that it can be connected with its needed quick connectors and adapter to the engine that is operating at that moment in the bed of the laboratory. The engine has an inlet and an outlet port which are the parts that are going to be coupled to the module.

4.2.2 Selection of components

In this section different models for each component are selected considering cost and behaviour, out of all, a discussion process is made and the most suitable device is installed on the project. The criteria followed to select the component are explained in each component section.

4.2.2.1 Radiator

The radiator has to have the capacity to dissipate the heat that the coolant has after refrigerating the engine. Moreover, it requires two connection points for the inlet pipe (hot coolant) and the outlet pipe (cold coolant). Moreover, two ports for connecting it to the expansion tank are as well needed.

Figure 62. *Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core, reference: 233254 (Northernradiator, 2020).*

The radiator presented in Figure 62 fits, for example, a 2007-2009 DODGE, and it has the specifications presented in Table 13.

Table 13. *Specifications for the Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core, reference: 233254.*

Technical data	
Core height (mm)	676.3
Core width (mm)	396.9
Depth (mm)	25.4
Inlet bore (mm)	31.8
Outlet bore (mm)	50.8
Heater return (mm)	19.1

Source: Northernradiator, 2020.

To connect the radiator to the inlet pipe, a rubber adapter is going to be needed to fit the hose to the inlet hole. After looking into the dimensions of the radiator and analysing the space that there is in the laboratory, it can be stated that the radiator is going to fit and it will be possible to leave the space of 50 mm between it and the wall to make the air able to circulate.

Heat dissipated by the radiator:

Newton's law of cooling describes the rate of heat transfer from a surface at T_s to the surrounding medium at T_∞ as

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \tag{1}$$

where the heat transmission surface area is A_s, and the convection heat transfer coefficient is h.

As a result, to accelerate the amount of heat transfer, one option is to raise the convective heat transfer coefficient h, which might necessitate the installation of a pump or fan or the replacement of a current one with a bigger one, but this strategy is not always feasible. Another option is to enhance the surface area by attaching extended surfaces called fins composed of highly conductive materials like aluminium to the surface. Extruding, a thin metal sheet on a surface produces finned surfaces. In exposing a greater surface area to convection, fins improve heat transfer from a surface. In this scenario, the assumption will be that convection is the only source of heat transmission.

Another important parameter that has to be taken into account is the fin efficiency η_{fin} as the temperature of the fin will decrease all along the fin. Thus, much less heat transfer from the fin to the environment is going to be produced due to the diminishing temperature near the fin tip. Fin efficiency is defined as the influence of this drop in temperature on heat transfer.

$$\eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{fin,max}} = \frac{Actual\ heat\ transfer\ rate\ from\ the\ fin}{Ideal\ heat\ transfer\ rate\ from\ the\ fin\ if\ the\ entire\ fin\ were\ at\ base\ temperature} \tag{2}$$

So, the equation presented in (1) has to be adapted to consider the fin efficiency:

$$\dot{Q}_{fin} = \eta_{fin}\, hA_{fin}(T_s - T_\infty) \tag{3}$$

To solve η_{fin}, from equation (2) the following formula is used:

$$\eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{fin,max}} = \frac{\sqrt{hpkA_c}(T_b - T_\infty)}{hA_{fin}(T_b - T_\infty)} = \frac{1}{L}\sqrt{\frac{kA_c}{hp}} = \frac{1}{aL} \tag{4}$$

where L is the length of the fin and a is a parameter determined by the following expression:

$$a = \sqrt{\frac{hp}{kA_c}} \tag{5}$$

where p is the perimeter of the fin, k is the Thermal Conductivity which for aluminium is $239\frac{W}{m\cdot K}$ and A_c, is the cross-sectional area $(L \cdot t)$.

However, for calculating the rate of heat transfer from a finned surface, we must account both the unfinned and finned portions of the surface. As a result, the heat transfer rate for a surface with n fins can be stated as

$$\dot{Q}_{total,fin} = \dot{Q}_{unfin} + \dot{Q}_{fin} = hA_{unfin}(T_b - T_\infty) + \eta_{fin} hA_{fin}(T_b - T_\infty)$$

$$= h\left(A_{unfin} + \eta_{fin} A_{fin}\right)(T_b - T_\infty) \quad (6)$$

Thus, to solve the equation 6, it is necessary to determine the A_{fin} and the A_{unfin} (Cengel, 2019).

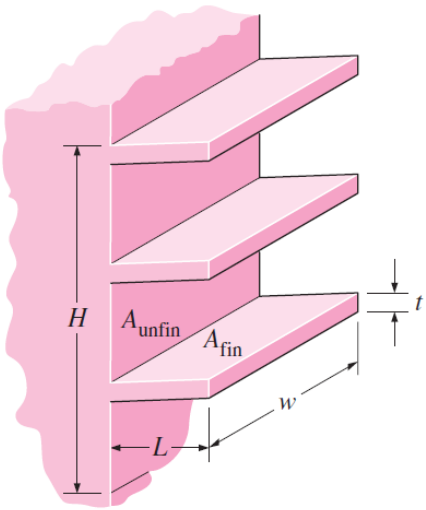


Figure 63. *Unfinned and fined areas are associated with a rectangular surface with three fins (Cengel, 2019).*

In Figure 63, it can be seen schematically that:

$$A_{unfin} = wH - 3wt$$

$$A_{fin} = 3(2LW + tw + 2Lt)$$

Thus, the heat transfer that is going to take place in the Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core, is calculated as follows:

As the dimensions of the Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core, 233254 are: 396.9 x 676.3 x 25.4 (mm) the following simplifications are done.

It is considered that H= 400 (mm) and not 396.9 (mm) there is one fin each 2 (mm), and these fins have a “t” of 6 (mm), in total there are approximately 50 fins.

$$A_{unfin} = 676.3 \cdot 400 - 50 \cdot 676.3 \cdot 6 = 67630\, mm^2 = 0.068\, m^2$$

$$A_{fin} = 50 \cdot (2 \cdot 25.4 \cdot 676.3 + 6 \cdot 676.3 + 2 \cdot 25.4 \cdot 6) = 1935932\, mm^2 = 1.94\, m^2$$

The convection heat transfer coefficient (h), for transferring heat from aluminium to air in passive cooling is:

$$h = 5\frac{W}{m^2K}$$

It is also needed to determine the thin efficiency with equation (4):

$$\eta_{fin} = \frac{1}{aL} = \frac{1}{\sqrt{\frac{hp}{kA_c}}L} = \frac{1}{\sqrt{\frac{5\cdot(2\cdot 0.006+2\cdot 0.6763)}{239\cdot(0.0254\cdot 0.006)}}\cdot 0.0254} = 0.46$$

Then,

$$\dot{Q}_{total,fin} = 5\cdot(0.068 + 0.46\cdot 1.94)\cdot(90-20) = 336.14\, W$$

This is the heat in W, dissipated by the radiator. However, the heat that is needed to be dissipated is much more of this value. Thus, a radiator of a more powerful engine is an interesting option for installation. A good option is to use the radiator that works on the MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP.

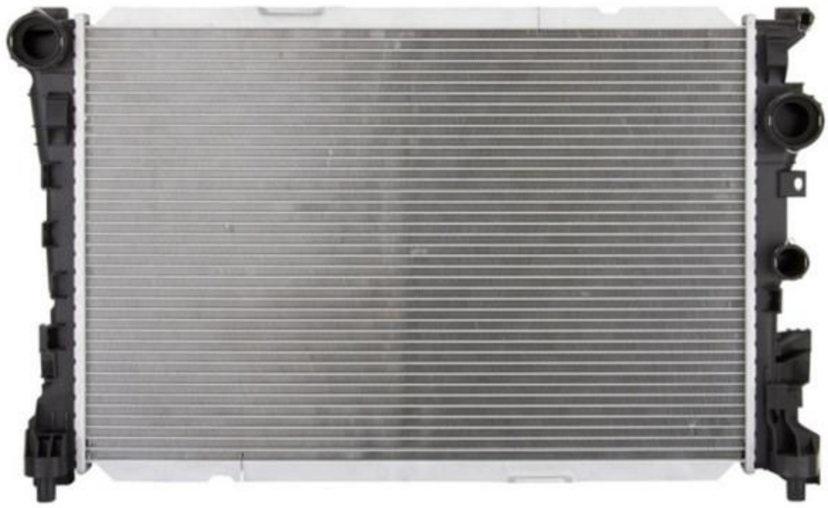


Figure 64. *NRF Radiator, engine cooling Aluminium 59133 for a MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP engine (Trodo, 2018).*

This radiator is used for an engine that has 631 HP, so the radiator is going to have enough capacity to dissipate the heat from the engines that are currently in the laboratory. Moreover, this radiator with that capacity allows for the installation of bigger engines and ensures that they are going to be cooled down.

It has the following specifications presented in Table 14.

Table 14. NRF Radiator, engine cooling Aluminium 59133 specifications for a MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP.

Technical data	
Material	Aluminium
Net length (mm)	428
Net width (mm)	640
Net depth (mm)	32
Radiator type	Welded cooling fins
Manufacturer	NRF

Source: Trodo, 2018.

Considering that it has 50 fins, of 7 (mm) in width and the space between two fins is 1.5 (mm). Then the total heat dissipated with this radiator is:

$$A_{unfin} = 640 \cdot 428 - 50 \cdot 640 \cdot 7 = 44800\ \text{mm}^2 = 0.045\ \text{m}^2$$

$$A_{fin} = 50 \cdot (2 \cdot 32 \cdot 640 + 7 \cdot 640 + 2 \cdot 32 \cdot 7) = 2294400\ \text{mm}^2 = 2.29\ \ \text{m}^2$$

The convection heat transfer coefficient (h), for transferring heat from aluminium to air in passive cooling is:

$$h = 5\frac{W}{m^2K}$$

It is also needed to determine the thin efficiency with equation (4):

$$\eta_{fin} = \frac{1}{aL} = \frac{1}{\sqrt{\frac{hp}{kA_c}}L} = \frac{1}{\sqrt{\frac{5 \cdot (2 \cdot 0.007 + 2 \cdot 0.640)}{239 \cdot (0.032 \cdot 0.007)}} \cdot 0.032} = 0.51$$

Then,

$$\dot{Q}_{total,fin} = 5 \cdot (0.044 + 0.51 \cdot 2.29) \cdot (90 - 20) = 424\ W$$

As can be seen, the heat dissipated by this radiator is bigger than the one done by the Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core, reference: 233254. However, the NRF Radiator, engine cooling Aluminium 59133 specifications for a MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP is more expensive, as it has a cost of 262 € (Trodo, 2018). The Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core has a price of 118.26 € (Autonosat, 2013). Although the difference in costs is considerable, as the radiator presented in Figure 64 has better specifications, it will be the selected one for the cooling unit.

4.2.2.2 Fan

The cooling fan has the function to reduce the temperature of the refrigerant in case the radiator cannot do it by itself (Nice, 2000). Most of the cars used nowadays have incorporated a fan in the cooling system, moreover, without a fan, the coolant will overheat and cause great damage to the engine. Nonetheless, in the studied case, the possibility to install a radiator with much more capacity than the required to reduce the temperature of the coolant by itself is studied. For instance, if the radiator selected is used for an engine with lots of horsepowers, the SISU engine, and the Opel engine would meet their necessities and it could be mounted without a fan.

The idea of a cooling system without a fan could be a possible solution, but it has some drawbacks that made us rule out these options. The most important or relevant was the disadvantage of not having enough capacity in case the university want to install other motors. If we did not have this in mind, the characteristic of creating a cooling system module for different engines with different HP (horsepower) will faint. For example, the montage without a fan could be suitable for the studied types of engines, but if a new engine with more power is installed in the laboratory, the radiator might not be enough to cool down the refrigerant and therefore overheat. On the other hand, if a fan is not installed, the energy consumption will decrease, but as in the laboratory we do not have a charging system installed (it is used on the general grid instead), it does not matter.

Another fact to take into account is the installation of an engine drive fan or an electric fan. According to Staff (2015), electric fans are the most efficient. This is mainly because the engine-driven fans draw power from the crankshaft due to the traction the belts do to transmit the power the cylinders do. On the other hand, electric fans do not need the help of the crankshaft to be used and it will make the engine work at higher power. Therefore, the electric fan is the one selected.

One characteristic of the cooling fans is their positioning. Air can be pushed or pulled through the radiator using electrical fans. If it is in front of the radiator is a pusher fan. Because of its position in front of the radiator, a pusher fan can restrict airflow when the vehicle is in motion. On the other hand, a puller fan is located directly behind the radiator. The puller fan draws air through the radiator and, because it is behind the radiator, has less of an impact on airflow at high speeds than a pusher fan. The positioning of the puller fan makes it a better option for cooling systems and a more powerful option than pusher fans in terms of the cooling capacity (Holley.com, 2021). Therefore, due to the possibility of selection, a puller fan-type configuration will be assembled.

The requirements of the fan are a voltage of 12 V (typical power converter voltage) and a current that will be determined by the fan-selected. The power supplies used for the fan will be the same as the ones selected on the gasoline injection system presented in section 4.1.1.6. The selection methodology consisted of searching for the desired piece of enough powerful one in used in cars that have lots of HP. In our case, the SISU engine and the Opel engine have a low horsepower compared with a Ferrari, for that reason, it was studied the possibility to install fans that work with the MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP (which have a much bigger horsepower). If done that, we could ensure that the actual motor and the future engines can work perfectly without any damage done to the system.

The first option of a fan suitable for the Mercedes AMG is the AKS DASIS 128198N (Figure 65).

Figure 65. *AKS DASIS 128198N fan (Autoteile, 2013).*

This fan has enough power to cool down the refrigerant inside the radiator and it will only be used as a helping tool when the radiator cannot dissipate the heat by itself. The power consumption is 850 W and it works with a voltage of 12V (Piezas de vehículos, 2022). The total cost of the fan is 588 € (Autonosat, 2013).

Table 15. *AKS DASIS 128198N fan specifications.*

Technical data	
Nominal power (W)	850
Weight (Kg)	5.962
Length (mm)	800
Width (mm)	650

Source: Autonosat, 2013.

The second option, NRF 47853 Fan is presented in the following Figure.

Figure 66. Design of the NRF 47853 fan (Autonosat, 2013).

The NRF 47853 Fan has a diameter of 515 mm and it is used in some Mercedes models, such as the MERCEDES-BENZ SLS AMG Coupé (C197) 6.2L Gasoline 631 HP. The power consumption is 850 W and has a nominal tension of 12 V (Piezas de vehículos, 2022).

Table 16. Technical data of the NRF 47853 fan.

Technical data	
Nominal tension (V)	12
Nominal power (W)	850
Diameter (mm)	515
Number of fins	9

Source: Autonosat, 2013.

It has some equal specifications related to the AKS DASIS 128198N fan. However, this is a little bit more expensive as it has a price of 631 € (Car parts, 2019).

The last option studied is the NRF 47699 (Figure 67), which is not a suitable fan for the Mercedes AMG car as it has a small dissipated heat capacity, nonetheless, it could function for the OPEL and SISU engine, moreover, it is the most affordable fan out of all.

Figure 67. Design of the NRF 47699 fan (Autonosat, 2013).

The presented fan is smaller than the other two (290 mm) as it does not have the same power to reduce the temperature. The model can be found in some Volkswagen cars and works with a tension of 12 V and power consumption of 500 W (Piezas de vehículos, 2022). The cost is 136 € (with VAT included) which makes it the cheaper option (Autonosat, 2013).

Table 17. Technical data of the NRF 47699 fan discussed above.

Technical data	
Nominal tension (V)	12
Nominal power (W)	500
Diameter (mm)	290
Number of blades	9
Number of poles	2

Source: Autonosat, 2013

The team concluded that the best for the project was to use the NRF 47853 fan. Even if it costs about four times more than the price of the fan for the NRF 47699 fan discussed. An important factor that has been very important to decide which to choose has been its dimensions. After going to the lab and realising the dimensions of a fan installed in a vehicle, it has been discarded the model presented in Figure 67. Thus, the team has finally chosen the NRF 47853 which has a nominal output of 859 W and better specifications than the AKS DASIS 128198N fan.

4.2.2.3 Extra coolant pump

This component is not strictly required on a typical cooling system, nonetheless every day its usage is increasing and some manufacturers are applying it to their cars (Know Your Parts, 2014). The extra coolant pump is mounted to achieve the perfect amount of flow rate into the radiator and to help to prevent cavitation inside the system. Also, in most of the decreased engine speed motors, the coolant in the heater core would lose the majority of its heat before passing through to the outlet. If drivers were stuck in stop-and-go traffic or cruised at lower RPMs, they would have insufficient heating to function well. As a result, installing an auxiliary coolant pump would be sufficient to keep the heater core heated (Gimeno, 2022).

In the studied motor, the cooling system does not require an extra pump. The engine has already incorporated a pump that will bomb the refrigerant through the engine without any complications, nonetheless, the study of installing an extra pump has the goal of reducing the cavitation (when the radiator is very separated from the engine block) effect inside the pipes and critical zones of the engine (radiator, valves, etc.), and secure the estimated flow to maximize the efficiency. Moreover, the extra coolant pump was planned to max out the capacity of the cooling system in case the engine might want to be changed in the future for another one with more horsepower.

To achieve the extra power for future applications, two types of pumps were discussed. The solution to the problem could be solved by two means, by installing a water pump, or by mounting a coolant pump. The first option (water pump) is normally the cheapest option on the market, also, it can handle a range of temperatures that go from 85 ºC up to 110 ºC (McNally, 2022) depending on the pump selected. On the other hand, the extra coolant pump suits all the requirements to keep the engine unharmed as it is specialized to function with the refrigerant and not with water. Moreover, it can work at temperatures up to 125 ºC and is made with anti-corrosive materials (VOVYO PUMP, 2019).

Thus, multiple options were discussed hereafter. The first option is the BOSCH universal auxiliary electric water coolant pump 0392020034 (Figure 68).

Figure 68. *BOSCH universal auxiliary electric water coolant pump 0392020034 (eBay, 2019).*

This model is described as a water pump, nonetheless, it is usable as an extra pump in the cooling system in a wide range of engines (eBay, 2019). It works at 12 volts and can deliver 750L/h, which is more than the required in the system to maintain a good working flow rate. One drawback is the inlet aperture which is about 20 (mm), meaning that an adapter might be used as the selected diameter of the pipes is 50 (mm). The price of the bomb is 108,7 € approximately (eBay, 2019).

Table 18. Technical data of the BOSCH universal auxiliary electric water coolant pump 0392020034.

Technical data	
Nominal voltage (V)	12
Flow rate (l/h)	750
Length (mm)	150
Inlet diameter (mm)	20
Outlet diameter (mm)	20
Outer diameter (mm)	61

Source: eBay, 2019.

The NISSENS 831053 water pump (Figure 69) is the second discussed pump for the cooling system. It cost less than the BOSCH universal auxiliary electric water coolant pump 0392020034 as it has a price of 90,58 € (Car parts, 2019).

Figure 69. *Picture of the NISSENS 831053 water pump (Autonosat, 2013).*

The NISSENS 831053 water pump offers a working voltage of 12 V and it is found in a great range of vehicles on the market, such as Ford, Audi, Renault, Porsche, etc (Autodoc, 2022). The working temperature of the pump is not available on the internet but as it is a very common model on modern cars it should handle the high temperatures of the coolant.

***Table** 19. Technical data of the NISSENS 831053 water pump.*

Technical data	
Nominal voltage (V)	12
Inlet diameter (mm)	20
Outlet diameter (mm)	20
Length (mm)	175

Source: Autonosat, 2013.

On the other hand, a specialized coolant pump was studied, the SHENPENG P6216 12v electric coolant pump (Figure 70).

***Figure 70.** SHENPENG P6216 12v electric coolant pump (Alibaba, 2021).*

The SHENPENG P6216 12v electric coolant pump can achieve extreme temperatures such as -40 ºC and 125 ºC. It also works with 12 V and a power of 72 W and it is specialized to work with coolant fluid. So, both the temperature problem and the corrosion or damage of the pump with time will not be a problem. The price of the specialized coolant pump is 53 € (Alibaba, 2021).

This pump has the following specification presented in Table 20.

Table 20. Technical data of the SHENPENG P6216 12v electric coolant pump.

Technical data	
Nominal voltage (V)	12
Max lift (m)	15
Working temperatures (ºC)	-40 to 125
Weight (kg)	0.65
Max flow (L/min)	43
Inlet/outlet diameter (mm)	20
Power consumption (W)	72

Source: Alibaba, 2021.

In conclusion, the selected pump to use in the cooling system module is the SHENPENG P6216 12 V electric coolant pump. The team came to the conclusion that it is the most suitable pump for our system as it can handle better the temperature and it is specialized in coolants and not only water, meaning that it is more resistant to these liquids than the water pumps, reducing the damage that can be done to the engine in the future. Also, it is the pump with more information, therefore we can have better control over the cooling module assembled. Moreover, the power supplier that the SHENPENG P6216 12v electric coolant pump will use is selected in section 4.1.1.6.

One drawback that it has, is the diameter of the inlet and outlet. Both have the same aperture and it is of a different size from the pipes selected, therefore, an adapter is needed to be mounted into the system.

4.2.2.4 Coolant

The coolant that is going to be circulating has to be compatible with both engines. The idea is to keep the coolant inside the radiator that is part of the remote module every time the engine placed in the bed is changed. However, as the coolant gets progressively acidic over time, it may lose its anti-corrosion characteristics and begin to produce corrosion. Corrosion can harm the engine's radiator, thermostat, water pump, and other cooling system components (Fast Eddies Wash and Lube, 2017). Thus, every time the motor that is placed in the bed of the laboratory is changed; a new coolant can be added to the refrigerant system. If an engine is kept there for a long time, it is important to notice that the coolant also has to be changed.

The idea is to introduce the coolant through an upper entrance that the radiator has.

The first option is to use the one presented in Figure 71.

Figure 71. Universal coolant Glycol Purple G13 (Skruvat. fi, 2022).

Glycol G13 is a “vag coolant g13” that can operate for the SISU diesel and the OPEL gasoline engines. It has the following properties:

Table 21. *Glycol G13 freezing and boiling point.*

Technical data	
Freezing Point (ºC)	-69
Boiling Point (ºC)	175

Source: CarPhrases, 2020.

As can be seen, the coolant will not freeze because the temperature of -69 ºC will not be reached. Furthermore, the coolant's boiling point of 175°C ensures that it will not evaporate since when the temperature reaches 90°C, the fan gets activated and cools the refrigerant (CarPhrases, 2020).

The price for 5 L of Universal coolant Glycol Purple G13 in Skruvat. fi is 18.31 € (Skruvat .fi, 2022).

Another possible coolant to be used is the one presented in the following Figure.

Figure 72. *Mannol AF12+ MN4012-5 Antifreeze coolant (Autodoc.es, 2022).*

The main specifications that it has been presented in the following Table.

Table 22. *Mannol AF12+ MN4012-5 Antifreeze coolant.*

Technical data	
Freezing Point (ºC)	-40
Boiling Point (ºC)	125

Source: Autodoc.es, 2022

The cost of one unit is 38.31 €. (Autodoc.es, 2022).

The selected product is the Universal Coolant Glycol Purple G13 as it is cheaper than the other option and can handle higher temperatures in case the fluid over-heats. The second option would be enough for a typical engine (it is very rare to achieve 175 ºC in a normal motor and with 125 ºC it would run smoothly enough), but due to the price of it and the plan to over-dimension the component in case more powerful engines are installed, the first option, the Universal Coolant Glycol Purple G13, is selected.

4.2.2.5 Hoses/pipes

It is important to use pipes with big dimensions, for example, 50 mm in diameter, to use the remote module designed with an engine with more power than the ones that are in the laboratory now. Then, if the pipe is big enough, the flow of coolant that is going to be able to circulate will have the capacity to refrigerate bigger engines that could be used in the future in the laboratory.

The cooling system that is operated remotely is going to have an inlet pipe where the water pump, the mechanic valve and the temperature interrupter are going to be placed. Through this pipe, the hot coolant arrives at the radiator. Then, at the end of the radiator, once the temperature of the refrigerant is decreased, it passes just through the outlet pipe to the engine. In this outlet pipe, there are no components, just the quick connectors.

To make a balance between cost and performance, a good option for the hose's distribution is as follows: between the outlet port of the engine where the hot coolant leaves it and the water pump a rubber hose is going to be used. Then, between the water pump and the radiator, as there will be extra pressure, a metallic pipe will be needed. Finally, in the outlet pipe, the same rubber hose as the one used in the inlet tube can be used.

Another important aspect to consider for the hoses is their dimensions. As mentioned before, it is important to use a bigger pipe than the one that would be required for the engines as then, if in the future, a bigger engine is incorporated in the laboratory, it will be possible to circulate enough coolant without damaging the pipes due to extra pressure and prevent them and the water pump from cavitation. Thus, the hoses will have a diameter of 50 (mm).

An option to ensure the connection of the water pump with the temperature interrupter and the radiator is to use the following Stainless Steel Flexible Hose Pipe presented in Figure 73.

Figure 73. *Stainless Steel Flexible Hose Pipe (Indiamart, 2021).*

The pipe shown in Figure 73 has the following properties depicted in Table 23.

Table 23. *Stainless Steel Flexible Hose Pipe specifications.*

Technical data	
Diameter size (mm)	50
Without Braid	Max. Working Pressure: 0.98 bar
Single Braid	Max. Working Pressure: 27.5 bar
Double Braid	Max. Working Pressure:43.15 bar
Length (m)	Up to 15
Material Grade	SS 304 / 316
Material	Stainless Steel

Source: Indiamart, 2021.

It has a price of 3.6 € (Indiamart, 2021). However, as it has to be imported from India the cost will be a little more expensive due to its transport. An average cost for sending a package with a similar dimension of 2 meters of these metallic hoses is 65 € (Parcelabc, 2014)

For the rubber hose, it is going to be used a Gates Green Stripe® 2-Ply Straight Coolant Hose stick which is designed for demanding heavy-duty coolant/air applications. It is made from a sophisticated EPDM tube that resists "cold water leaks" and stays soft and flexible even under unfavourable working conditions (Gates, 2022).

EPDM stands for Ethylene Propylene Diene Monomer is a synthetic rubber that is used to create a wide range of products, including rubber tubing. EPDM tubing has a wide range of applications because of its resistance to heat, chemicals, ozone, abrasion, and weather (Vanguard Products, 2021).

The pipe that is going to suit the requirements for the designed installation is the 24232 2" X 3FT GS 2 PLY STRAIGHT. It has the specifications presented in Table 24.

Table 24*. 24232 2" X 3FT GS 2 PLY STRAIGHT EPDM tube specifications.*

Technical data	
Temperature range (ºC)	-40 to 125
Length (m)	0.914
Hose Inside Diameter (mm)	50
Working Pressure (bar)	4.14

Source: Gates, 2022.

To make an idea of how it is, in Figure 74, there is a portion of it.

Figure 74*. 24232 2" X 3FT GS 2 PLY STRAIGHT EPDM hose (Gates, 2022).*

It is very important to be aware that this type of hose cannot be used for fuel or oil transfer applications. However, as their goal is to transport Glycol G13, it is a good option for connecting the different components of the remote module. It has a price of 45 € for every 0.914 meters of pipe plus 29 € for sending it to Finland (Amazon, 2022). Thus, it is important to calculate enough number of meters needed and then buy it all together to save shipping costs. For the remote cooling module that is being designed, it will be required 2 pieces of 0.914 m to ensure that all the connections are going to be accomplished. So, the total cost of the rubber hoses is 119 € including the transport costs.

4.2.2.6 Temperature interrupter normally open (contact at 90 ºC)

To activate the fan and in consequence, cool down rapidly the refrigerant temperature that passes through the radiator, the temperature of the fluid is measured. Then, if it is 90 ºC or more, the fan is going to start working. To achieve this, a normally open temperature switch is needed. Its working principle is as follows: it will be normally opened without allowing electricity to circulate to the fan, then when it detects that the coolant temperature is 90 ºC or more, it starts making contact (closes) and activates the fan. A temperature sensor is used to monitor the engine temperature.

Figure 75. *90°C Normally Open Thermostat Thermal Temperature Switch NO (Switchelectronics, 2020).*

The temperature switcher presented in Figure 75 has the following specifications:

Table 25. *Technical data for the: 90°C Normally Open Thermostat Thermal Temperature Switch NO.*

Technical data	
Terminal Type (mm)	6.3
Dielectric Strength	1000 VAC 1 minute
Insulation Resistance (MΩ min.)	100
Electrical Life (Cycles)	100,000
Operating Temperature (ºC)	220 Max
Closing Temperature (ºC)	90
Contact Resistance (mΩ)	50 max.
Contact Configuration	Normally Open

Source: Switchelectronics, 2020.

The cost for 1 component of the 90°C Normally Open Thermostat Thermal Temperature Switch NO is 11.5€ (Switchelectronics, 2020).

There is another thermostat that could be used in the installation. It is presented as follows.

Figure 76. *Disc thermostat 3F11- 325 (Farnell.com, 2021).*

The normally open switcher presented in the above Figure has the following specifications.

Table 26. *Disc thermostat 3F11- 325 main specifications.*

Technical data	
Terminal Type (mm)	12.7
Resistive	10 A @ 240 VAC
Insulation Resistance (MΩ min)	100
Weight (kg)	0.057
Operating Temperature (ºC)	169 Max
Closing Temperature (ºC)	90
Contact Configuration	Normally Open

Source: Franell, 2021.

The total cost of acquiring this normally open switcher is 52.19 €. The price of the components is 11.13 €, but as it has to be sent from the USA, the cost raises considerably (Farnell.com, 2020). Thus, the thermostat presented in Figure 75 is much cheaper and in addition, has better specifications as it can work at a wider range of temperatures in case the coolant gets warmer than expected.

4.2.2.7 Expansion tank and cap

As the water gets warmer, the pressure in closed heating systems increases. These pressure oscillations might cause harm to the system's components over time. An expansion tank is meant to relieve this strain and help your system last longer.

When mounting the expansion tank, it is important to place it above the engine. It is connected to the radiator pressure cap with the expansion bleed hose. It also has a coolant overflow hose connected to the outlet radiator hose through which the cold coolant is going to enter the engine.

One option is to use the Expansion Tank presented in Figure 77.

Figure 77. Schmiedmann expansion tank for cooling engine system (Schmiedmann. fi, 2018).

This expansion tank has the following specifications presented in Table 27. It costs 57.6 € (Schmiedmann, 2018).

Table 27. Schmiedmann expansion tank model 17137529273 specifications.

Technical data	
Model	Schmiedmann 17137529273
Weight (kg)	0.48
Dimensions (LxWxH) (mm)	190x190x190

Source: Schmiedmann, 2018.

Another option is to use an expansion tank that fits an Opel engine as the one that is planned to incorporate into the laboratory. This is presented in the following figure.

Figure 78. Radiator/ Expansion Coolant Header Tank 022953219 For Vauxhall/Opel, Chevrolet & Saab (Fruugo, 2017).

The expansion tank presented in Figure 78 does not include further data and it has a cost of 32 € (Fruugo, 2017).

As the difference in cost is low and more specifications are provided from the Schmiedmann expansion tank for the cooling engine system, this is going to be the one used in the developed remote cooling system of this project.

4.2.2.8 Piston valve

The mechanic valve regulates the quantity of coolant that is circulating in the system to control its temperature and the cavitation inside the engine. The piston valve is used to increase or decrease the flow rate depending on the temperature of the engine, for instance, if the coolant is overheating, the flow should decrease to occur more heat exchange between the fluids (coolant and air) in the radiator.

Another added utility of the valve is the capacity to control the cavitation inside the cooling system. Cavitation consists of the formation of vapour bubbles in the liquid as a result of sudden changes in pressure or velocity (Helloauto, 2022). The bubbles appear at those points where the fluid velocity is higher and the pressure decreases significantly, causing the fluid to change from a liquid to a gaseous state. These bubbles move towards areas of higher pressure, which causes them to implode and thus suddenly return to the liquid state (Universidad de Valencia, 2013). In general, the consequences of the phenomenon are the creation of turbulence and friction in the liquid, which leads to a loss of performance in the affected system. In a forced circulation system for engine cooling, the existence of cavitation can hinder or even prevent the fluid from moving properly. It can also lead to corrosion of metal in contact with the point where cavities are generated. Thus, the utilization of a piston valve tries to control the cavitation effect when it appears on the engine. Once the vibrations in the cooling system start to appear the piston valve should close partially to let the fluid flow and decrease the pressure inside the pipe which will lead to a reduction of the cavitation effect.

The piston valves came out to be the best option to control the flow inside the radiator as they have a high precision to control the aperture of the valve. Hereunder some options are discussed.

The first option is the Burkert Type 2702 Screwed Manual Throttling Valve (Figure 79).

***Figure** 79. Burkert Type 2702 Screwed Manual Throttling Valve (Valvesonline, 2016).*

It is a bidirectional valve that offers great control over the flow of the fluid. It is conformed of stainless steel so the corrosion will not affect the valve in the future. Moreover, it can support great temperatures (-10 ºC to 180 ºC) and can handle well high pressures (from 0 to 16 bars for some diameters and from 0 to 10 bars for the rest of the diameters). The manual piston valve is available with an aperture of 50 (mm) which is the selected size for the pipes of the cooling system, if there are changes on the hoses, an adapter should be used. The total cost of the valve is 631 € (with the VAT) (Valvesonline, 2016).

The technical data of the Burkert Type 2702 Screwed Manual Throttling is displayed in Table 28.

***Table** 28. Technical data of the Burkert Type 2702 Screwed Manual Throttling Valve.*

Technical data	
Port size (mm)	50
Maximum temperature (ºC)	180
Max operating pressure (bar)	0 - 10
Seal material	PTFE
Weight (kg)	3.72

Source: Valvesonline, 2016.

The other option discussed is much more affordable than the Burket Type 2702 Screwed Manual Throttling as it cost approximately 45 € (Anon, 2022). The second option is the Angle seat valve DIN-DVGW with backflow preventer DN25 (Figure 80).

***Figure** 80. Angle seat valve DIN-DVGW with backflow preventer DN25 (Heiz24, 2022).*

The piston valve can handle up to 10 bar and have a maximum temperature of 90 ºC. The body material is made of pressed brass (an alloy of copper and zinc mainly) which is a very useful material against corrosion. The diameter of the port is available in 40 mm and 50 mm among other measures.

***Table** 29. Technical data of the Angle seat valve DIN-DVGW with backflow preventer DN25.*

Technical data	
Port size (mm)	50
Max operating pressure (bar)	0 – 10
Seal material	EPDM
Maximum temperature (ºC)	90

Source: Heiz24, 2022.

With both options in mind, the selected piston valve is the Burkert Type 2702 Screwed Manual Throttling Valve. The maximum temperature reachable by the valve had a key role when choosing the valve, that is because if the coolant reached the maximum temperature of the valve, the system could be affected and therefore could damage the engine. The price was also a thing to take into account. The selected type (631 €) is more expensive than the Angle seat valve DIN-DVGW with backflow preventer DN25 (45 €), but it is preferable to expend more money on this component than having to change the entire system because a failure occurred due to an overheating problem.

4.2.2.9 Coolant temperature sensor

Although the normally open switcher works depending on the temperature of the coolant, a temperature sensor would not be needed as the engines have it. However, the team has decided to incorporate one temperature sensor in the hose through which the hot coolant passes. The Engine Control Unit (ECU), is going to use this data to manage the fuel injection and ignition time. However, this project is going to be used to control the radiator fan (Autotechlabs, 2015).

A sensing probe and an electrical connector are included. The majority of coolant temperature sensors are negative temperature coefficient types, which means as the temperature increases, the resistance will decrease. In most cars, it is located in the thermostat housing to activate or deactivate the thermostat (HELLA, 2018).

So, it needs to find a coolant temperature sensor compatible with the Opel Engine studied in this project. The chosen component is the RIDEX 830C0064 Coolant Temperature Sensor. It accomplishes the necessities as it has a temperature range from -40 ºC to 150 ºC. Moreover, it has two poles and an operating voltage of 12 V (Autonosat, 2013).

Figure 81. *RIDEX 830C0064 Coolant Temperature Sensor (Autonosat, 2013).*

This temperature sensor has a price of 14 € in AUTODOC and the product number is 830C0064 (Autonosat, 2013).

The temperature sensor presented hereunder could be as well a good option.

Figure 82. *FACET 7.3015 Coolant temperature sensor (Autodoc.es, 2022).*

The sensor presented in Figure 82 has a screw dimension M14x1,5 and a temperature range between -20 ºC and 140 ºC, it costs 11.56 € (Autodoc.es, 2022).

Even if this second model presented is cheaper, the team has decided to choose the RIDEX 830C0064 Coolant Temperature Sensor as it has better specs than the FACET 7.3015 Coolant temperature sensor.

4.2.2.10 Quick connectors

For connecting the designed remote module to the different engines that can be run in the laboratory there are important components to achieve the connection between the hoses of the engine and the pipes of the cooling module. These components are quick connectors.

As a requirement, it is interesting to have an internal diameter of 50 mm, as the hoses of the installation have these dimensions. If the hoses of the engines have a different diameter, a rubber adapter can be used to ensure the connection.

Figure 83. *Quick Connector PE Plastic 50mm Diameter Ball Valve (Amazon, 2022).*

It is important to mention that this connector works differently than the one presented for the fuel installation with a male connector fitting the female one. Here, there is only the element presented in Figure 83 to which the pipe from the engine is going to be connected to one side, and the tube from the remote coolant module is going to fit the other port. Then, both pipes are going to be connected. It has a cost of 21.5 € each, so, as two components are needed, one for the hot coolant pipe and the other for the cold one, the total cost of it is 43 (Amazon, 2022).

Instead of the quick connector presented in Figure 83, there is as well the following option.

Figure 84. *Flexible Pipework Quick Coupling 50mm (WATER GARDENING DIRECT, 2021).*

This component also accomplishes the requirements. One couple of male-female cost 14.68 €, so as two are needed the total cost is 29.36 € (WATER GARDENING DIRECT, 2021). However, as sometimes the coolant is going to flow with high pressure, and the component Quick Connector PE Plastic 50mm Diameter Ball Valve is much more resistant, it will be the selected one for the mounting.

4.2.2.11 Pipe adapter for the pump

As the water pump has an inlet and outlet diameter of 20 mm and the selected pipes have a 50 mm diameter, an adapter to connect these components is needed.

Figure 85. *PVC hub to hub reducer coupling pipe adaptor 50mm x 20mm (Amazon.es, 2022).*

The units presented in Figure 85 will be enough to ensure the union between the pipe and the water pump. Two of them are needed which cost 15.21 € (Amazon.es, 2022).

4.2.2.12 Structure supporting the remote module

One of the principal goals of this project is the adaptability that the design of the refrigeration module brings to the laboratory. One of its main characteristics with the incorporation of quick-connectors is to have the capacity of being connected and disconnected to the running engine at that moment easily. So, when installing different engines, the space that the module uses in the laboratory has to be free. Thus, the structure where the cooling unit is placed must have wheels mounted on its legs. Possible castors for the installation are presented in the following figure.

Figure 86. *Cast iron red tyre with steel housing. The swivel plated castor is screw mounted. (Essentracomponents, 2021).*

The specifications of this wheel can be analysed in the following Table.

Table 30. *Fixed plate castor made from rubber with zinc plated steel housing.*

Technical data	
Wheel Material	Cast Iron
Caster Housing Material	Steel
Colour	Red
Caster Type	Swivel Plate Castor
Mount Type	Screw Mount
Load Capacity (kg)	300.0
Wheel Width (mm)	30.0
Wheel Diameter (mm)	125.0
Overall Height (mm)	161.0

Source: Essentracomponents, 2021.

As Table 30 shows, the load capacity of each wheel is 300 kg. As four wheels are mounted in the module, it can weigh a maximum of 1200 kg. The module is not going to be that heavy, so, with these castors, it is ensured that it is going to resist it. Furthermore, if in the future some other components have to be added, there will be a certain margin. However, in case a very heavy component is needed in the future, there is always the capacity to add more wheels. The cost of four is 327.70 € (Essentracomponents, 2021).

A cheaper option would be the one presented in the following figure.

Figure 87. *Swivel Caster - Wheel Material Nylon; Caster Housing Material Zinc Plated Steel (Essentracomponents.com, 2021).*

Its principal specifications can be analysed in the following Table.

***Table 31.** Zinc Plated Steel Castor main specs.*

Technical data	
Wheel Material	Nylon
Caster Housing Material	Zinc Plated Steel
Colour	Natural
Caster Type	Bolt Hole Castor with Brake
Mount Type	Bolt Hole
Load Capacity (kg)	120.0
Wheel Width (mm)	30.0
Wheel Diameter (mm)	100.0
Overall Height (mm)	127.0

Source: Essentracomponents, 2021.

Each wheel has a load capacity of 120 kg, as shown in Table 31. Because the module has four wheels, it can support a maximum weight of 480 kg. Each castor cost 43.95 €, so four of them would have a price of 175.81 € (Essentracomponents.com, 2021). As the module structure is heavier than this, these wheels are not a good option to pick even if they are much cheaper.

Another functionality that is decided to include in the module, is to make its height variable. To do this, the cooling designed module will be placed on a table with two adjustable legs. By pressing two buttons on the table, you can lengthen or shorten it. The table is actuated by an electric motor that is already built into the foundation.

***Figure 88.** Variable-length RODULF sitting/standing desk, ehite140x80 cm (IKEA, 2012).*

This table is made of stainless steel, polyester, rubber, acrylic paint and plastic edge. Its dimensions are 80 cm wide and 140 cm long. The cost is 319 € + 50 € if brought on site. However, there are two other options. These are 319 € + 0 € if picked up at the IKEA shop and 319 € + 25 if picked up at an IKEA collection point (IKEA, 2012).

4.2.3 Remote cooling system module assembly

Once the selection process has been made, the assembly stage begins. The first step is to deliberate how much space in the current laboratory is going to be used. The available space can be seen in Figure 89 which displays the layout of the engine laboratory in NOVIA UAS.

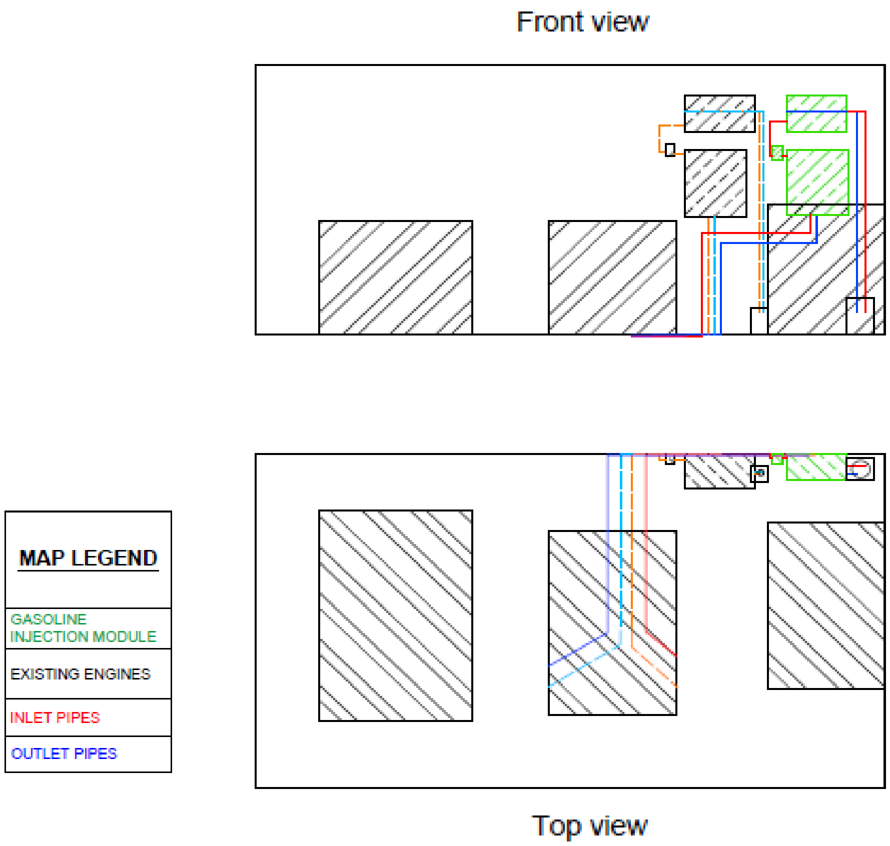


***Figure 89**. Schematic front view and top view of the space occupied in the laboratory (Author's own).*

There is plenty of space where install the cooling system, nonetheless, it has to be near the hot coolant outlet and the cold coolant inlet to raise its efficiency and reduce the problems of flow rate and cavitation, therefore the best possible place is the signalised in Figure 90 with purple colour.

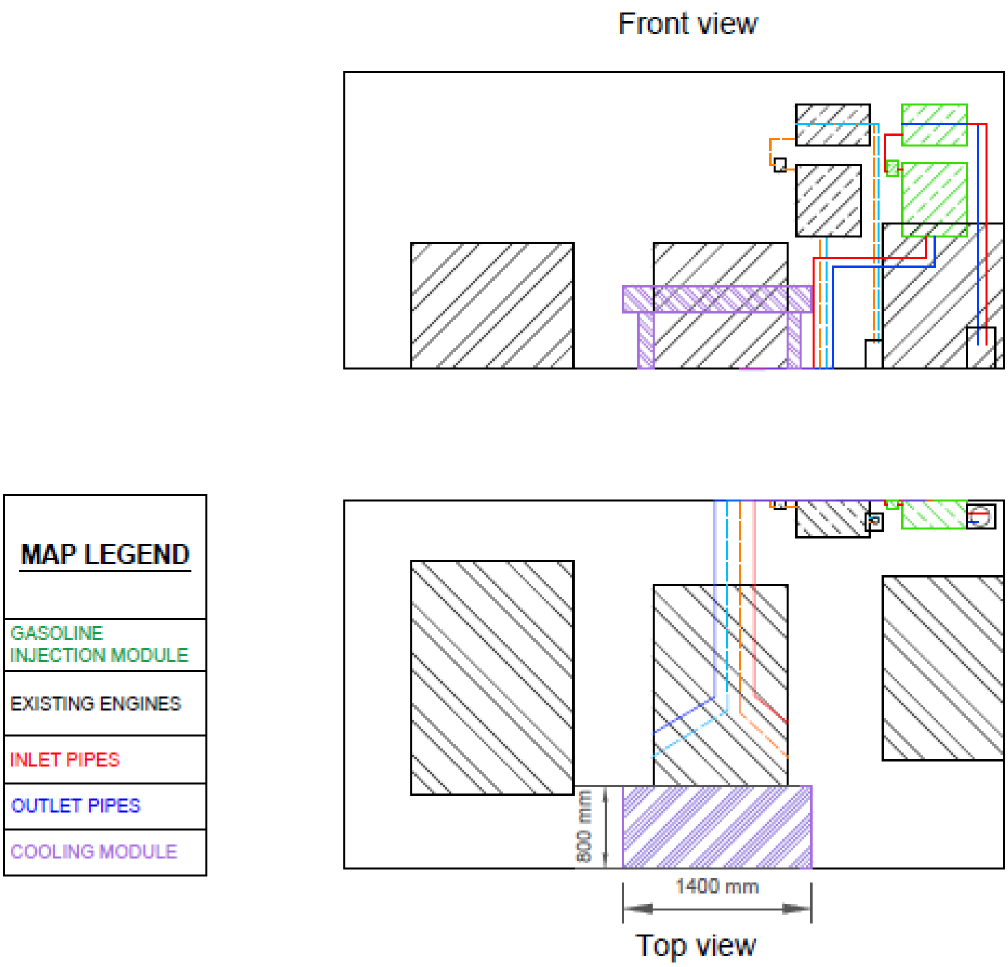


***Figure 90**. Schematic view of the space occupied by the cooling system module in the laboratory (Author's own).*

The purple zone maximizes the efficiency of the cooling system as it is the nearest option for both coolant pipes (inlet and outlet). Other discussed options were to install the module between engines, whether it was on the left or the right of the studied motor. The team concluded that none of the options where the module was placed aside from the engine was the best idea. For instance, if the cooling system was mounted on the left of the studied engine, the cold coolant inlet pipe might be too long and it will be more difficult to pump the coolant through the system. If mounted on the right side, the cold coolant inlet pipe is smaller, but the pipe for the outlet coolant might be too long. Therefore, the option where the dimensions of the pipes are small as possible for both is chosen.

Once the installation zone was clear it is necessary to take measures of the space. The perimeter available can be seen in Figure 90 which displays the purple zone measures.

Knowing the dimensions of the zone, the main idea was to build a portable device that could be moved in any direction and increase or decrease its height. The radiator, the fan and the pump will be mounted on the portable device. The idea was to make it from a material that could handle high temperatures because of the radiator, therefore, the wood became the first material to be discussed. Hardwood can handle well high temperatures as it can handle 220 ºC for several hours until it ignites. Because the coolant temperature is lower, the wood seemed a good option. Nonetheless, according to Fire Engineering Staff (2021), the wood that is in contact with steam pipes for too long can ignite over the years. As the planning was to create a module that could work for the future and bigger engines, the wood as supporting material for the radiator and the portable device was no longer an option. Therefore, other materials and alloys were searched.

The selected option is the 304 stainless steel which is austenitic steel. This alloy is one of the most used in the world and is what exhaust manifolds are made from, therefore, if it can handle the temperatures of an exhaust manifold, the supporting structure could handle the temperatures of the radiator (NEMA Enclosures, 2012). Furthermore, they provide high oxidation resistance. The price of the steel varies according to the piece searched, for instance, a table with the total price of the structure divided by the different parts is made in Appendix XI. Also, in Appendix XI table, there are added costs for the cutting of some steel parts such as the steel sheet used to support the radiator and the fan. Moreover, the costs of welding are also included in the budget, but both, the welding and cutting operations maybe could be done in Technobothnia's facilities, so there could be a reduction in the total cost of this alternative is selected.

4.3 Exhaust gas extractor design

As presented in section 3, currently in the laboratory there is an extractor that has a unique length that fits the exhaust gas system extraction of the SISU Diesel engine. In case it is desired to change the extension of the extractor. Furthermore, to have the possibility to achieve 4 different lengths from 50 (mm) to 50 (mm) up to a total of 200 (mm).

So, the idea is to design a system for the extractor in the lab that is used in that bed that can have different lengths and change them easily.

4.3.1 Extractor design with an easy-to-use variable-length system

The team pretends to fix with a screwed union to the actual metallic hose another one that has four different holes separated from each other by 50 mm. This distance is going to be the increment of length that the extractor is going to have to fit into its new engines. Then, another metallic pipe is going to be mounted inside of it. It will have two metallic elements on both sides of the tube that are going to be the ones that are fixed into theses 50 mm separated holes. They are going to work with the following principle: when pressed, they will become smaller (spring mechanism) which will allow this interior pipe to move along the pipe with perforations on the outside. Finally, this pipe with the metallic components is going to have a flexible ending part that is going to make the connection between the extractor of the engine and the extractor of the laboratory much easily done.

4.3.2 Selection of components

To build the new extractor, some parts that are mounted in the laboratory nowadays can be used, but some others have to be bought. These are the metallic hose with holes, the pipe that fits this holed hose, the two metallic components that materialise the connection between these two pipes, the flexible part in the ending part of the extractor and the rigid one that is going to ensure the connection linking the engine and the laboratory extractors. However, this rigid one can be obtained by cutting one piece from the moving one. The flexible part and this firm one can be mounted by welding them to the hose that is going to be displaced through the holed hose.

CO_2, NOx, SO_2, and H_2O are the most common exhaust gases. These gases condense as a corrosive condensate when the temperature drops (Olofsson, 2012). Thus, the material that is going to be used is stainless steel as it can be very resistant in terms of corrosion.

4.3.2.1 Hose with holes

The idea is to buy the metallic pipe with no holes and then make it as the price will be lower than purchasing a holed hose. The holes are going to be done with the equipment that is in the Technobothnia laboratories. The holes are used, one for screwing this pipe to the fixed one placed currently in the laboratory and the others are used to allow the 115 mm hose to move through it. The requirement that this pipe has is to be resistant to the exhaust gases leaving the engines and have a diameter of 120 mm to fit in the actual extractor that has a 125 mm diameter.

So, one option is presented in the following Figure.

Figure 91. *Exhaust gas Tube, rigid, 120 mm (Trotec, 2022).*

It is a chimney pipe with a conical plug connection. Thus, is going to accomplish the function of extracting the exhaust gas from the engine that will be running in the lab at that moment. It is made out of aluminium which will resist the mounting and the exhaust gases passing through it. It costs 45.35 € (Trotec, 2022).

Another option is the pipe presented in the following Figure.

Figure 92. *Exhaust gas pipe acid-resistant 120 mm diameter (Puuilo. fi, 2020).*

This pipe would also accomplish the requirements. It costs 49.88 €, but, as the material is unknown and it is a little bit more expensive, the team has preferred to pick the pipe presented in Figure 91.

4.3.2.2 Interior moving hose

This pipe is the one that is going to move along the hose presented in section 4.3.2.1. It has a diameter of 115 mm. To this pipe, is going to be added the two metallic components that when pressed reduce its size and make this pipe able to circulate. One option is the pipe presented in the following Figure.

Figure 93. *Stainless Steel Tube 115 mm (Amazon, 2022).*

Another possible option is to work with the pipe presented in the following figure.

Figure 94. High Quality 32mm 115mm diameters UNS N06601 Nickel Alloy Inconel pipe (Alibaba.com, 2021).

The material from the second presented pipe (Figure 94) is Nickel Alloy which is resistant to the function that it has to accomplish to let the exhaust gases circulate through. It costs 42.26 € (Alibaba.com, 2021). Nevertheless, it has been decided to choose the pipe presented in Figure 93 as it is made out of a more resistant material against corrosion which is Stainless Steel. Furthermore, from this chosen pipe (Stainless Steel Tube 115 mm), the one-piece is going to be cut and welded after to the flexible curved part. This portion of the tube is going to be the one that is going to connect the exhaust gas pipe from the running engine at that moment in the lab. It costs 29 € (Amazon, 2022).

4.3.2.3 Metallic components to fix both pipes

These metallic components work with the following principle. When pressed, they have a spring mechanism that makes them decrease their length. Thus, this allows the metallic hose presented in Figure 93 to move across the holed pipe. They are mounted by being screwed into the stainless-steel tube.

Figure 95. *Hand Tight Nipple 1/4 NPT 3 inch long with Soft Tip - Brass (Amronintl, 2015).*

Another option is presented hereunder.

Figure 96. *CGA 540 Hand Tight Replacement Nipple (Aviationspares.com, 2020).*

The model presented in Figure 96, has free shipping but the minimum order is 100 €. Moreover, its diameter is 76.2 mm which is much bigger than the one needed for accomplishing the mounting (Aviationspares.com, 2020). Thus, the component chosen is the one presented in Figure 95.

These selected Tight Nipples have a diameter dimension of 6.35 mm. They are made of Brass which is a highly malleable material with enough resistance to support the burden that is going to receive in this mounting. Particularly these Tight Nipples have a working pressure of 206.8 bar, a value that is more than sufficient. Each Nipple has a cost of 15 €, so as two of them are needed, the total cost is 30 € but the shipping and taxes raise the cost to 84.38 € (Amronintl, 2015).

4.3.2.4 Flexible pipe

To provide more flexibility to the laboratory extractor, it has been decided to incorporate a flexible pipe in the curved part. This will allow making the system less rigid and in case any of the designed lengths that the system can adopt fits the engine that is mounted in the bed at that time. This component can make the connection between both extractors easily. This is the one presented in the following Figure.

Figure 97. *DN 25 ISO-KF Flexible metal hose MF, DN 25 KF, 250mm (Eurovacuum, 2019).*

The hose presented in Figure 97 has as main features that it remains in formable shape, it has fewer vibrations, it is mechanically formed and it is 100 % leak tested (Eurovacuum, 2019).

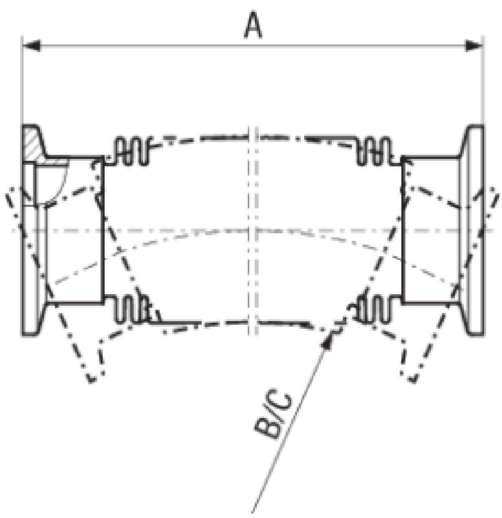


***Figure** 98. DN 25 ISO-KF Flexible metal hose MF, DN 25 KF principal dimensions (Eurovacuum, 2019).*

Figure 98 provides its principal dimensions which are described in the following table as well as its main specifications.

Table 32. Flexible metal hose MF, DN 25 KF dimension and specifications.

Technical data	
Type	DN 25 ISO-KF
Dimension A (mm)	250, 500, 750, 1000, 1500, 2000
Dimension C (mm)	115
C=	Radius for single bending
Internal pressure	Max. 4 bar
Material flange	Stainless steel 304
Material bellows	Stainless steel 316Ti

Source: Eurovacuum, 2019.

Another option is the one presented in the following Figure.

Figure 99. *Aluminium Flexible Hose 115mm 4.53" Alloy Flexi Pipe Air Ducting Tube Flexipipe (eBay, 2022).*

The pipe presented in Figure 99 is a good option for mounting the extractor as it has the required dimensions and is made out of aluminium which is resistant to the exhaust gases from the engines. It costs 56.52€ (eBay, 2022). However, as the flexible pipe presented in Figure 97 has further specs, it is going to be the chosen option. In the case of dimension, A, has to be shorter than the ones stipulated in Table 32. However, this is not a problem as the component can always be cut and then welded to achieve the specific needed length. This component has a cost of 62 € (Eurovacuum, 2019).

5. Results

5.1 Laboratory schematic view after the rearrangements

Once discussed the dimensions of the components and how much space is going to be available, a scheme corresponding to the final installation is presented (Figure 100). This scheme pretends to ease the comprehension of the whole installation and the magnitude it would have as an assembly of all the products in reality as it is not the objective of this thesis.

Figure 100. *Final installation scheme (Author's own).*

The existing laboratory engines or devices (such as the diesel injection system) can be appreciated in black colour. At the moment there are 4 engines in the lab, but to simplify the schematic process, both engines that are on the right side of the laboratory are shown as one big engine. The studied engine (SISU 420 DWI) is represented in the middle of the Figure between both black rectangles. Moreover, is considered that the installation of the gasoline engine will be in the same place as where the SISU engine is, so the middle rectangle represents both, the SISU engine and the Opel engine.

Once known the working capacity and the availability of space in the room, the gasoline injection device was made. The fuel tank, fuel consumption device and the gasoline filter were made in green colour (placed on the right side of the picture). The placement decision was explained in section 4.2.3, but to sum up, it was installed on the right side of the diesel injection system because it was the place with more space that was nearer to the engine.

The next studied installation was for the cooling system. As explained in the sections above, the main idea was to make a remote compatible cooling system for both motors. The cooling system is represented in purple colour. In addition, the measurements of the portable device are found as well in Figure 101. Furthermore, the purple zone may vary in the future as some bigger engines could be installed and the optimal placement could differ from the selected on the studied motors.

The last components assembled were the laboratory exhaust gas system pipes (represented in pink colour). These pipes are a continuation of the used nowadays but with some modifications that increase the modularity of the exhaust gas system. For instance, in the top view of the laboratory presented in Figure 100 and zoomed-in in Figure 101, the screws (represented as a mini rectangle) can be appreciated on both sides of the extractor pipe.

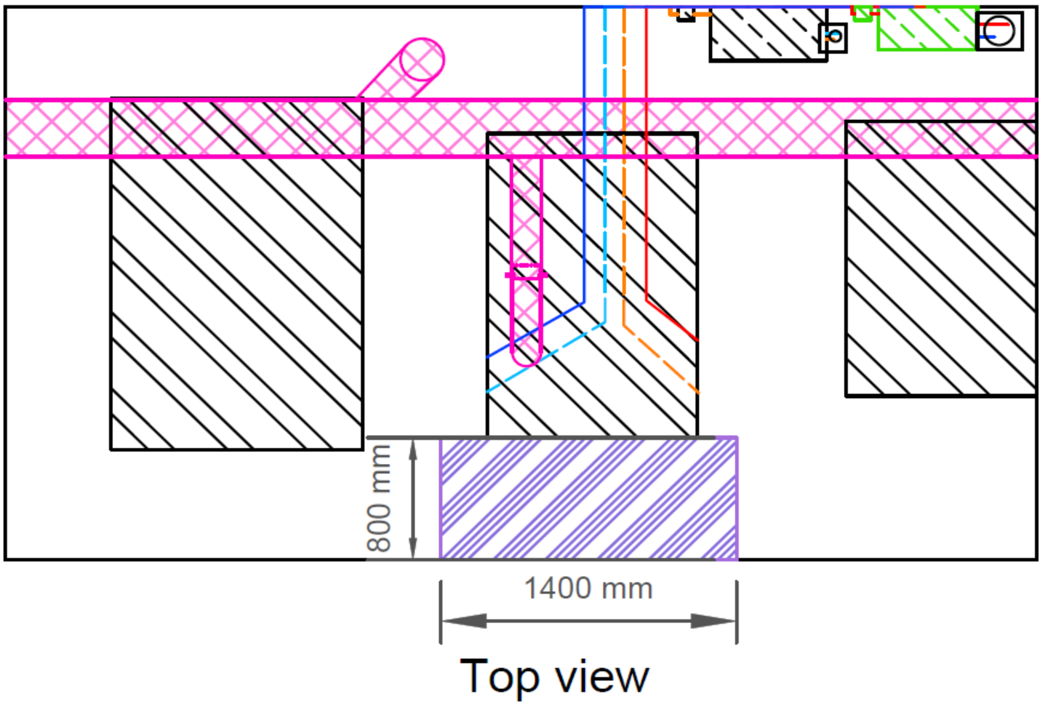


Figure 101. *Top view of the laboratory with the final installation components (Author's own).*

The function of the screws is to subject the pipe that catches all the gasses exiting the engine. Moreover, two nipples were installed to modify the length of the extractor pipe as it could extend or shrink providing more modularity and compatibility to the system.

5.2 Remote cooling module 3D design

Once all the components are determined, a 3D design of how the remote cooling module is going to be can be done. For this, it was also needed to take some measure of the space that is available in the laboratory to place it there. One of the requirements that have been taken into account is that between the radiator and the right wall of the laboratory has to be a minimum distance of 500 mm that as can be seen in Appendix II has been accomplished. In this section, the 3D model of the cooling module is presented in the following Figure.

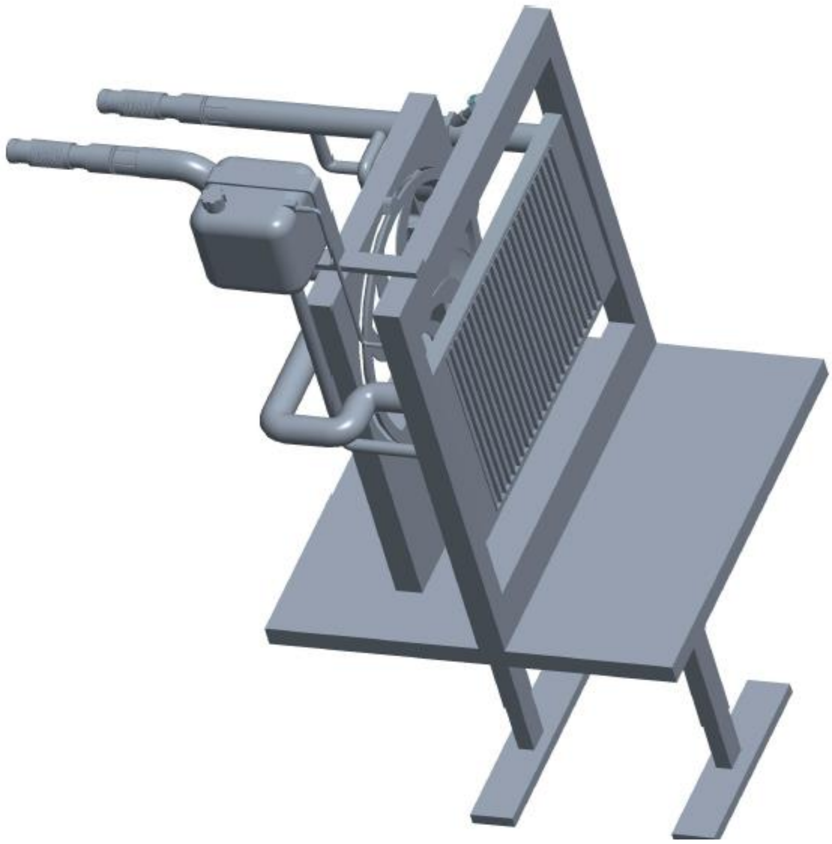


Figure 102. *Remote cooling module 3D design is done with Creo Parametric (Author's own).*

As Figure 102 does not provide details about the different components that the module has and its dimensions, further information is included in the Appendices. The top and the front view is provided in Appendix II. Moreover, the right and left ones are presented in Appendices III and IV. A detailed scheme of the radiator and expansion tank is added in the right view and one of the radiator fan in the left view. The different components that the module has are presented in Appendix V. Finally, because one of the key advantages of this remote cooling module was the ability to connect it to different engines, the height of the legs that support the module is variable depending on the dimensions that the engine mounted in the bed gas. This is demonstrated in Appendix VI, which has a design with two different elevations.

5.3 Extractor modification 3D design

Similarly, to the remote cooling module, after choosing the needed components, a three-dimension (3D) design of how is it going to be is done. As mentioned during the report, the main objective was to incorporate into the current extractor the capacity to vary its length. To achieve it, some measurements of the lab and the actual extractor has been done to adjust the scale of the 3D design presented in the following figure.

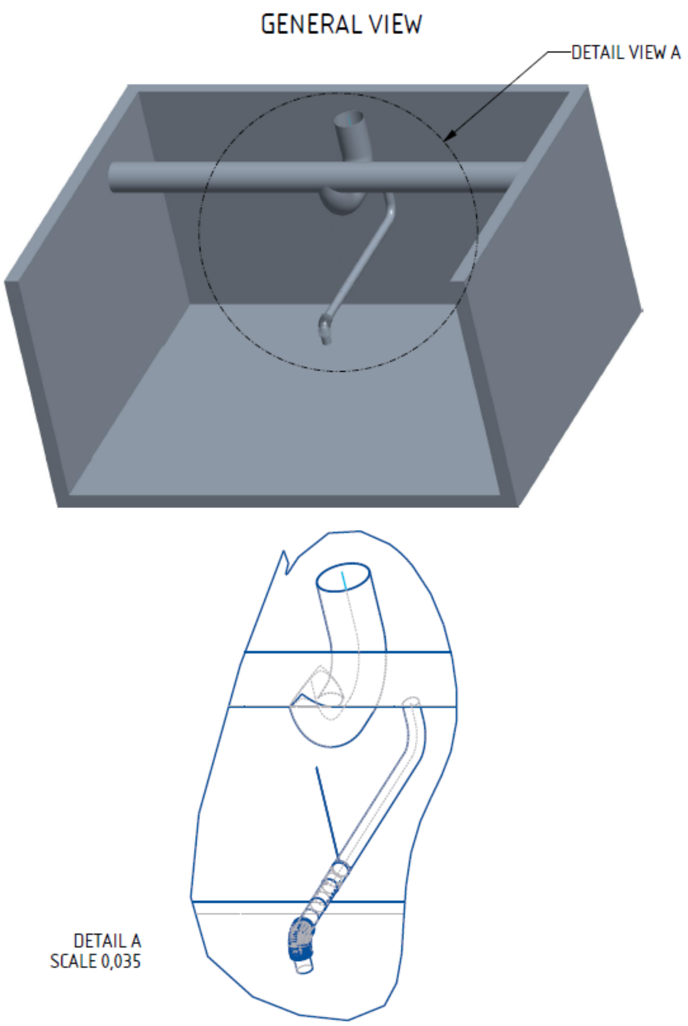


Figure 103. *Laboratory extractor 3D design is done with Creo Parametric (Author's own).*

The design of the extractor in the laboratory pretends to show schematically where is it placed in the laboratory and which form it has. Even though a detailed view (A) is presented, to make it more understandable, further detail about it is presented in the

Appendices. Appendix VII contains the top and front views. In addition, Appendix VIII has the left view. A detailed view of the ending part of the extractor designed in this project is incorporated, presenting the principal dimensions. Appendix IV lists the various components that make it up. Finally, because one of the primary benefits of this extractor was the possibility to make its length vary, two different configurations have been provided. The total maximum variation can be 200 mm, as there are 4 different holes separated by 50 mm, so it could adopt four different lengths. Appendix X contains a design with both positions exemplifying this.

5.4 Remodelling cost estimation

The economic feasibility of the project was one of the main things to have in mind when designing the whole system. Therefore, in this section, an approximation of the total cost of the selected components that are going to be used is presented. In addition, on one hand, it will be analysed the indicative cost that would have the project if picking all the cheapest components and on the other hand, the price that would has if chosen the most expensive options.

Amongst the following components, a criterion was applied to choose elements that took into account both performance and cost: fuel tank (35 litres), fuel feeding pump 2.6 l/min @ 3 bar, filter 5-micron, power supplier 12 V @ 17 A, 200-Watt, distributor fuel pump 5 bars @ 5.6 l/min, coolant radiator MERCEDES-BENZ SLS AMG Coupé, fan 850-Watt, water pump 43 l/min, normally open interrupter 90 ºC and various ancillary equipment including pipe, hose adapters and quick connectors. The cost of the optimal installation (selected components discussed in section 4) is 7124€. While the cheapest option is about 5604 € and the most expensive option costs 7782€. These costs are detailed in the tables presented in Appendix XII, Appendix XIII, and Appendix XIV.

First, analysing the cost of a gasoline injection system, there is one component that increases its cost considerably. It is the Mass Flow Meter and Fuel Temperature Control model AVL 735S /753Ce as it costs about 2439 €. Since the component could not be replaced with a less expensive replacement due to market unavailability, the team chose to use the same technology as the current SISU engine because of its proven outcomes.

Secondly, the remote coolant module is the most expensive portion of the project due to its complexity, since it requires more components. The choice of the Burkert Type 2702 Screwed Manual Throttling Valve, which costs 631 €, is a crucial factor that directly influences the total cooling system's cost. The Angle seat valve DIN-DVGW with backflow preventer DN25 is another choice for this component that costs 45 € and is significantly less expensive than the chosen option. The team picked the most expensive one to guarantee good performance because the chosen valve (Burkert Type 2702 Screwed Manual Throttling Valve) could handle a higher temperature range, from -10 ºC to 180 ºC. The alternative option considered (Angle seat valve DIN-DVGW with backflow preventer DN25) has a maximum working temperature of 90 degrees Celsius, which is insufficient for the system's requirements. Furthermore, the costs of cutting steel for the cabinet's construction components such as the coolant radiator MERCEDES-BENZ SLS AMG Coupé, the water pump 43 l/min, and the fan 850 Watt are ignored as they may be done in Technobothnia facilities.

Finally, the cost of the exhaust gas system is more equal between the least and most expensive options, with just a difference of 40 €. Because the many components investigated, such as the 125 mm diameter holed pipe, the displacing internal tube, the nipples, and the flexible pipe, only differ in external treatment but the main structural materials have very similar properties, the cost does not vary that much.

The installation costs are not included in the three parts of the thesis because the University's specialists could handle the operation without incurring additional costs.

6. Discussion

In this chapter, it will be examined whether the primary objectives were met, as well as the results' validity, by placing the findings in the perspective of past research and theory. Finally, the limitations, consistency concerns, and contradictions of the study will be addressed.

In terms of the thesis' initial goals and objectives, the results indicate that the main purpose of the project which was to develop a remote cooling module has been achieved. This objective was analysed in section 2.2 when a study background of the importance of the cooling systems, the types that nowadays exist and their principal components is conducted. The relevance of installing it in the laboratory is huge. It can work with both, diesel and gasoline types of engines. This has been possible after finding the proper refrigerant which is compatible with these two types of motors. Another important point was to provide it with the capacity to cool down different types of engines with various output power values. Here, to accomplish it, the decision taken by the team has been to oversize the unit. In terms of 3D design, the final result was satisfying, as it was able to develop all the needed components and connect each other to see how would it look. Moreover, it was also important to ensure that it accomplishes the space limitations that the laboratory has. Finally, comprehensive documentation about the different views of the module is as well included in the report to understand easily the assembly done.

Another goal was to design a gasoline fuel injection system that could be used in the laboratory with the Opel engine as currently there is only a Diesel installation. Chapter 4.1 presents several components that could be useful based on the current state of the engine presented in section 3. More precisely, focused on the unit that is built now for the diesel one, which is discussed in section 3.1.1. The goal was accomplished by selecting the best pieces and putting them in a 2D design to demonstrate how they would be integrated into the laboratory.

The final objective was to develop a model of the extractor that is currently in the lab. This one is linked to the most significant goal (developing the remote cooling system) and is thought to give the laboratory more versatility as discussed in section 4.3.1. This simulation was successfully conducted using Creo Parametric, allowing the extractor to adjust its length up to 200 mm if needed.

Concerning other published work, the team has spent a significant amount of time determining which components are required to provide gasoline to the engine, as in the case of Kiss, *et al.* (2014). However, unlike the study conducted by Hung, *et al.* (2009), this project does not include electronic control of the gasoline injection into the engine to manage the system and provide convenient data collecting. Besides the cooling system, according to Hosoz and Kilicarslan (2004), water-cooled systems are much better for the types of engines researched in this project because they are far more efficient. Furthermore, water-based refrigerant units are less expensive than air-cooled systems, according to Yang *et al.* (2020). This is a crucial issue because the installation cost must always be taken into account. The fundamental problem with the extractor in the third section, which is based on the exhaust gas system, is related to its constant dimension, as Shaheen *et al.*, (2020) mentioned. So, since the exhaust gases cannot be thrown away, this fact compromises the ability to run different engines in the laboratory.

The reliability of the results of the project is impacted by some impediments experimented while taking measures of some of the different parts of the laboratory and from the engines. The main reason was due to its inaccessibility or because the placed engines in the laboratory did not permit accurate measurements. However, it has not affected the aim of the thesis as the three different designs have been developed with no problems. This is because the most important measurements had been taken to know which are the most important features that the designs must-have.

Furthermore, the project has run into problems while studying the various components needed to complete the 3D designs. Due to a lack of resources and permits to seek components in professional companies in the numerous areas covered by the thesis, some of the components chosen are not optimal. Additionally, some of the components chosen were not available in Finland and must be imported from other countries. As a result of the shipping and import duties, the price increases. An average percentage increase in the basic price owing to taxes and shipping of the components, according to Ryan (2022), is roughly 30%. The fuel feeding pump is a component where the team encountered greater issues. It has only been found in the United States, and there is no cost-effective way to get it to Finland. As a result, the team has decided to put out an effort into this component, as it is a critical device for the fuel injection system. However, all of the design's necessary components have finally been found. These have great specifications and a reasonable price, to be sure. So, despite having this problem, the team was able to accomplish the thesis' initial targets by putting in more hours of labour than those previously established for component search and selection.

In terms of consistency and inconsistencies, it is worth noting that as previously stated, an electronic monitoring system for the petrol injection system is missing, as it is incorporated for the SISU Diesel engine. It would be necessary to incorporate it into the gasoline engine to know its consumption based on its operation and to be able to study it in detail to optimise the speed at which the different simulations are carried out in the laboratory. It must be said that this was not one of the objectives of the thesis, but if we had had more time, it would certainly have been the next thing to be incorporated. Even so, the team has tried to control this aspect and to know the fuel consumption and other important parameters such as the oil temperature. This is achieved thanks to the AVL meter explained in section 4.1.1.4 Fuel Balance and Fuel Temperature Control. After all, the project's achievements, are a big upgrade of the current Technobothnia laboratory facilities in terms of incorporating a gasoline fuel injection design, a cooling system that can be connected to the engine working there at that moment and a length adaptable exhaust gases extractor. Moreover, its progression has been exhaustively reasoned in earlier sections, ensuring that they are consistent with the aims and objectives accomplished.

To sum up, because of the need to remodel some parts of the running SISU Diesel engine to make it more flexible, the goals were met, and the setup has improved noticeably. As a result of this, the provided 3D designs presented in the Appendices show the improvements made.

7. Conclusions

The actual laboratory lacks a gasoline engine which is very common in actual cars and is widely used around the world. The objective was to integrate a gasoline motor into the lab and all the components required to keep the engine running at high efficiency. However, due to the lack of knowledge and the great amount of work that the initial objective supposed, the work was divided into subgroups and just some of the auxiliary components are studied in this project. Therefore, the plan in mind was to create a gasoline injection system, a cooling system compatible with both engines and upgrade the exhaust system for running more engines in the actual bed. Moreover, all the systems designed have been oversized to achieve high-efficiency rates if bigger engines are installed.

The Gasoline injection system has been decided to be mounted on the right side of the laboratory next to the Diesel injection system. The placement of the system is because the water pipes already installed on the wall do not allow to place it just in front of the engine that is going to be run in the bed where the actual SISU 420 DWI is placed. Therefore, the right-side alternative was chosen because it boosted engine efficiency by reducing the distance travelled by fuel from the gasoline tank to the engine.

The components that integrate the gasoline injection system were carefully selected using criteria of performance, and cost and modelled on similarly sized Opel vehicles. The gasoline system included the following devices: Fuel Tank (35 L), Fuel Feeding Pump 1.6 L/min @ 3 bar, Filter 5-micron, Power Supplier 12 V – 200-Watt, Mass Flow Meter and Fuel Temperature Control model AVL 735S /753Ce, High-Pressure Pump @ 2.75 - 8.3 bar, 18 mm to 10 mm adapter, 12 mm to 10 mm adapter, 10 mm hose and quick connector (10 mm diameter). The total indicative cost of the gasoline injection system is 3202€.

Another objective was the modularity and the compatibility of the cooling system for both engines and future motors installed in the laboratory. The actual cooling system used on both engines was very simple and it was not the optimal option, therefore, a redesign of the cooling system for both motors was made. The solution was to use a height-adjustable table with wheels incorporated into it to make it mobile. Furthermore, a 3D design of the cooling system was made with all the selected components included. In this design, the supports that hold components such as the radiator or the fan are made of stainless steel. As it is used to make motor parts, it will withstand high temperatures in case it touches hot areas of the cooling module. Additionally, stainless steel is easy to acquire because of its popularity. The selection criteria of the components are the same as those used for gasoline injection systems and most of the components are over-dimensioned to ensure that the engine can run smoothly and the cooling system could be compatible with bigger engines that could be installed in the future. The components that comprise this system are the MERCEDES-BENZ SLS AMG Coupé radiator (434 W heat capacity), a fan 12 V @850 W, a water pump 12V @72 W, a coolant (from -69 ºC to 175 ºC), a 50 mm steel and rubber hose, the thermostat, the expansion tank (190x190x190 mm), the throttling valve (maximum temperature of 180 ºC), a temperature sensor (from -40 ºC to 150 ºC), a 50 mm aperture quick connector, and the portable device. All these components have an indicative cost of 3701 €.

The last system studied was the laboratory exhaust system. The main plan was to elaborate a design that used most of the actual exhaust gas pipes that are currently in the laboratory. The team came up with the solution to add an adjustable pipe that could vary its length with a pair of nipples. This pipe is connected to the existing extractor main pipe used for the current SISU engine; therefore, the installation costs are minimum. Also, the gas entry into the system is remade as an adjustable flexible pipe that is used to ensure maximum compatibility in case different engines are installed in the future. In this case, the selection criteria differed from the other modules because the components used are not common in a road vehicle. Therefore, we ensured that the materials and dimensions of the pipes selected were suitable for safe exhaust gas ventilation. The indicative cost for the fabrication components is estimated to be 221 €.

Moreover, to create high compatibility of every system designed with other engines, quick connectors were used, so, the pipes could be disconnected from the system and others could be connected easily.

Also, there is an analysis of all the costs of the installation, from the price of the components to the cutting and welding of steel to create the supports for the cooling system. It is important to mention that some costs are avoided as in Technobothnia’s facilities there is the possibility to do these types of operations and could be achieved without any cost (cost of the working personnel). The costs presented on the document are with the VAT (Value Added Tax) which increased the cost of every piece. Furthermore, the shipping costs raised the total cost as most of the components were acquired online on foreign pages.

All the components selected raised a price of 7124 €, which is 1520 € more expensive than the cheaper option. Nevertheless, this option has been selected to ensure the correct operation of future engines installed in the laboratory.

All the objectives planned at the beginning of the thesis were satisfied. Furthermore, 3D and 2D schemes were made to ease the lecture and the understandability of the project. Moreover, the university could consider this thesis as an upgrade for the engine laboratory and could study the feasibility of the elements of the systems designed. In addition, an improvement of the cooling system for the SISU engine is made with the portable device idea as it will increase the efficiency of the engine and can be placed wherever the personal want. And, if the university chose to put a different engine in the lab, the idea from our thesis could be implemented to make the present extractor more versatile by allowing it to adapt to four various lengths.

8. References

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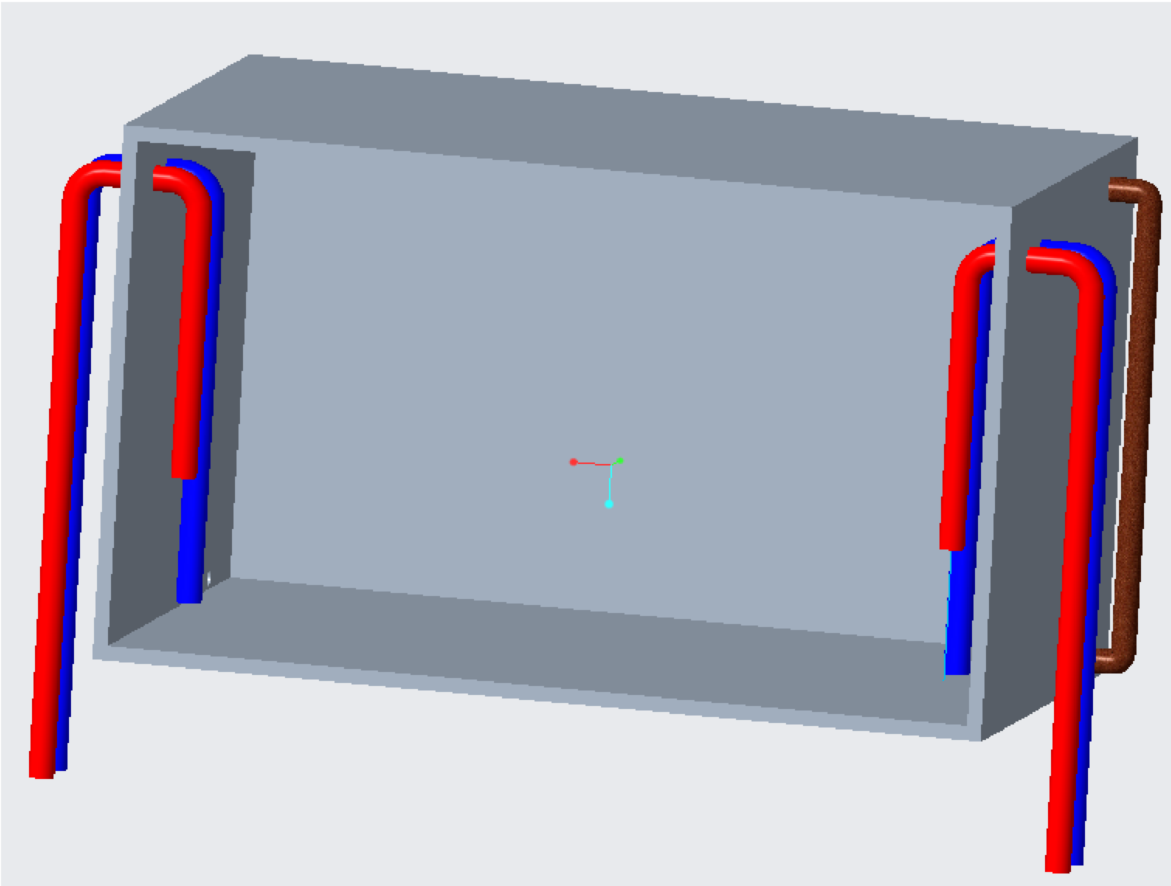
9. Appendices

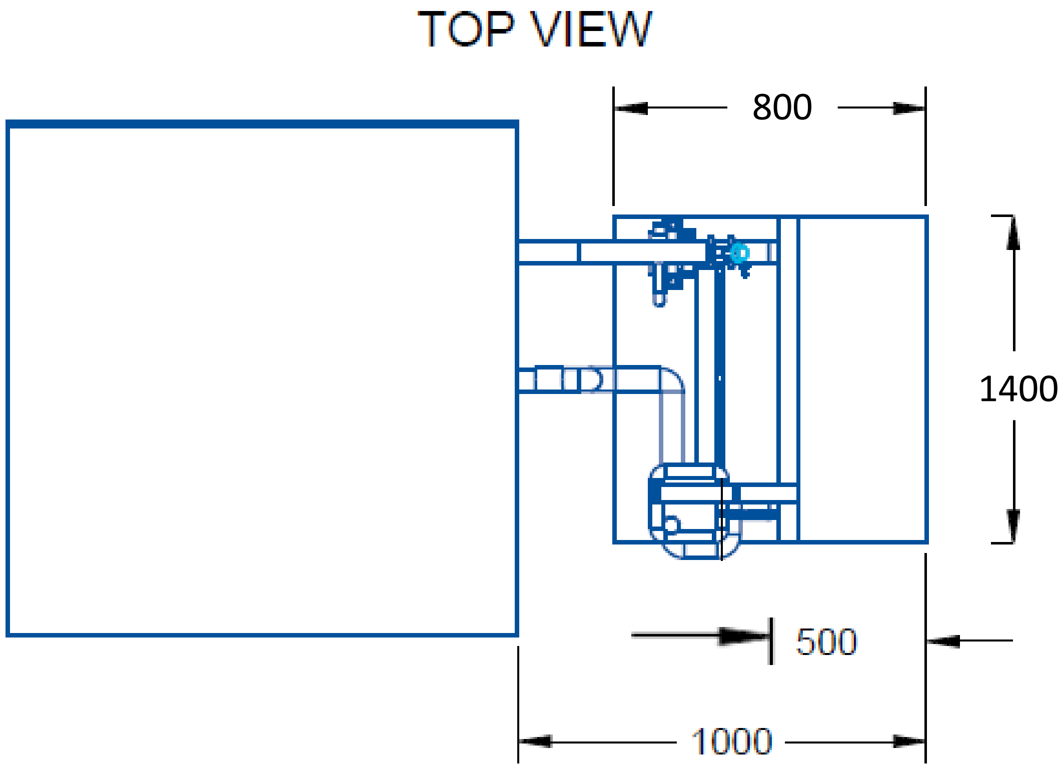
Appendix I: Fuel tank inside view.

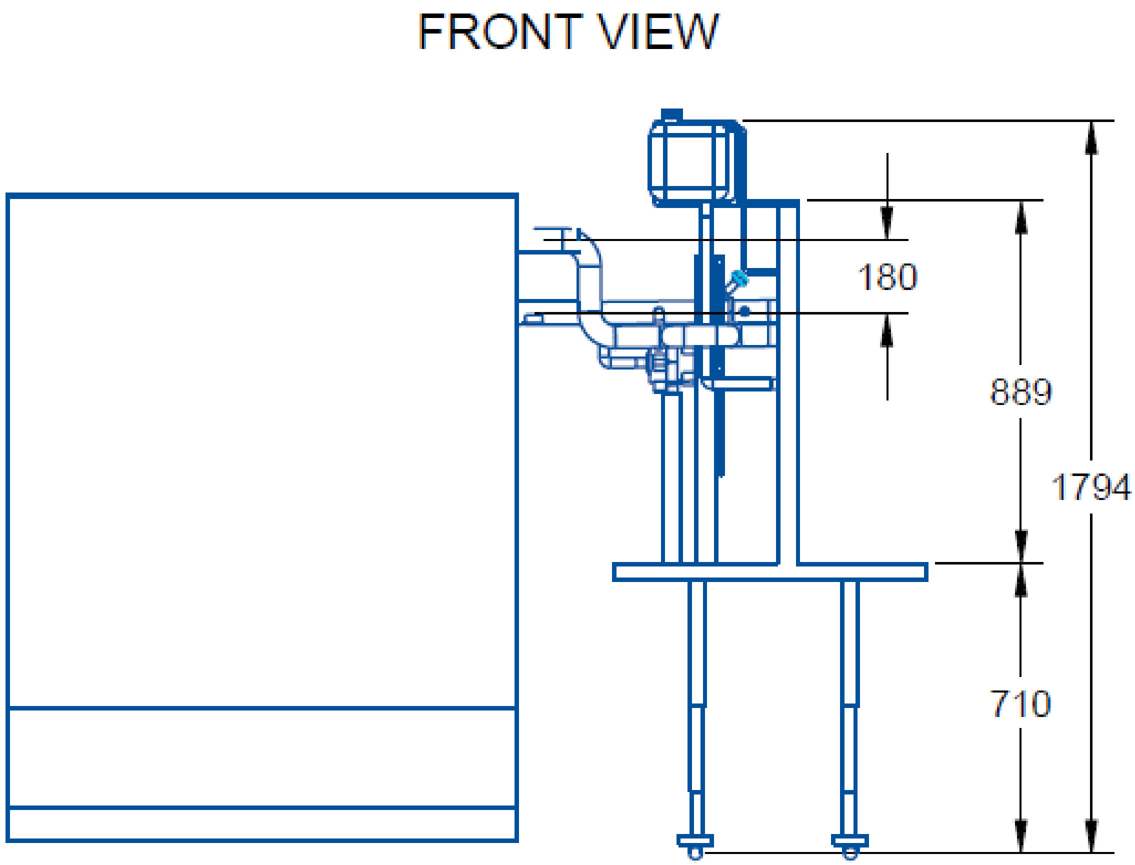
Scheme of the inside of a fuel tank device where it shows the deepness of the inlet (red) and outlet tubes (blue).



Appendix II: Top and Front view - cooling module.

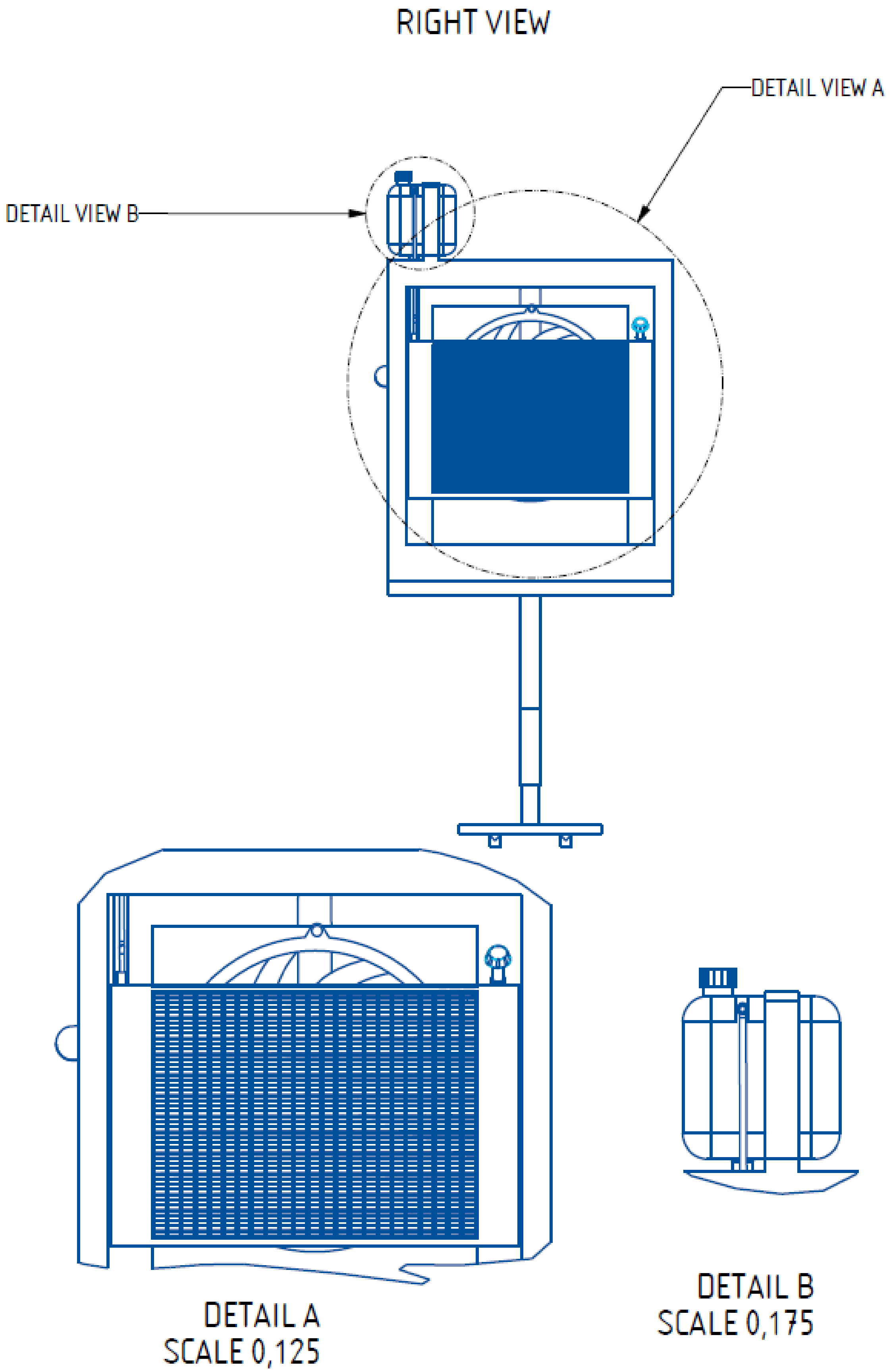
The dimensions are in mm.





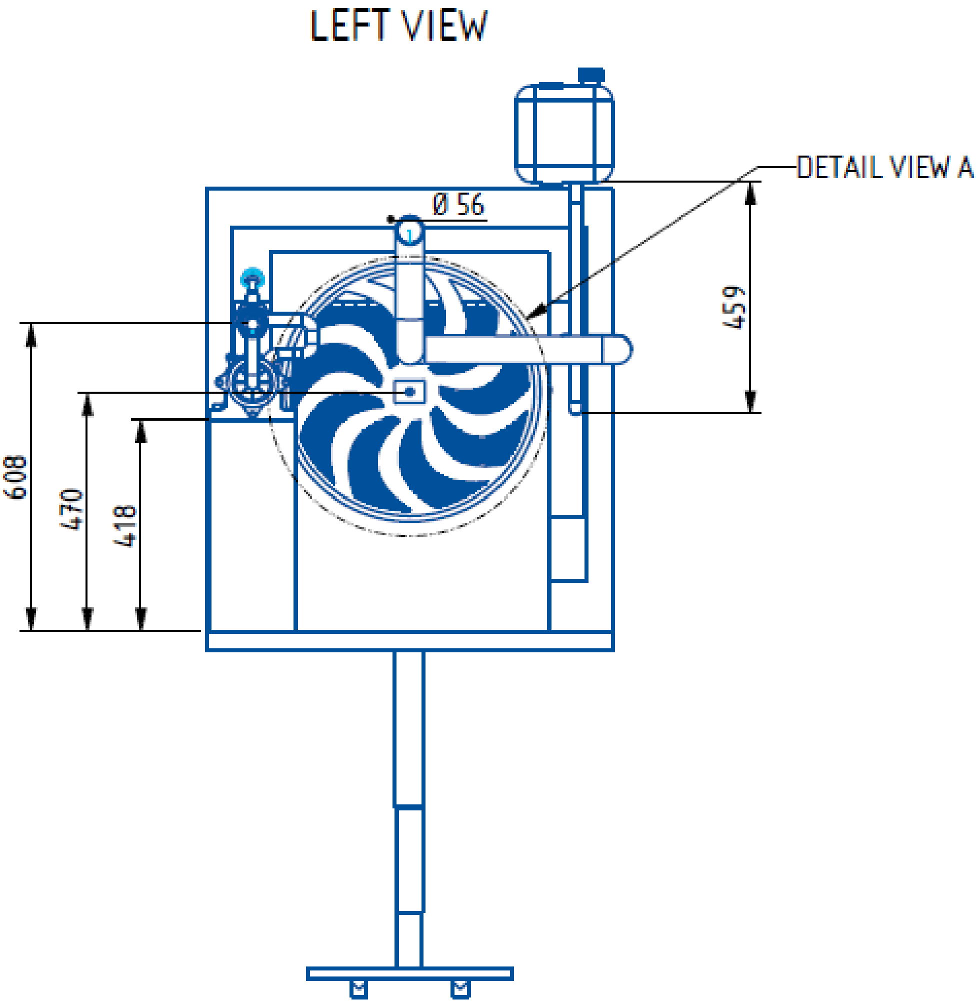
Appendix III: Right view - cooling module.

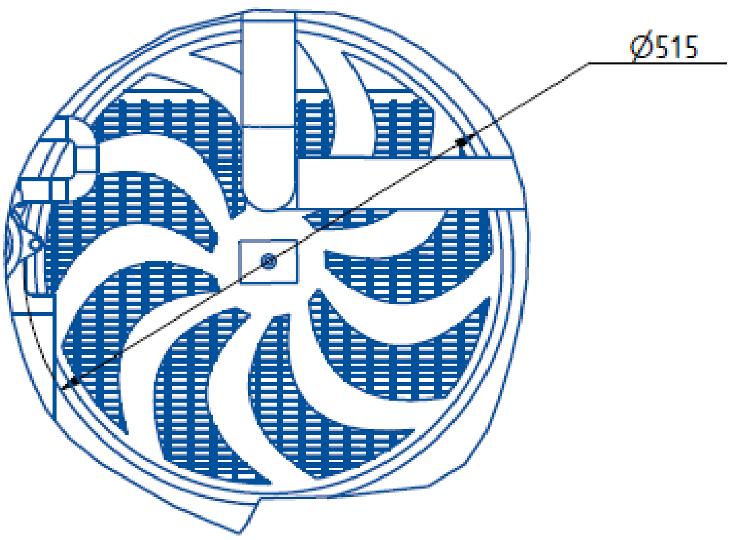
Detailed views of the radiator and the expansion tank are presented. The dimensions are in mm.



Appendix IV: Left view - cooling module.

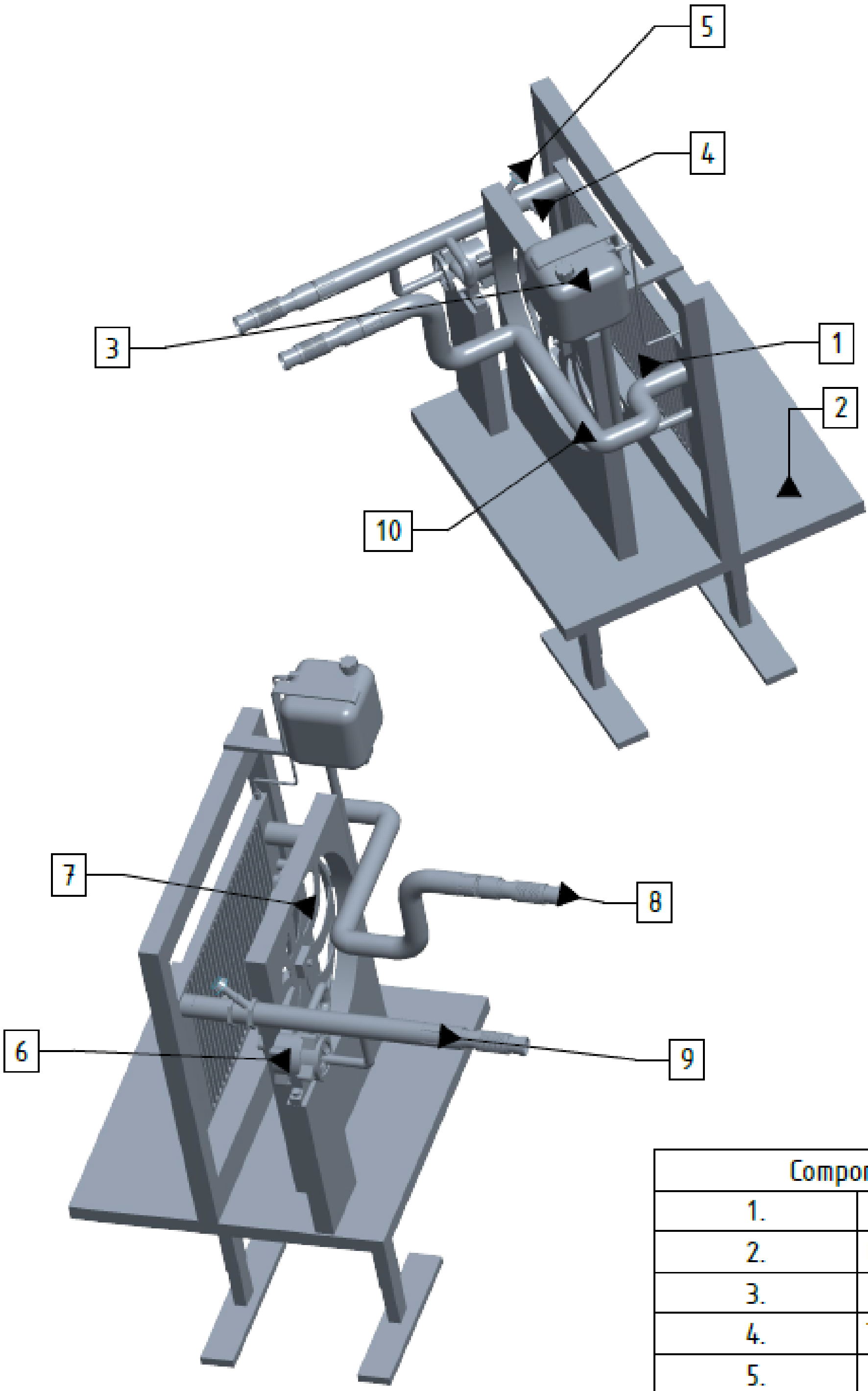
Detail view of the fan is presented. The dimensions are in mm.





DETAIL A
ESCALA 0,150

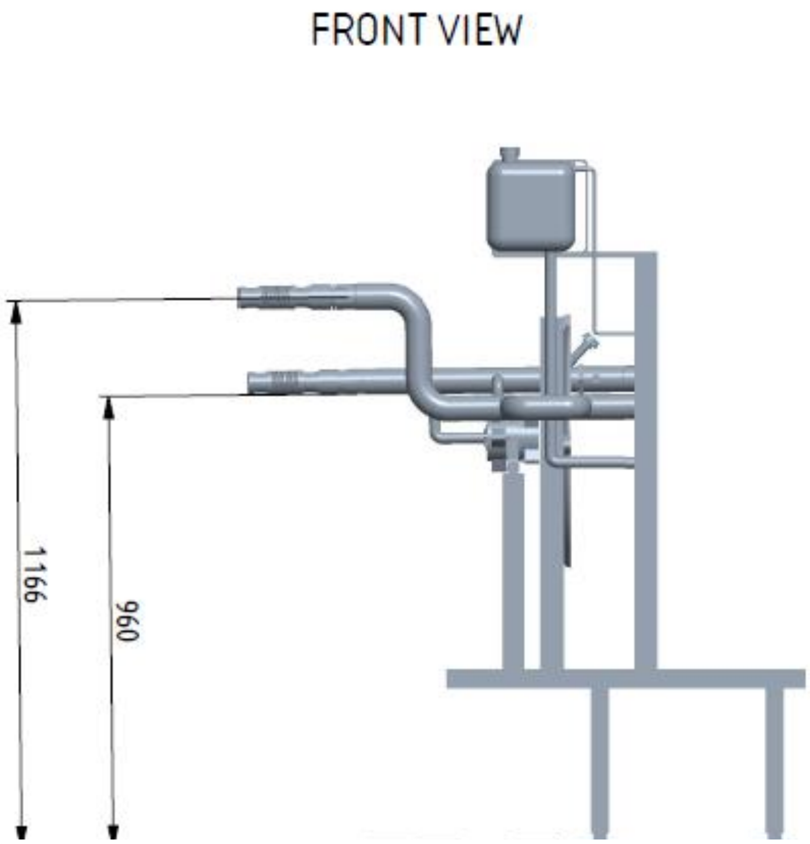
Appendix V: Components list remote cooling module.

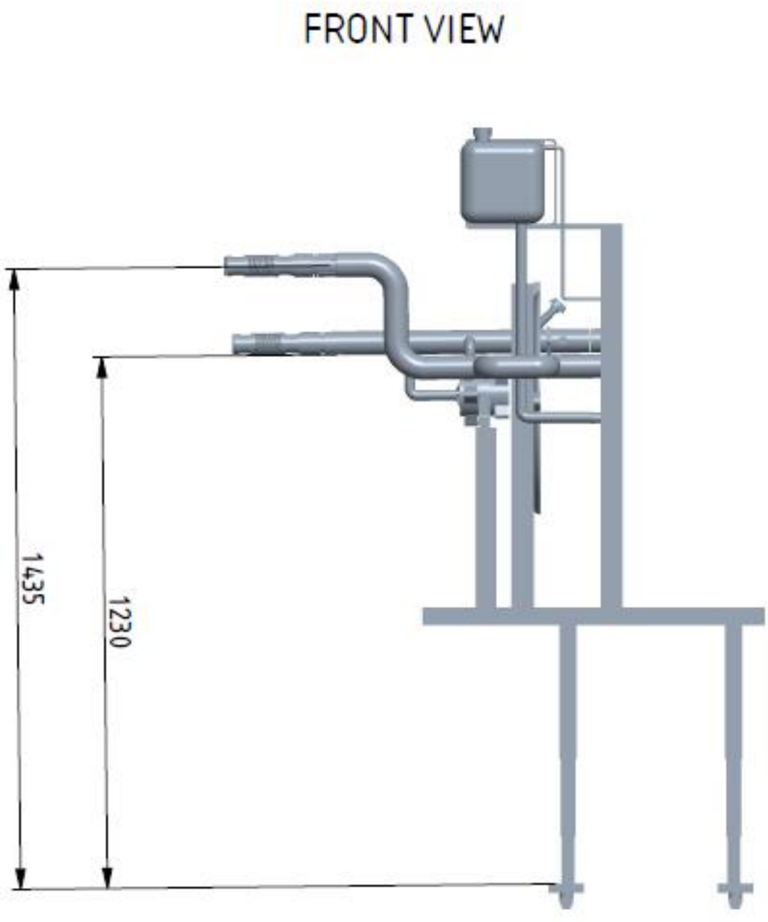


Components	
1.	RADIATOR
2.	MODULE SUPPORT
3.	EXP. TANK
4.	TEMP. SENSOR
5.	PISTON VALVE
6.	WATER PUMP
7.	FAN
8.	MALE CONNECTOR
9.	FEMALE CONNECTOR
10.	HOSE

Appendix VI: Cooling module adaptability.

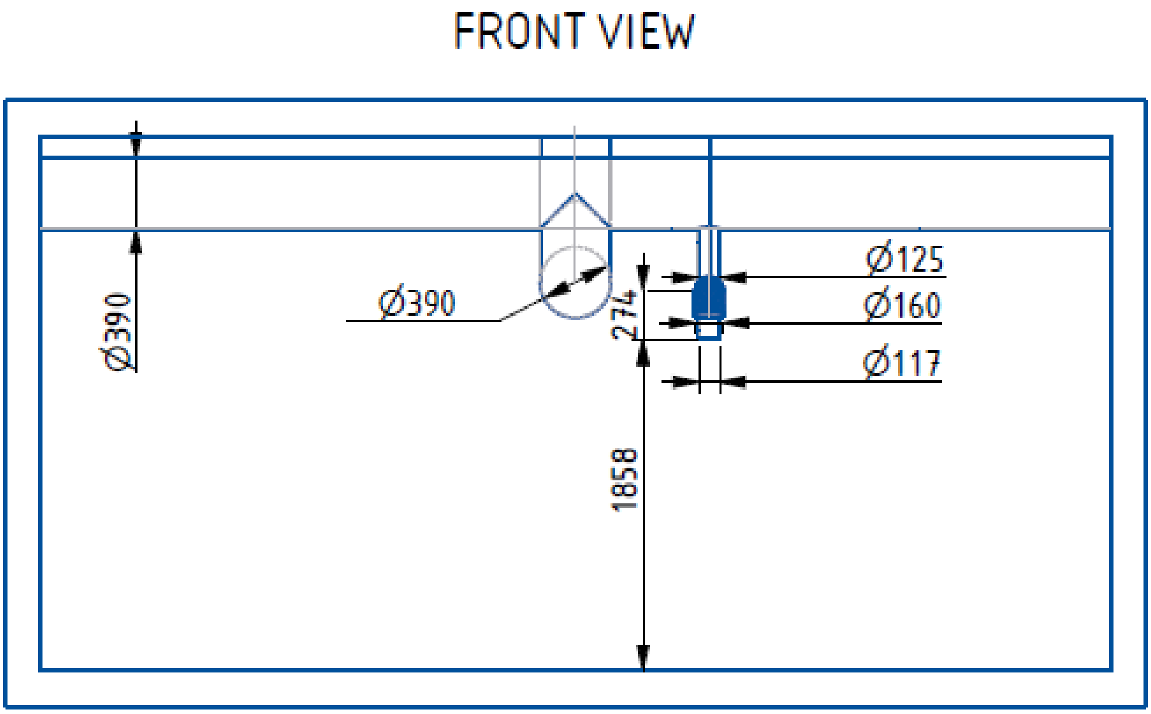
Schematic representation to show the different heights that the supporting legs of the module can adopt. The dimensions are in mm.

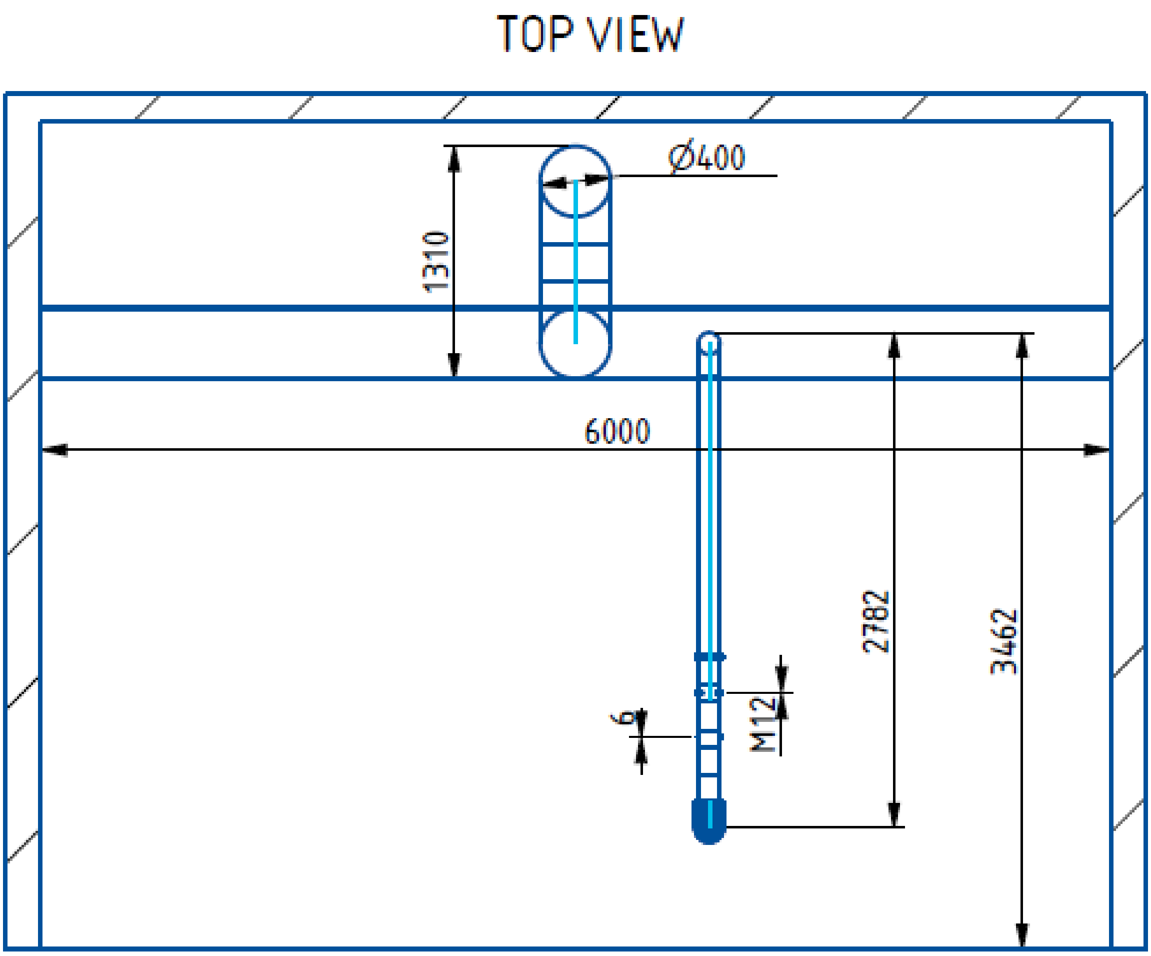




Appendix VII: Front and top view - extractor.

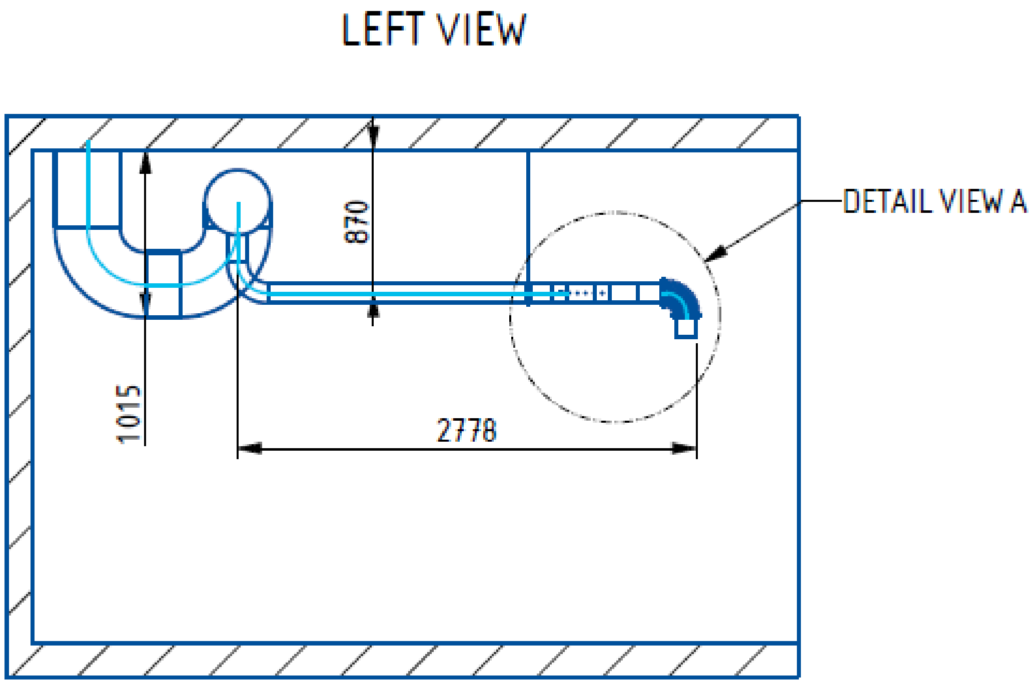
The dimensions are in mm.

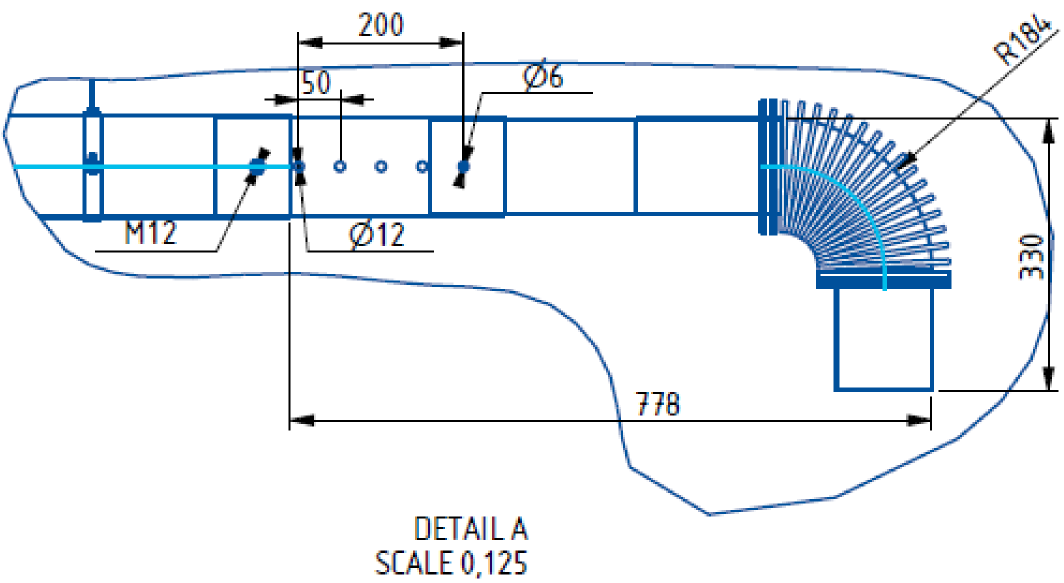




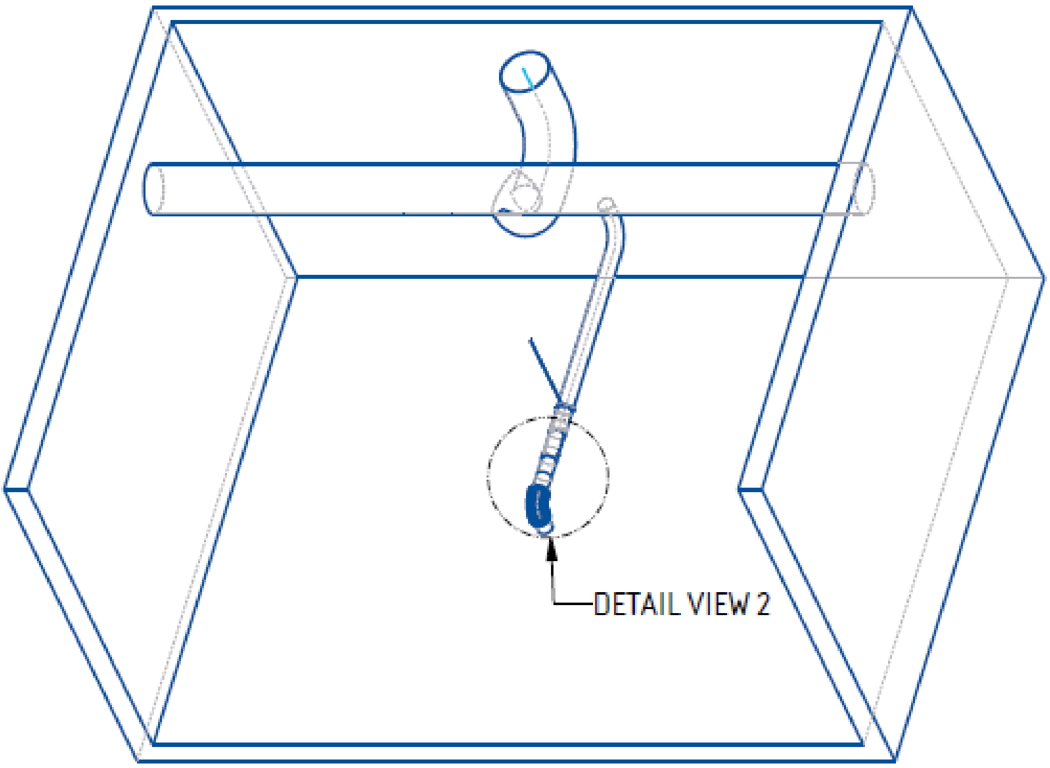
Appendix VIII: Left view - extractor.

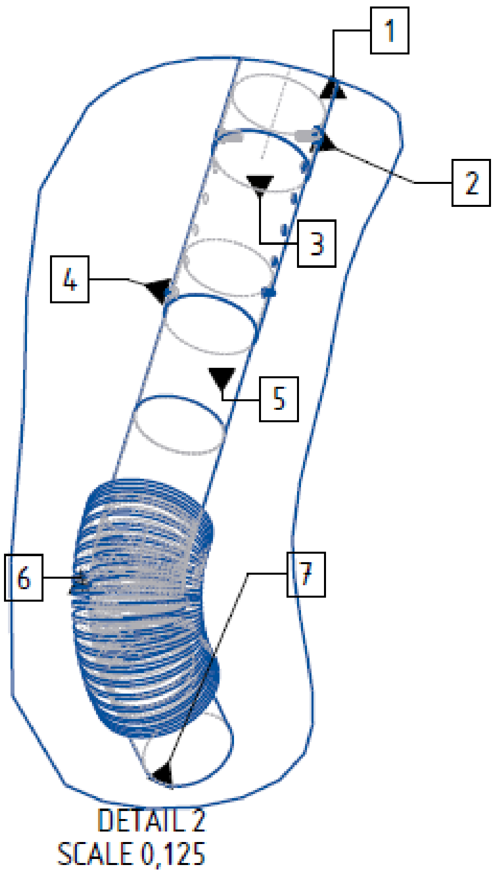
Detailed views of its ending part. The dimensions are in mm.





Appendix IX: Components list extractor.



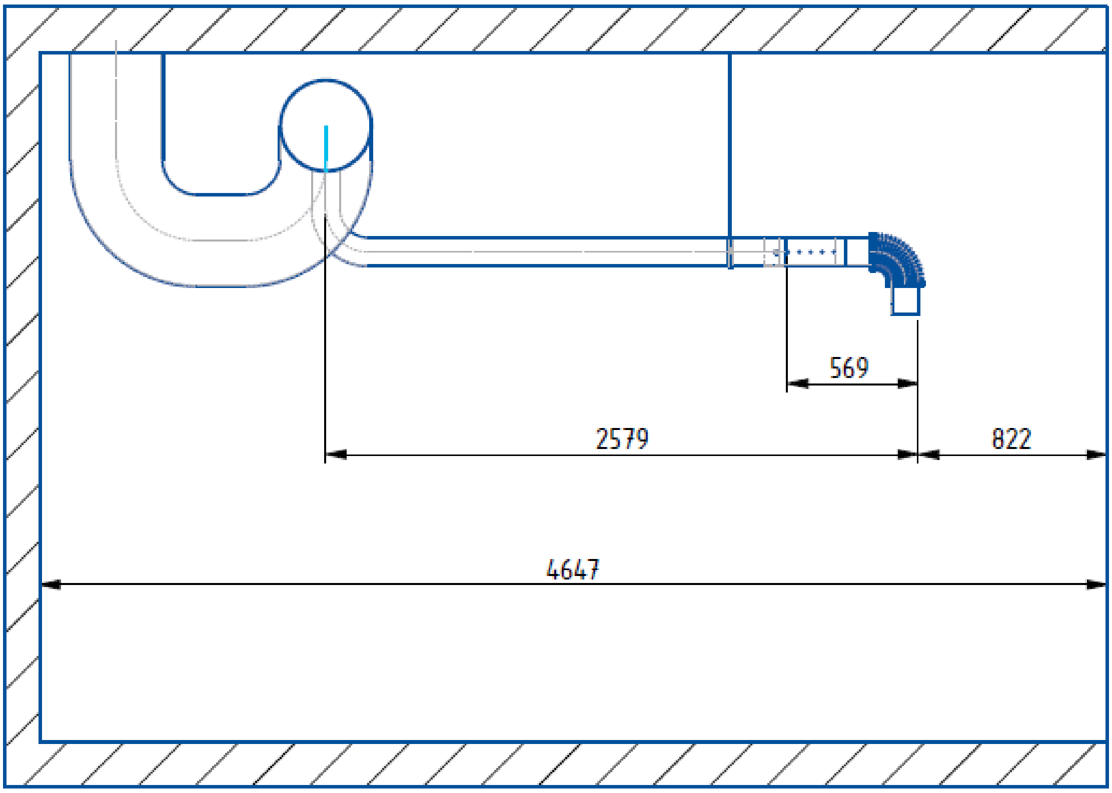


COMPONENTS	
1.	ACTUAL PIPE
2.	SCREWS M12
3.	HOLED PIPING
4.	NIPPLE
5.	PIPE
6.	CURVED PIPING
7.	END PIPE

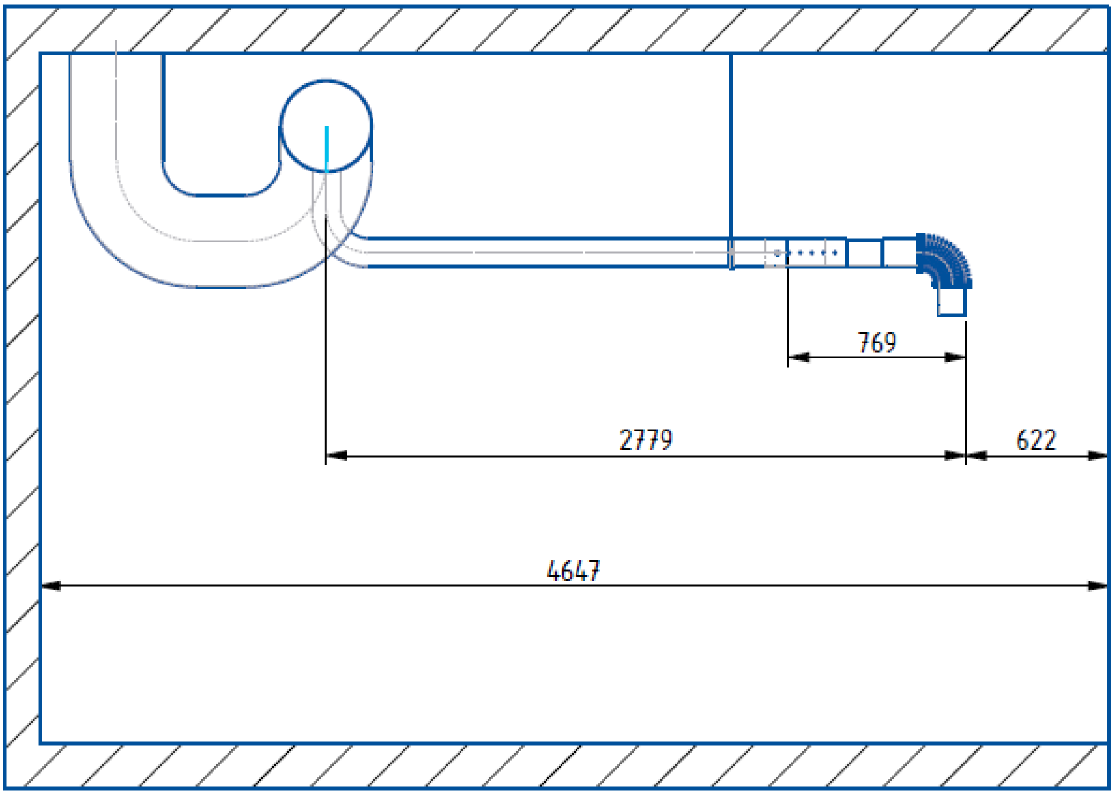
Appendix X: Extractor adaptability.

Schematic illustration of two different lengths that the extractor can adopt.

LEFT VIEW



LEFT VIEW



Appendix XI: Structure cost - cooling module

Budget of the components that support the remote cooling unit.

Component	Price with VAT and shipping costs
304 stainless steel plate to recover the table surface	277.92 €
304 stainless steel plate to support the radiator	238.4 €
304 stainless steel plate to support the fan	404.56 €
304 stainless steel plate to support the pump	57.25 €
304 stainless steel bars to support the expansion tank	2.96 €
304 stainless steel bars to support the expansion tank	1.92 €

Operation	Price
Cutting of the radiator support	Done in Technobothnia laboratories
Cutting off the fan support	Done in Technobothnia laboratories
Cutting of the expansion tank support bars	Done in Technobothnia laboratories
Welding of every component	31 € per kg needed in an experimented Company or done in Technobothnia laboratories.

Appendix XII: Total cost of the installation.

In the following table appear the list of the selected components with their cost (including VAT).

COST OF THE COMPONENTS SELECTED	
Gasoline injection system	
Component	**Price**
Murray Motorsport Fuel Tank 7.7 Gallon - 35 Litre	322.42 €
WALBRO GSL Fuel Pump 160LPH	240,2 €
KAMOKA F322501 fuel filter	27.55 €
Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C	2438.7 €
AEM's 400lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009)	55 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply	37.18 €
Straight Barbed 18mm to 10mm Hose Pipe Connector Tube Fitting Fuel	3.2 €
Straight Barbed 12mm to 10mm Hose Pipe Connector Tubing Fitting Fuel	4 €
1/4" quick coupling with ball bearing: Female and spout for 10mm hose, 112C31S, 01995	8.42 €
FUEL HOSE 10MM from Biltema	64.80 €
TOTAL	**3202 €**

COST OF THE COMPONENTS SELECTED	
Cooling system	
Components	**Price**
NRF Radiator, engine cooling Aluminium 59133	262 €
NRF 47853 fan	631 €
SHENPENG P6216 12v electric coolant pump	53 €
Universal coolant Glycol Purple G13	18.31 €
Stainless Steel Flexible Hose Pipe	65 €
24232 2" X 3FT GS 2 PLY STRAIGHT EPDM hose	119 €
Disc thermostat 3F11- 325	52.19 €
Schmiedmann expansion tank	57.6 €
Burkert Type 2702 Screwed Manual Throttling Valve	631 €

RIDEX 830C0064 Coolant Temperature Sensor	14 €
Quick Connector PE Plastic 50mm Diameter Ball Valve, Water Tube Fitting, Ball Valve Hose Fitting	43 €
Cast iron red tyre with steel housing x4	327.7
Variable-length RODULF sitting/standing desk	319 € + 0€ if collected at the IKEA store 319 € + 25 if collected at an IKEA collection point **319 € + 50 € if they bring the component to the facilities**
304 stainless steel plate to recover the table surface	277.92 €
304 stainless steel plate to support the radiator	238.4 €
304 stainless steel plate to support the fan	404.56 €
304 stainless steel plate to support the pump	57.25 €
304 stainless steel bars to support the expansion tank	2.96 €
304 stainless steel bars to support the expansion tank	1.92 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply x2	74.36 €
PVC hub to hub reducer coupling pipe adaptor 50mm x 20mm	15.21 €
TOTAL	**3701 €**

COST OF THE COMPONENTS SELECTED	
Laboratory exhaust gas system	
Components	**Price**
Exhaust gas Tube, rigid, 120 mm	45,35 €
Stainless Steel Tube 115 mm	29 €
Hand Tight Nipple 1/4 NPT 3 inch long with Soft Tip - Brass	84.38 €
DN 25 ISO-KF Flexible metal hose MF, DN 25 KF, 250mm	62 €
TOTAL	**221 €**

TOTAL COST OF THE PROJECT
7124 €

Appendix XIII: Hypothetic most expensive cost of the installation.

The total cost of the installation with the most expensive components and the price (including VAT) of each included.

COST OF THE MOST EXPENSIVE COMPONENTS	
Gasoline injection system	
Components	**Price**
A H Fabrications 8 Gallon Racing / Competition / Track Alloy Fuel Tank - 028	507 €
WALBRO GSL Fuel Pump 160LPH	240,2 €
FILTRON PE 946/6 fuel filter	54 €
STARK SKFP-0160089 Fuel Pump	180 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply x3	37,18 €
Straight Barbed 18mm to 10mm Hose Pipe Connector Tube Fitting Fuel	3.2 €
Straight Barbed 12mm to 10mm Hose Pipe Connector Tubing Fitting Fuel	4 €
Parker Steel Hydraulic Quick Connect Coupling female	53.32 €
Parker Steel Hydraulic Quick Connect Coupling male	84.5 €
FUEL HOSE 10MM from Biltema	64.80 €
Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C	2438.7 €
TOTAL	**3667 €**

COST OF THE MOST EXPENSIVE COMPONENTS	
Cooling system	
Components	**Price**
Mercedes Sprinter Radiator - 26 5/8 x 15 5/8 x 1 Core	376.58 €
NRF 47853 fan	631 €
BOSCH universal auxiliary electric water coolant pump 0392020034	108.7 €
Mannol AF12+ MN4012-5 Antifreeze coolant	32.64 €
Stainless Steel Flexible Hose Pipe	65 €
24232 2" X 3FT GS 2 PLY STRAIGHT EPDM hose	119 €
90°C Normally Open Thermostat Thermal Temperature Switch NO	11.5 €
Schmiedmann expansion tank	57.6 €
Burkert Type 2702 Screwed Manual Throttling Valve	631 €

RIDEX 830C0064 Coolant Temperature Sensor	14 €
Quick Connector PE Plastic 50mm Diameter Ball Valve, Water Tube Fitting, Ball Valve Hose Fitting	43 €
Cast iron red tyre with steel housing x4	327.7
Variable-length RODULF sitting/standing desk	319 € + 0€ if collected at the IKEA store 319 € + 25 if collected at an IKEA collection point **319 € + 50 € if they bring the component to the facilities**
304 stainless steel plate to recover the table surface	277.92 €
304 stainless steel plate to support the radiator	238.4 €
304 stainless steel plate to support the fan	404.56 €
304 stainless steel plate to support the pump	57.25 €
304 stainless steel bars to support the expansion tank	2.96 €
304 stainless steel bars to support the expansion tank	1.92 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply x2	74.36 €
PVC hub to hub reducer coupling pipe adaptor 50mm x 20mm	15.21 €
TOTAL	**3860 €**

COST OF THE MOST EXPENSIVE COMPONENTS	
Laboratory exhaust gas system	
Components	**Price**
Exhaust gas pipe acid-resistant 120 mm diameter	49.88 €
High Quality 32mm 115mm diameters UNS N06601 Nickel Alloy Inconel pipe	42.26 €
CGA 540 Hand Tight Replacement Nipple	100 €
DN 25 ISO-KF Flexible metal hose MF, DN 25 KF, 250mm	62 €
TOTAL	**255 €**

TOTAL COST OF THE MOST EXPENSIVE OPTION OF THE PROJECT
7782 €

Appendix XIV: Hypothetic cheapest cost of the installation.

The total cost of the installation with the cheapest components and the price (including VAT) of each included.

COST OF THE CHEAPER COMPONENTS	
Gasoline injection system	
Components	Price
Murray Motorsport Fuel Tank 7.7 Gallon - 35 Litre	322.42 €
Fuel lab low-pressure in-tank lift pump	75.2 €
KAMOKA F322501 fuel filter	27.55 €
AEM’s 400lph Metric High Flow, high-pressure Inline Fuel Pump (PN 50-1009)	55 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply	37.18 €
Straight Barbed 18mm to 10mm Hose Pipe Connector Tube Fitting Fuel	3.2 €
Straight Barbed 12mm to 10mm Hose Pipe Connector Tubing Fitting Fuel	4 €
1/4" quick coupling with ball bearing: Female and spout for 10mm hose, 112C31S, 01995	8.42 €
FUEL HOSE 10MM from Biltema	64.80 €
Mass Flow Meter and Fuel Temperature Control model AVL 735S /753C	2438.7 €
TOTAL	**3037 €**

COST OF THE CHEAPER COMPONENTS	
Cooling system	
Components	Price
NRF Radiator, engine cooling Aluminium 59133	262 €
NRF 47699 fan	136 €
SHENPENG P6216 12v electric coolant pump	53 €
Universal coolant Glycol Purple G13	18.31 €
Stainless Steel Flexible Hose Pipe	65 €
24232 2" X 3FT GS 2 PLY STRAIGHT EPDM hose	119 €
90°C Normally Open Thermostat Thermal Temperature Switch NO	11.5 €
Expansion Coolant Header Tank 022953219 For Vauxhall/Opel, Chevrolet & Saab	32 €

Angle seat valve DIN-DVGW with backflow preventer DN25	45 €
FACET 7.3015 Coolant temperature sensor	11.56 €
Flexible Pipework Quick Coupling 50mm	29.36 €
Swivel Caster - Wheel Material Nylon; Caster Housing Material Zinc Plated Steel x4	175.81 €
Variable-length RODULF sitting/standing desk	**319 € + 0€ if collected at the IKEA store** 319 € + 25 if collected at an IKEA collection point 319 € + 50 € if they bring the component to the facilities
304 stainless steel plate to recover the table surface	277.92 €
304 stainless steel plate to support the radiator	238.4 €
304 stainless steel plate to support the fan	404.56 €
304 stainless steel plate to support the pump	57.25 €
304 stainless steel bars to support the expansion tank	2.96 €
304 stainless steel bars to support the expansion tank	1.92 €
Hengfu HF200W-FSM-12 - 12 Volt 17 Amp Single Output Power Supply x2	74.36 €
PVC hub to hub reducer coupling pipe adaptor 50mm x 20mm	15.21 €
TOTAL	**2351 €**

COST OF THE CHEAPER COMPONENTS	
Laboratory exhaust gas system	
Components	**Price**
Exhaust gas Tube, rigid, 120 mm	45,35 €
Stainless Steel Tube 115 mm	29 €
Hand Tight Nipple 1/4 NPT 3 inch long with Soft Tip - Brass	84.38 €
Aluminium Flexible Hose 115mm 4.53" Alloy Flexi Pipe Air Ducting Tube Flexipipe	56.52€
TOTAL	**216 €**

TOTAL COST OF THE CHEAPEST OPTION OF THE PROJECT
5604 €