VŠB -Technical University of Ostrava

Faculty of Mechanical Engineering

Department of Energy Engineering

DESIGN OF EXHAUST SYSTEM FOR THE EXPERIMENTAL MEASURING STAND EQUIPPED WITH AN INTERNAL COMBUSTION ENGINE

Návrh systému odvodu spalin z měřícího standu vybaveného spalovacím motorem

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VŠB - Technical University of Ostrava
Faculty of Mechanical Engineering
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Diploma Thesis Assignment

Student: **Midhun Kumar Suresh Kumar Balamani, BTech**

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The thesis language: English

Description:

Create a design of universal exhaust system for the experimental measuring stand, the system must be designed for different types of combustion engines with an output up to 100 kW.
Content of the diploma thesis:
1. Background research in the field of combustion engine exhaust systems for mobile applications and for co-generation units.
2. The technical design of the exhaust system allows the installation of internal combustion engines with an output up to 100 kW.
3. Connection diagram.
4. Design drawing of planning layout of the proposed system's integration into the existing space.
5. Modification of the proposed system with respect to the utilization of waste heat in the existing storage system.

References:

STONE, Richard. Introduction to internal combustion engines. 3rd ed. Warrendale, Pa.: Society of Automotive Engineers, c1999. ISBN 978-0768004953.
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Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Dean

Student's affidavit

I declare that I have prepared the whole diploma thesis including appendices independently under the leadership of the diploma thesis supervisor, and I stated all the documents and literature used.

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ANNOTATION OF MASTER THESIS

SURESH KUMAR BALAMANI, Midhun Kumar. *Design of Exhaust System for the Experimental Measuring Stand equipped with an Internal Combustion Engine: Diploma Thesis*. Ostrava: VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Energy, 2019, 69 p. Supervisor: Pavlik, P.

Master thesis deals with design of the exhaust system for measuring stand consisting of an internal combustion engine which releases flue gas, a sampling system, a filter, a blower, a heat exchanger, a silencer and a safety system. The introduction describes the origin of the exhaust system, it's problems and the purpose of the universal exhaust system. The theoretical part describes about the IC engine, it's process and mechanism. It also has description about the emission of exhaust gases. The specification of the engine to be used is also described. The second half of the thesis is mainly focused on the design of the universal exhaust system and also the sampling system. The calculation for the pipe diameter and the design of the heat exchanger is also included. The conclusion contains the overview of all the task done by me during the thesis.

ANOTACE DIPLOMOVÉ PRÁCE

SURESH KUMAR BALAMANI, Midhun Kumar. *Návrh systému odvodu spalin z měřícího standu vybaveného spalovacím motorem: Diplomová práce*. Ostrava: VŠB – Technická univerzita Ostrava, Fakulta strojní, Katedra energetiky, 2019, 69 s. Vedoucí práce: Pavlik, P.

Tato diplomová práce se zabývá návrhem systému pro odvod spalin z měřícího standu vybaveného spalovacím motorem s vnitřním spalováním. Navrhovaný systém se skládá z potrubního vedení, vzorkovací odběrové sondy, filtru, dmychadla, výměníku tepla, tlumiče a bezpečnostního systému. V úvodní části je vysvětlena potřeba vytvoření univerzálního výfukového systému. Teoretická část práce se zabývá spalovacími motory, jejich principy funkce a jejich konstrukcí. Jsou zde také popsány emise spalovacích motorů a specifikace parametrů pro návrh samotného systému odvodu spalin. Druhá část práce se věnuje návrhu univerzálního systému pro měřící daný stand. Tato část také obsahuje výpočet hlavních parametrů potrubí a návrh výměníku tepla. Závěr práce poté hodnotí, zda bylo při řešení práce dosaženo stanovených cílů.

Contents

List of used signs and symbols

Symbols	Parameters	Units
ρ	Density	Kg/m^3
μ	Viscosity	$N.s/m^2$
χ, F	Correction factor	-
ΔT_{lm}	Log mean temperature difference	°C
Δp	Pressure drop	N/m^2
A	Area of the Heat exchanger	m^2
BF	Baffle length	m
C_p	Specific heat	J/kg.K
D	Diameter of the pipe	m
f	Friction factor	-
h	Heat transfer Coefficient	$W/m^2.K$
k_f	Thermal conductivity	W/m.K
L	Tube length	m
ṁ	Mass flow rate	Kg/s
m	Number of baffles	-
N_L	Number of tubes in a row	-
Nu_D	Nusselt number	-
p	Pressure	Bars
Pr	Prandtl number	-
P	Power consumption	W
q	Heat energy	J/s
Re_D	Reynold's number	-
S	Surface Area	m^2
T_{max}	Maximum Temperature	°C
T_1	Inlet gas temperature	°C
T_2	Outlet gas temperature	°C
t_1	Inlet water temperature	°C
t_2	Outlet water temperature	°C
T_{avg}	Average water temperature	°C
U	Overall heat transfer Coefficient	$W/m^2.K$
V_∞	Velocity of water from the cooler	m/s

V_{max}	Maximum velocity of the water when crossing the tubes	m/s
w	Velocity	m/s
W	Width of the heat exchanger	m

List of Abbreviations

Abbreviations	Definitions
AWD	All-wheel drive
BDC	Bottom dead centre
BTDC	Before top dead centre
DSO	Digital storage oscilloscope
DVSA	Driver and vehicle standards Agency
EPA	Environmental protection Agency
HC	Hydro Carbon
ICE	Internal combustion engine
LCD	Liquid crystal Display
LED	Light emitting diode
NO_X	Oxides of Nitrogen
OBD II	On-board Diagnostics II
OIML	International Organisation of legal Metrology
PCM	Phase change materials
PM	Particulate Matters
PC	Passenger cars
RDE	Real driving emissions
RPM	Revolution per minute
RPS	Revolution per second
TDC	Top dead centre
T	Turbo
UK MOT	United Kingdom Ministry of Transport
UV	Ultra-Violet
WLTP	Worldwide Harmonised Light Vehicle Test Procedure

1. Introduction

The exhaust system originally invented to silence the noise from the engine by the high-pressure exhaust gases and also sent the toxic gas out of the driver's compartment. But turns out, it started polluting the environment day by day. So, when people started studying about this environmental pollution, awareness started to implement in the production of exhaust system. Now, emission control became an integral part in the exhaust system. So, few steps need to done in order to control. There should be no leakage in the catalytic converter. It also has to do with the customer demands for comfort and long-life guarantee for the exhaust system. These should be fulfilled in order to be considered as a best car among the others [1].

The exhaust gas from vehicles has been increasing very recently. In order to reduce it, the motor industry has been promoting diesel engines cleaner, due to their greater fuel economy and lesser maintenance requirements. Nevertheless, diesel engines emission characteristics are dissimilar and a rise in the diesel cars at the expense of petrol cars could have huge impact on air quality, global warming and other ecological problems. But then there is no strong evidence for the solution to this problem due to the lack of measurements of emission. Therefore, a solution to the emission should be analysed.

For this case, the purpose of universal exhaust system comes into action. In the universal exhaust system, the flue gas can be sampled and analysed. The engine can be modified and analysed on this system. Only analysing the flue gas doesn't give any benefits to them. So, a purpose can be giving to the outgoing flue gas by producing the energy from the heat produced by them.

2. IC Engine

An Internal Combustion Engine (ICE) basically alters chemical energy into mechanical energy. Inside this machine, combustion happens with the aid of fuel and spark plug in the combustion chamber. This combustion creates force to move the piston and thus producing mechanical energy. There are few things the engine should be taken care of. But the vital thing is engine cooling and the exhaust system of the engine which can be seen further in this paper.

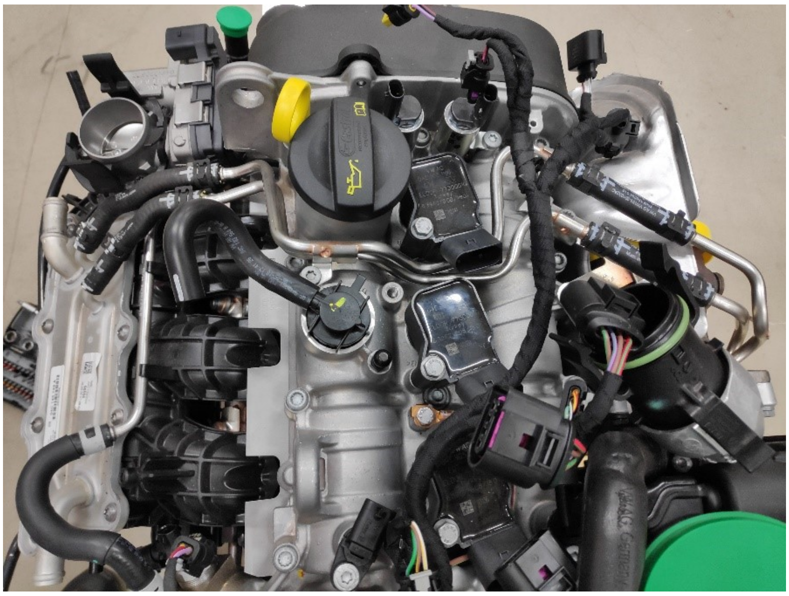


Figure 1: Internal Combustion Engine (Author)

2.1. Combustion process

Before we look into the Exhaust system, I would like to discuss about the basic combustion process happening in the IC engine. Combustion additionally called burning, is that the basic chemical action of releasing energy from a fuel and air mixture. In an internal combustion engine (ICE), the ignition and burning of the fuel arises inside the engine itself. The engine then partly converts the energy from the combustion to figure. The engine consists of a set cylinder and a moving piston. The expanding combustion gases push the piston, that successively rotates the rotating shaft. Eventually, through a system of gears in the powertrain, this motion moves the vehicle's wheels.

There are two categories of internal combustion engines presently in production: the spark ignition petrol engine and the compression ignition diesel engine. Most of those are four-stroke cycle engines, that means four piston strokes are required to finish a cycle. The cycle includes 4 processes such as intake, compression, combustion, and exhaust.

Spark ignition petrol and compression ignition diesel engines vary in how they distribute and burn the fuel. In a spark ignition engine, the fuel is mixed with air then sent into the cylinder throughout the intake method. Once the piston compresses the fuel-air mixture, the spark ignites it, inflicting combustion. The expansion of the combustion gases pushes the piston during the power stroke. In an ICE, solely air is inducted into the engine and so compressed. Diesel engines spray the fuel into the hot compressed air at an appropriate measured rate, triggering it to ignite [2].

2.2. Input Air System

The intake and exhaust system deal with the incoming flow of fresh air and the outgoing flow of used gases in the engine.

2.2.1. Air intake system

The intake system of air permits fresh air to enter the engine [3]. The main parts are:

- air cleaner,
- supercharger,
- intake manifold,
- intake port and
- intake valve.

Air Cleaner

The operative potency, smart performance and sturdiness of associate engine rely principally upon its cleaner. It's a tool, that cleans associated filters the air already getting inside the combustion chamber of an engine.

An IC engine uses large quantities of air for combustion, the ratio being 6-7 kg of air for every kg of fuel burst. The volume of the air used is concerning 10,000 l/l of fuel. Unfiltered air might contain several particles of abrasive mud and different matter, that might cause fast wear.

Superchargers

A compressor could be a device for increasing the gas pressure into the engine so a lot of fuel are often burnt and therefore the engine output inflated. The pressure within the manifold of a compressor engine are going to be bigger than the atmosphere pressure. Supercharged air is given by positive displacement blowers or by centrifugal blowers. These may belt driven by engine itself or from a separate power source such as electric motor or from exhaust gas turbine.

Inlet Manifold

The manifold is needed to deliver into the cylinders either a combination of fuel and air from the mechanical device or solely air from air-cleaners. The inlet manifolds are created in one or 2 items either from cast iron or metallic element alloy. They're conjointly secured from separate castings into one unit. The manifold flanges are linked to the engine block or plate by means that of asbestos-copper gaskets, studs and nuts.

Intake Valve

The intake valve lets the air inside, and the exhaust valves lets the exhaust air outside. The more air you can transfer, air inside and outside of the engine, the more resourceful, and therefore power the engine will have. This is why the engine valve plays a pretty critical role in an engine's performance.

2.3. Technical Process for Four Stroke Engine

A four-stroke cycle engine is an IC engine that operates four separate piston strokes (intake, compression, combustion, and exhaust) to complete one operating cycle. The piston makes 2 complete passes within the cylinder to complete one operative cycle. A functioning cycle involves two revolutions (720°) of the crankshaft. The four-stroke cycle engine is that the most typical kind of small engine. A four-stroke cycle engine finishes five Strokes in one operating cycle, that includes the four process namely intake, compression, ignition, power, and exhaust Strokes [4].

2.3.1. Intake Stroke

The intake process is once the air-fuel mixture is presented to spread inside the combustion chamber. The intake process happens when the piston transfers from TDC to BDC and then the intake valve is open. The movement of the piston toward BDC creates a coffee pressure within the cylinder. Close gas pressure forces the air-fuel mixture through the open valve into the cylinder to fill the unaggressive space created by the piston movement. The cylinder endures to fill somewhat past BDC because the air-fuel mixture endures to flow by its own inertia whereas the piston begins to vary direction. The valve remains wide open many degrees of shaft rotation once BDC. Dependent to engine style, the valve closes and therefore the air-fuel mixture is closed within the cylinder.

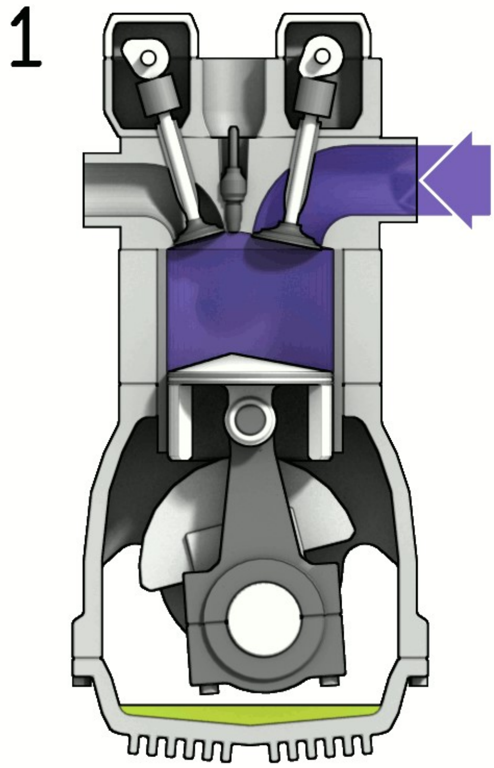


Figure 2: Intake Stroke [4]

2.3.2. Compression Stroke

The compression stroke is once the air-fuel mix sealed inside is compressed in the cylinder. This chamber is closed so that it could form the charge. The charge is that the capacity of compressed air-fuel mixture sealed inside the combustion chamber prepared for ignition. Pressuring the air-fuel mixture permits a lot of energy to be discharged once the charge is kindled. Intake and exhaust valves should be closed to make sure that the cylinder is closed to produce compression.

Compression is that the method of reducing or squeeze a charge from an outsized volume to a smaller volume within the combustion chamber. The regulator helps to take care of the momentum necessary to compress the charge. Once the engine piston compresses the charge, a rise in compressive force provided by work being done by the piston causing heat to be created. The compression and heating of the air-fuel vapor within the charge ends up in a rise in charge temperature and a rise in fuel vaporization.

The rise temperature happens uniformly throughout the combustion chamber to supply quicker combustion (fuel oxidation) when ignition. the rise in fuel vaporization happens as little droplets of fuel become volatilised a lot of fully from the heat generated. The raised droplet expanse exposed to the ignition flame permits a lot of complete burning of the charge within the combustion chamber. Only petrol vapor ignites. A rise in droplet surface area lets petrol to release more vapor instead of the remaining a liquid.

The more the charge vapor molecules are compressed, a lot of energy obtained from the combustion method. The energy required to compress the charge is considerably but the gain good made throughout the combustion method. As an example, during a typical small engine, energy required to compress the charge is just common fraction the number of energies made throughout combustion.

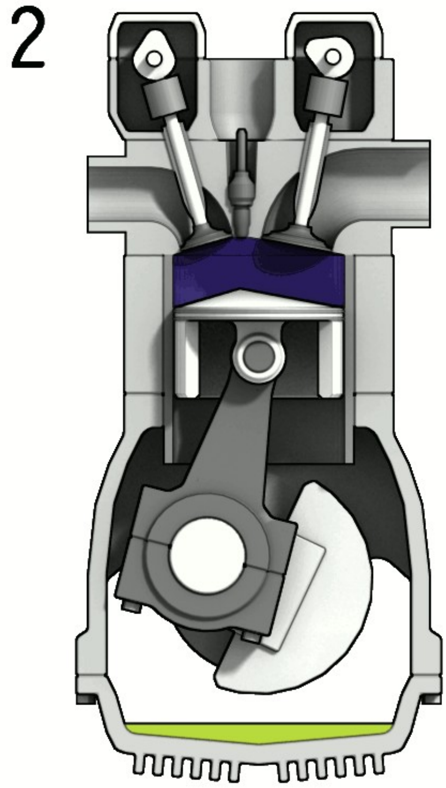


Figure 3: Compression Stroke [4]

2.3.3. Ignition Event

The ignition (combustion) event happens once the charge is lit and rapidly oxidised through a reaction to unharness heat energy. Combustion is that the speedy, oxidizing reaction during which a fuel with chemicals combines with chemical element within the atmosphere and releases energy within the form of heat.

Proper combustion involves a brief however finite time to unfold a flame throughout the combustion chamber. The spark at the spark plug starts burning at approximately 20° of crankshaft spin before TDC (BTDC). A flame front is that the borderline wall that separates the charge from the combustion end products. The flame front increases after the combustion chamber till the complete charge has burned.

Power Stroke

The power stroke is one of the engine operation Stroke in which hot growing gases force the piston head other way from the cylinder head. Piston force and subsequent motion are transferred through the rod to use torsion to the rotating shaft. The torque applied initiates crankshaft rotation. The amount of torsion created is decided by the pressure on the piston, the scale of the piston, and also the throw of the engine. During this Stroke, all two of the valves are closed.

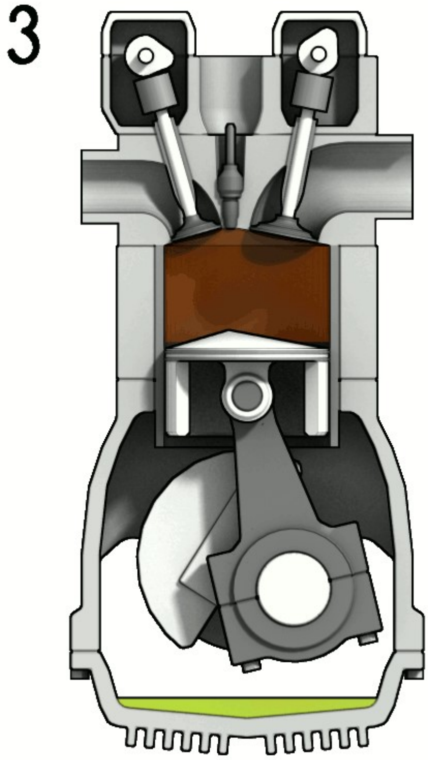


Figure 4: Power Stroke [4]

Exhaust Stroke

The exhaust stroke happens once used gases are ejected outside from the combustion chamber and free to the atmosphere. The exhaust stroke is the last stroke and happens once the exhaust valve is exposed and the intake valve is shut. Piston movement empties exhaust gases to the outside.

As the piston grasps BDC throughout the power stroke, combustion is complete and the cylinder is occupied with exhaust gases. The valve opens, and inertia of the regulator and different moving elements push the piston back to TDC, forcing the exhaust gases out through the open valve. At the end of the exhaust stroke, the piston is at TDC and one operative cycle has been completed.

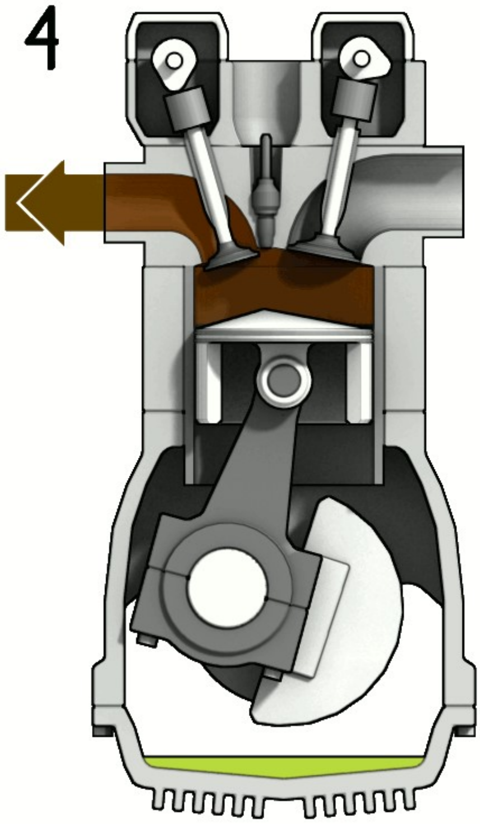


Figure 5: Exhaust Stroke [4]

2.4. Skoda Octavia Engine

The consumption of fuel of this engine is 8.8 litres/100km - 27 mpg US (Average), 0 to 100 km/h in 9.1 seconds, an extreme maximum speed of 211 km/h, a curb weight of 1375 kgs, the Octavia 1 Combi 1.8T 20V has a turbocharged In-line 4-cylinder petrol engine [5].

This engine gives a maximum power of 110 kW at 5700 rpm and a maximum torque of 210 Nm at 1750-4600 rpm. The power is transmitted to the road by the all-wheel drive (AWD) with a 5 speed Manual gearbox.

Figure 6: Skoda Octavia 1 Engine 1.8T 20V 110kW at 5700 rpm [12]

The Octavia model is a car manufactured by Skoda, sold new from year 1999 to 2000, and available after that as a used car.

2.4.1. Skoda Octavia 1 Combi 1.8T 20V Engine Technical Data

Table 1: Skoda Octavia 1 Combi 1.8T 20V Engine Technical Data [5]

Engine type - Number of cylinders :	I 4
Fuel type :	Petrol
Engine size - Displacement - Engine capacity :	1781 cm^3 or 108.7 cu-in
Bore x Stroke :	81.0 x 86.4 mm
	3.19 x 3.39 inches
Compression Ratio :	10
Maximum power - Output - Horsepower :	110 kW @ 5700 RPM
Maximum torque :	210 Nm @ 1750-4600 RPM
Fuel Consumption - Economy - Combined:	8.8 L/100km
Fuel Consumption - Economy - Extra Urban:	L/100km
Fuel Consumption - Economy - City:	L/100km
Range :	715 Km
CO_2 emissions :	205 g/Km (estimate)
Top Speed :	211 km/h
Acceleration 0 to 100 km/h (0 to 62 mph) :	9.1 s
Weight-Power Output Ratio :	9.2 kg/hp

3. Exhaust Systems

It is a system used to guide the exhaust gas from the engine to outside. An exhaust system is typically piping used to director reaction exhaust gases away from a controlled burning in an engine or stove.

3.1. Parts of Exhaust System

This system comprises of an exhaust manifold, catalytic converter and a muffler. It can also have a turbocharger to increase the efficiency of the engine.

3.1.1. Manifold

The Exhaust manifold of a vehicle plays the chief role in a car or truck's exhaust system. It links to each exhaust port on the engine's cylinder head, and it directs the hot exhaust down into one modest exhaust pipe. With the assist of the exhaust manifold gaskets, it also avoids the toxic exhaust fumes from sneaking into the vehicle and harming the occupants. Unnecessary to say, it's pretty significant to have your exhaust manifold in decent working order. Manifold is usually made of cast iron.

3.1.2. Catalytic Converter

A catalytic converter is an exhaust emission control machine that alters toxic gases and pollutants in exhaust gas from an ICE into less-toxic pollutants by speeding up a redox reaction. Catalytic converters are typically used with IC engines fuelled by either petrol or diesel—counting lean-burn engines in addition to kerosene heaters and stoves.

3.1.3. Muffler

Mufflers are put in among the exhaust of most combustion engines. The muffler is designed as a device to scale back the volume of the sound pressure formed by the engine by acoustic quieting. The sound of the burning-hot exhaust gas leaving the engine at top speed is abated by a sequence of passages and chambers lined with roving fiberglass insulation and/or resonating chambers harmonically modified to cause damaging interference, whereby opposite sound waves stop one another out.

3.2. Exhaust of flue gas

The petrol-powered internal combustion engine takes air from the atmosphere and petrol, a hydrocarbon fuel, and through the method of combustion lets out the chemical energy kept within the fuel. Of the entire energy freed by the combustion method, nearly 30% is used to push the vehicle, the remaining 70% is vanished to friction, aerodynamic drag, accessory operation, or it's unused as heat transferred to the cooling system [15].

Modern petrol engines are very resourceful when related to predecessors of the late '60s and early '70s when emissions control and fuel economy were first becoming a major alarm to automotive engineers. Commonly speaking, the more economical an engine develops, the lesser the exhaust emissions from the pipeage. However, as clean as engines operate nowadays, exhaust emission standards frequently tighten. The technology to accomplish these ever-tightening emissions goals has ran to the advanced closed loop engine control systems developed on today's Toyota vehicles. With these developments in technology arises the enlarged emphasis on maintenance, and when the engine and emission control schemes flop to function as planned, analyzed and repair [6].

3.2.1. Basic Principle

To understand how to diagnose and repair the emissions control system, one must first have a working information of the basic combustion chemistry which takes place within the engine. That is the purpose of this section of this thesis.

The petrol burned in an engine comprises many chemicals, though, it is mainly made up of hydrocarbons. Hydrocarbons are chemical compounds created from hydrogen atoms that chemically bond with carbon atoms. There are numerous dissimilar types of hydrocarbon compounds identified in petrol, conditional to the number of hydrogen and carbon atoms present, and the way that these atoms are bonded.

Within an engine, the hydrocarbons in petrol will not burn except they are mixed with air. This is where the chemistry of burning process begins. Air is self-possessed with roughly 21% oxygen (O_2), 78% nitrogen (N_2), and minute quantities of other inert gases.

In fuel, the hydrocarbons unremarkably react solely with the gas throughout the combustion process to make vapour (H_2O) and carbon dioxide (CO_2), making the fascinating impact of heat. Unfortunately, beneath certain engine in operation conditions, the nitrogen conjointly reacts with the oxygen to make nitrogen oxides (NO_x), a criteria air waste.

The magnitude relation of air to fuel plays a crucial role within the potency of the combustion process. The perfect air/fuel magnitude relation for optimal emissions, fuel economy, and smart engine performance is about 14.7 pounds of air for individually one pound of fuel. This "ideal air/fuel ratio" is denoted as stoichiometry, and is the goal that the feedback fuel control system repetitively shoots for. At air/fuel ratios wealthier than ratio, fuel economy and emissions can agonize. At air/fuel ratios leaner than stoichiometry, power, drivability and emissions will agonize.

3.2.2. Under "Ideal" Combustion Conditions

In a flawlessly functioning engine with perfect combustion settings, the following chemical reaction would take place:

- Hydrocarbons could respond with oxygen to split to vapor H_2O and CO_2
- N_2 would permit through the engine without being pretentious by the combustion process.
- In essence, solely harmless parts would stay and enter the atmosphere. Though modern engines are creating much lesser emission levels than their predecessors, they still fundamentally create approximate level of harmful emission production.

3.2.3. Harmful Exhaust Emissions

As formerly stated, even the furthermost modern, technologically progressive automobile engines are not "flawless", they still characteristically create some level of harmful emission production. There are numerous settings in the combustion chamber which avoid faultless combustion and cause unwelcomed chemical reactions to happen. The following are the examples of damaging exhaust emissions and their reasons.

3.2.4. Hydrocarbon (HC) Emission

Hydrocarbons are, fairly just, raw unburned fuel. When burning doesn't present itself the smallest bit, like a fail, enormous quantities of hydrocarbons are released from the combustion chamber.

A slight quantity of hydrocarbon is produced by a petrol engine owing to its design. A usual method recognized as wall quenching occurs as the combustion flame front burns to the relatively cool walls of the combustion chamber. This cooling extinguishes the flame earlier than all of the fuel is completely burned, exploit a little quantity of organic compound to be pushed out the valve.

Another reason of extreme hydrocarbon emission is linked to combustion chamber deposits. Since these carbon deposits are porous, hydrocarbon is compulsory pushed into these pores as the air/fuel mixture is compressed. When burning takes place, this fuel does not burn, though, as the piston starts its exhaust stroke, these hydrocarbons are freed into the exhaust stream.

The most common explanation for excessive organic compound emissions is misfire that happens because of ignition, fuel delivery, or air induction issues. Liable on how severe the misfire, insufficient spark or a noncombustible mixture (either too rich or too lean) will cause hydrocarbons to rise to fluctuating degrees. For instance, a complete misfire because of a shorted electrical device wire can cause hydrocarbons to extend dramatically. Conversely, a small lean misfire because of a false air coming into the engine, might cause hydrocarbons to extend solely slightly.

Excess organic compound may similarly be prejudiced by the temperature of the air/ fuel mixture because it arrives the combustion chamber. Overly low intake air temperatures will cause poor mixing of fuel and air, leading to partial misfire.

3.2.5. Carbon Monoxide (CO) Emission

Carbon monoxide (CO) may be a byproduct of incomplete combustion and is basically partly burned fuel. If the air/fuel mixture doesn't have enough chemical element gift throughout combustion, it'll not burn fully. once combustion takes place in associate degree chemical element starved atmosphere, there's light chemical element gift to totally oxidize the carbon atoms into carbonic acid gas (CO_2). once carbon atoms bond with just one chemical element atom carbon monoxide gas (CO) forms.

An oxygen starved combustion atmosphere happens as a results of air/fuel ratios that square measure richer than ratio (14.7 to 1). There square measure many engine operative conditions once this happens usually. as an example, throughout cold operation, warm-up, and power enrichment. It is, therefore, traditional for higher concentrations of carbon monoxide gas to be created below these operative conditions. Causes of excessive carbon monoxide gas includes leaky injectors, high fuel pressure, improper control system management, etc.

Once the engine is at heat idle or cruise, little or no carbon monoxide gas is created as a result of there's ample chemical element accessible throughout combustion to totally oxidize the carbon atoms. This leads to higher levels of carbonic acid gas (CO_2) the principal by-product of economical combustion.

3.2.6. Oxides of Nitrogen (NOx) Emission

High cylinder temperature and pressure that occur throughout the combustion method will cause nitrogen to respond with oxygen to make Oxides of nitrogen. Though there are numerous forms of nitrogen-based emissions that contain Oxides of Nitrogen, nitric oxide brands up the majority, about 98% of all NOx emissions created by the engine.

Generally speaking, the biggest quantity of NOx is created throughout moderate to serious load conditions once combustion pressures and temperatures are their uppermost. Though, minor quantities of NO_x can also be formed throughout cruise and light load, light throttle operation. Mutual reasons for extreme NOx comprise faulty EGR system operation, lean air/fuel mixture, higher temperature consumption air, overheated engine, unnecessary spark advance, etc.

3.2.7. Air/Fuel Mixture Impact on Exhaust Emissions

The HC and CO levels are comparatively little close to the theoretically ideal 14.7 to 1 air/fuel ratio. This reinforces the requirement to keep up strict air/fuel mixture management. Though, NO_x creation is incredibly high simply somewhat leaner than this ideal mixture range. This inverse connection among HC/CO creation and NOx creation poses a bad-behavior when monitoring total emission production. Because of this relationship, you'll be able to perceive the complexness in reducing all 3 emissions at an equivalent time.

4. Emission Standards

Emission standards are the lawful necessities governing air pollutants unrestricted into the atmosphere. Emission standards set quantitative restrictions on the acceptable quantity of definite air pollutants that may be unrestricted from definite sources over definite timeframes. They are normally designed to attain air quality standards and to guard human life.

4.1. European Exhaust Emission Standards

The first European exhaust emissions standard for passenger cars was presented in 1970. 22 years passed before the subsequent giant alteration when, in 1992 the 'Euro 1' standard heralded the fitting of catalytic converters to petrol cars to lessen carbon monoxide (CO) emissions [10].

The newest standard, 'Euro 6', applies to new type sanctions from September 2014 and all new cars from September 2015 and lessens some pollutants by 96% compared to the 1992 limits. The Euro 6 test became more stringent from September 2017 with the accumulation of a prolonged on-road emission test known as Real Driving Emissions or RDE.

4.1.1. Euro 1 (EC93)

July 1992

The beginning of the Euro 1 standard in 1992 needed the shift to unleaded petrol and the universal fitting of catalytic converters to petrol cars to lessen carbon monoxide (CO) release.

4.1.2. Euro 2 (EC96)

January 1996

The Euro 2 standard additionally condensed the limit for carbon monoxide emissions and also condensed the combined limit for unburned hydrocarbons and oxides of nitrogen for both petrol and diesel vehicles. Euro 2 introduced different emissions limits for petrol and diesel.

4.1.3. Euro 3 (EC2000)

January 2000

Euro 3 altered the test process to eradicate the engine warm-up period and additionally reduced allowed carbon monoxide and diesel particulate limits. Euro 3 also added a separate NOx limit for diesel engines and introduced separate HC and NOx limits for petrol engines.

4.1.4. Euro 4 (EC2005)

January 2005

Euro 4 (January 2005) and the later Euro 5 (September 2009) focused on cleaning up emissions from diesel cars, particularly dropping particulate matter (PM) and oxides of nitrogen (NOx). Few Euro 4 cars of Diesel were equipped with particulate filters.

4.1.5. Euro 5

September 2009

Euro 5 additionally stiffened the restrictions on particulate emissions from diesel engines and all diesel cars' essential particulate filters to meet the new necessities. There was some tightening of NOx limits too (28% reduction compared to Euro 4) as well as, for the first time, a particulates limit for petrol engines – valid to direct injection engines only.

Speaking about the actions of minute particle emissions, Euro 5 announced a boundary on particle numbers for diesel engines in addition to the particle weight restriction. This applied to new type sanctions from September 2011 and to all new diesel cars from January 2013.

4.1.6. Euro 6

September 2014

The Euro 6 standard enforces a additional, important reduction in NOx emissions from diesel engines (a 67% reduction compared to Euro 5) and creates alike standards for petrol and diesel.

Exhaust Gas Recirculation (EGR) – swapping some of the intake air (containing 80% nitrogen) with recycled exhaust gas – lessens the quantity of nitrogen obtainable to be oxidised to NOx throughout combustion but further exhaust after treatment may be compulsory in addition to the Diesel Particulate Filters compulsory to meet Euro 5.

Euro 6 diesel cars may also be fitted with:

- A NOx absorber (Lean NOx Trap) which stores NOx and reduces it to Nitrogen over a catalyst

- Selective Catalytic Reduction (SCR) which uses an additive (Diesel Exhaust Fluid (DEF) or AdBlue) containing urea injected into the exhaust to convert NOx into Nitrogen and water.

- The use of Cerium, a fluid injected into the fuel tank each time the vehicle is refuelled which helps the DPF regeneration by dropping the temperature wanted for regeneration.

Euro 6d-Temp, Euro 6d and Real Driving Emissions (RDE)

From 1 September 2017, more stringent and realistic tests will be used to certify new car models against the Euro 6 emission limits.

A new workroom test cycle known as WLTP (the Worldwide harmonised Light duty Test Procedure) will apply to all new type approvals and a year later, from 1 September 2018, will apply to all new car registrations.

An extra, on road, discharge trial known as the Real Driving Emissions or RDE test has been familiarized together with the WLTP laboratory test to aid make sure that cars meet emissions bounds in a much wider range of driving circumstances.

An RDE test will last between 90 and 120 minutes and take in a mix of 'normal' urban, rural and motorway driving.

RDE is being presented in two steps:

RDE step 1 – applies to new type sanctions from 1 September 2017 and to all new registrations from 1 September 2019.

- For RDE1 a NOx conformity factor of 2.1 will apply meaning that NOx emissions in the RDE1 test can be up to 2.1 times the Euro 6 laboratory limit of 80mg/km.

- Cars type permitted throughout this period will be labelled as meeting Euro 6d-temp.

RDE step 2 – applies to new type approvals from 1 January 2020 and to all new registrations from 1 January 2021.

- For RDE2 the NOx conformity factor is 1.0 but with an error margin of 0.5 meaning that NOx emissions in the RDE2 test can be up to 1.5 times the Euro 6 laboratory limit of 80mg/km.

- Cars type approved during this period will be described as meeting Euro 6d.

4.1.7. Comparison of all the Euro standards

Table 2: Comparison of all the Euro standards [10]

Euro	CO [g/km]	HC [g/km]	NO_X [g/km]	HC + NO_X [g/km]	PM [g/km]
Euro 1 Petrol	2.72	-	-	0.97	-
Euro 1 Diesel	2.72	-	-	0.97	0.14
Euro 2 Petrol	2.2	-	-	0.5	-
Euro 2 Diesel	1.0	-	-	0.7	0.08
Euro 3 Petrol	2.3	0.20	0.15	-	-
Euro 3 Diesel	0.64	-	0.50	0.56	0.05
Euro 4 Petrol	1.0	0.10	0.08	-	-
Euro 4 Diesel	0.50	-	0.25	0.30	0.025
Euro 5 Petrol	1.0	0.10	0.06	-	0.005
Euro 5 Diesel	0.50	-	0.18	0.23	0.005
Euro 6 Petrol	1.0	0.10	0.06	-	0.005
Euro 6 Diesel	0.50	-	0.08	0.17	0.005

4.2. Measurement Equipments

4.2.1. Brain Bee Emission Analysers

The Brain Bee Omni 800 range of emission analysers carries premium quality products organized with cutting edge technology and user-friendly features, to generate a high-quality emission package with a demonstrated track record [11].

The Omni 800 variety offers shared petrol and diesel emission testing to the peak standard and exceeds all UK MOT requirements, plus enhances many features that guarantees the Omni 800 primes the market in technology and user friendliness.

All three versions offer outstanding features and performance but enable customers to choose the best match to their requirements. The Omni 800 range can also be additional lengthened with some beneficial non-compulsory accessories.

The achievement and dependability of the Omni 800 range is constructed on three vital components, the AGS200 Gas bench, The OPA100 smoke chamber and the MGT300EVO Bluetooth/RF RPM module. These market chief components are used by many emission analyser manufacturers in the UK and well-known as the leading products in their field. As a result, Brain Bee surely propose 2 years warranty on all emission stations.

4.2.2. AGS-200 Gas Analyser

The AGS-200 Gas bench is a vital and significant portion of the Brain Bee Omni 800 emission analyser. The rapidity and precision of the analyser sets it head and shoulders above the rivalry contributing robust, reliable and proven measurements.

- DVSA approved for MOT testing
- OIML Class O approved
- Accurately measures CO, CO_2, HC, O_2, Lambda
- Protective internal filters for gas/water
- Automatic flow control & zeroing system
- Rapid heating times for quick testing
- Wireless comms of RPM & temp from MGT-300EVO

Figure 7: Brain Bee AGS 200 [11]

4.2.3. OPA-100 Diesel Smoke Meter

The OPA-100 diesel smoke metering unit adds to the entire superiority of the Omni 800 emission analyser. This highly specified market leading module gives wild and precise measurement of the smoke opacity by rapid chamber heating and fast pass technology.

- DVSA approved for MOT testing
- Type approved to latest specifications
- Accurately measures opacity of smoke
- Automatic glass cleaning system

- Wireless comms of RPM & temp from MGT-300EVO
- Fast pass system for rapid testing

Figure 8: Brain Bee OPA 100 [11]

4.2.4. MGT-300EVO

The MGT-300EVO universal RPM counter and temperature systems characterizes the technological level of the Brain Bee Omni 800 emission analyser. This market leading tool attaches to the vehicle and interconnects the outcomes via RF or Bluetooth to the AGS200 & OPA100, totally cable free. Furthermore, the MGT-300EVO can classify and separate background noises in the workshop, optimising the precision of the values noted.

- Cable free communication from vehicle
- Bluetooth or RF communication options
- Identifies and isolates background noise
- Oil temperature via dipstick probe
- RPM via engine acceleration sensor
- RPM via battery

Figure 9: Brain Bee MGT 300EVO [11]

5. Universal Exhaust System

The Universal exhaust system is a system capable of transporting or treating flue gas from the Internal Combustion Engine. It can also be modified to use the temperature of the flue gas to good use using a Heat exchanger. The Universal Exhaust System usually consist of blowers to maintain the flow, valves to control the flow of the gas, heat exchanger to use the temperature of the flue gas, a silencer to reduce the noise inside the room, some sensors to know the pressure and temperature of the gas as well as the room. A safety system can also be installed inside the room for the safety of the people using few sensors and a blower.

5.1. Connection Diagram

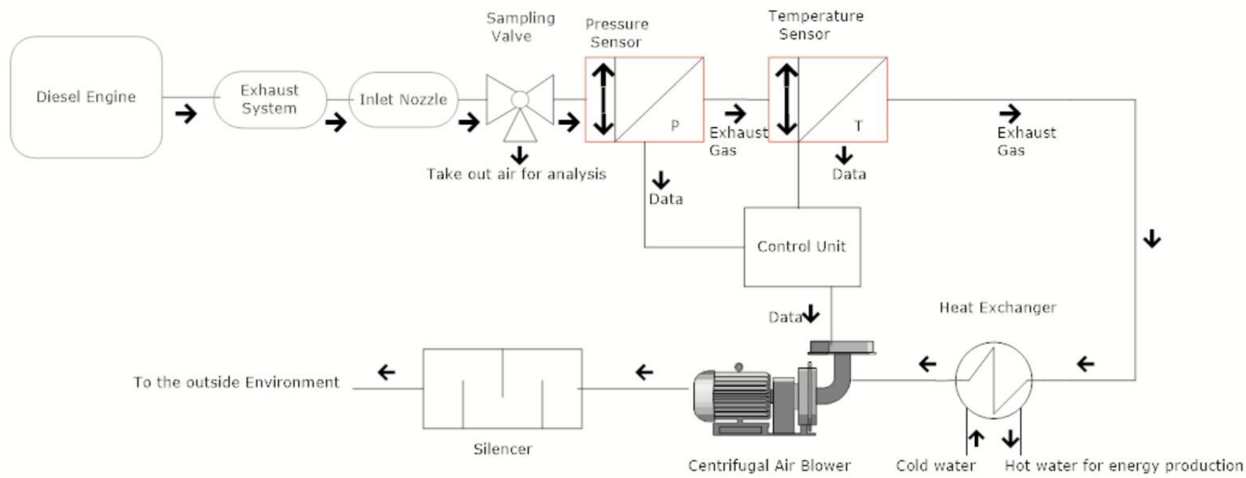


Figure 10: Connection Diagram of the Basic Principle (Author)

The Basic purpose of this system is to take the flue gas out of the room in a most efficient way. I designed a principle which has a nozzle that can be tighten to the exhaust pipe to take the flue gas into the system. The system contains a sample valve which is used to take sample of the flue gas in the middle of the process. A pressure sensor and a temperature sensor are added to the system to identify the pressure and temperature which is connected to a control unit. This control unit lets the blower to flow in the required volumetric flow. A heat exchanger is used to reduce the temperature of the flue gas and also to use the temperature to good use. Finally, a silencer is used to reduce the noise pollution inside the room.

5.2. Diameter Calculation

In order to sustain the mass flow of the flue gas inside the system, the diameter of the Universal Exhaust system should be calculated.

Mass flow equation can be written as

$$\dot{m} = S \cdot w \cdot \rho \tag{5.1}$$

where S is the surface area of the pipe m^2

w is the velocity of the flue gas m/s

ρ is the density of the flue gas in kg/m^3

From the above equation, the diameter can be derived which can be written as

$$D = \sqrt{\frac{4 \cdot \dot{m}}{\pi \cdot w \cdot \rho}} \tag{5.2}$$

The Engine used by me to propose the design was Škoda Octavia 1.8 20vT 110 kW at 5700-RPM.

4 Cylinder 1781 cm^3

Flywheel rotation 4600 RPM = 76.66 RPS

Exhaust pressure P = 5 bar

Exhaust Temperature 400 °C

As known, the entire 1781 cm^3 will be emptied by 2 revolution.

So, for 1 revolution

$\frac{1781}{2}$ cm^3 = 890.5 cm^3 will be emptied.

Volumetric flow rate can be calculated by 890.5 multiply by 76.66, which is 68271.67 cm^3/s

Now, the density can be found be $\rho = \frac{P}{R \cdot T_{max}}$ (5.3)

where R is the gas constant equals to 287 in J/(K.kg)

T_{max} is the maximum temperature of the incoming flue gas in °C

$$\rho = \frac{5 \cdot 10^5}{287 \cdot 400} = 3.48 \text{ kg/m}^3$$

The mass flow rate can be calculated by multiplying volume flow rate and density

Therefore, $\dot{m}$ = 0.237 kg/s

Using $\dot{m}$ value (in the diameter equation 5.2),

$$D = \sqrt{\frac{4\ .\ 0.237}{\pi\ .\ 20\ .\ 3.48}} = 65.8 \text{ mm}$$

Therefore approximately 80 mm is decided.

From this diameter, the actual velocity can be found (from the equation 5.2)

$$w = \sqrt{\frac{4\ .\ \dot{m}}{\pi\ .\ D\ .\ \rho}} = \frac{4\ .\ 0.237}{\pi\ .\ 0.08^2\ .\ 3.48} = 13.5 \text{ m/s.} \quad (5.4)$$

5.3. Heat Exchanger Calculation

In order to calculate and design a heat exchanger, some properties of flue gas and water in heat exchanger should be known. These properties can be calculated, derived from tables or assumed [13].

The Properties of the flue gas

Incoming gas Temperature T_1 = 400 °C

Outgoing gas Temperature T_2 = 200 °C

Density ρ = 3.48 kg/m^3

Mass flow ṁ = 0.237 kg/s

Viscosity μ = 23 . 10^{-6} N.s/m^2

The Properties of the water in the Heat Exchanger

Incoming water Temperature t_1 = 20 °C

Outgoing water Temperature t_2 = 120 °C

Density ρ = 1000 kg/m^3

Mass flow ṁ = 2 kg/s

T_{avg} = (120-20)/2 = 70 °C

Specific Heat at T_{avg} C_p = 4195 J/kg.K

Viscosity μ = 365 . 10^{-6} N.s/m^2

Calculation

Heat Energy q = ṁ . C_p . (t_2-t_1) = 2 . 4195 . (120-20) = 839000 J/s (5.5)

Log Mean Temperature Difference (LMTD) $\Delta T_{lm} = \frac{\Delta T - \Delta t}{ln\frac{\Delta T}{\Delta t}}$ (5.6)

$$= \frac{(400-200)-(120-20)}{ln\frac{400-200}{120-20}} = 226.33 \text{ °C}$$

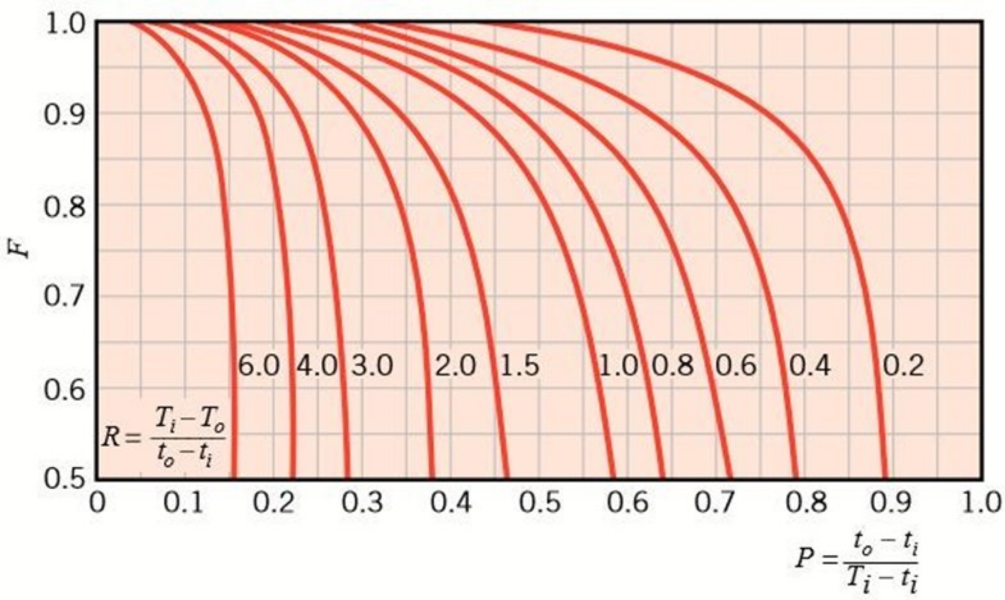
Correction factor

$R = \frac{t_2 - t_1}{T_1 - T_2} \frac{120-20}{400-200} = 0.5$ (5.7)

$P = \frac{T_1 - T_2}{T_1 - t_1} = \frac{400-200}{400-20} = 0.526$ (5.8)

From the Graph

Graph 1: Correction factor for a shell and tube heat exchanger with one shell and any multiple of two tube passes [13]



Correction factor F (χ)= 0.95

Assuming Dimensions

I chose the Tube and Shell Type Staggered Heat Exchanger

I assumed to take 4 rows of tube and 8 tubes in a row.

D = 0.02 m

S_L = 0.022 m

$S_T = 0.022$ m

$S_D = \sqrt{S_L^2 + (\frac{S_T}{2})^2} = \sqrt{0.022^2 + (\frac{0.022}{2})^2} = 0.0245$ m (5.9)

where S_L is the distance between the midpoint of the nearest tube in the same row in m

S_T is the distance between the midpoint of the nearest tube in different row in m

$N_L = 8$

Where N_L is the number of tubes in a row

Width $W = S_T \,.\, (N_L+2) = 0.022 \,.\, (8+2) = 0.22$ m (5.10)

Baffle Length

I assumed it to be

Baffle length $BF = \frac{2}{3} \,.\, W = \frac{2}{3} \,.\, 0.22 = 0.146$ m (5.11)

Flow Area $A = BF \,.\, W = 0.146 \,.\, 0.22 = 0.0322$ m^2 (5.12)

Water flowing on the Tube

$V_{\infty} = \frac{\dot{m}}{\rho . A} = \frac{2}{1000 \,.\, 0.0322} = 0.0619$ m/s (5.13)

where V_{∞} is the velocity of the cooler in m/s

$V_{max} = \frac{S_T}{S_T - D} \,.\, V_{\infty} = \frac{0.022}{0.022-0.02} \,.\, 0.0619 = 0.681$ m/s (5.14)

where V_{max} is the maximum velocity of water on the tube in m/s

Reynold's number $Re_{Dmax} = \frac{\rho . V_{max} . D}{\mu} = \frac{1000 \,.\, 0.681 \,.\, 0.02}{365 \,.\, 10^{-6}} = 37359.9$ (5.15)

Table 3: Constants for airflow over a tube bank of 7 or more rows [13]

	S_T/D							
	1.25		1.5		2.0		3.0	
S_L/D	C_1	m	C_1	m	C_1	m	C_1	m
Aligned								
1.25	0.348	0.592	0.275	0.608	0.100	0.704	0.0633	0.752
1.50	0.367	0.586	0.250	0.620	0.101	0.702	0.0678	0.744
2.00	0.418	0.570	0.299	0.602	0.229	0.632	0.198	0.648
3.00	0.290	0.601	0.357	0.584	0.374	0.581	0.286	0.608
Staggered								
0.600	—	—	—	—	—	—	0.213	0.636
0.900	—	—	—	—	0.446	0.571	0.401	0.581
1.000	—	—	0.497	0.558	—	—	—	—
1.125	—	—	—	—	0.478	0.565	0.518	0.560
1.250	0.518	0.556	0.505	0.554	0.519	0.556	0.522	0.562
1.500	0.451	0.568	0.460	0.562	0.452	0.568	0.488	0.568
2.000	0.404	0.572	0.416	0.568	0.482	0.556	0.449	0.570
3.000	0.310	0.592	0.356	0.580	0.440	0.562	0.428	0.574

Table 4: Correction factor C2 for NL <10 [13]

N_L	1	2	3	4	5	6	7	8	9
Aligned	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99
Staggered	0.68	0.75	0.83	0.89	0.92	0.95	0.97	0.98	0.99

From the above Tables, C_1, C_2 and m can be selected using the value of S_D/D, S_L/D and N_L

Therefore,

$C_1 = 0.46$

$C_2 = 0.98$

m = 0.562

From the Prandtl number graph or table, Pr is selected

Pr = 2.29

Nusselt number $Nu_D = C_2 \cdot 1.113 \cdot C_1 \cdot R_{Dmax}^{m} . Pr^{\frac{1}{3}} = 0.98 \cdot 1.113 \cdot 0.46 \cdot 37359.9^{0.562} . 2.29^{\frac{1}{3}}$

(5.16)

where C_1, C_2, m are the constants used (for the equation 5.16)

Pr is the Prandtl number

$Nu_D = 249.28$

Table 5: Thermophysical Properties of Saturated Water [13]

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	Specific Volume (m³/kg) v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	Specific Heat (kJ/kg · K) $c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	Viscosity (N · s/m²) $\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	Thermal Conductivity (W/m · K) $k_g \cdot 10^3$	Prandtl Number Pr_f	Prandtl Number Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K^{-1})	Temperature, T (K)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5	295
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1	300
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6	305
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9	310
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4	315
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7	320
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2	325
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0	330
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5	335
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0	340
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	668	22.6	2.45	0.933	64.1	595.4	345
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2	350
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3	355
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9	360
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1	365
370	0.9040	1.041	1.861	2265	4.214	2.017	289	11.89	679	24.5	1.80	0.978	59.5	728.7	370
373.15	1.0133	1.044	1.679	2257	4.217	2.029	279	12.02	680	24.8	1.76	0.984	58.9	750.1	373.15
375	1.0815	1.045	1.574	2252	4.220	2.036	274	12.09	681	24.9	1.70	0.987	58.6	761	375
380	1.2869	1.049	1.337	2239	4.226	2.057	260	12.29	683	25.4	1.61	0.999	57.6	788	380
385	1.5233	1.053	1.142	2225	4.232	2.080	248	12.49	685	25.8	1.53	1.004	56.6	814	385
390	1.794	1.058	0.980	2212	4.239	2.104	237	12.69	686	26.3	1.47	1.013	55.6	841	390
400	2.455	1.067	0.731	2183	4.256	2.158	217	13.05	688	27.2	1.34	1.033	53.6	896	400
410	3.302	1.077	0.553	2153	4.278	2.221	200	13.42	688	28.2	1.24	1.054	51.5	952	410
420	4.370	1.088	0.425	2123	4.302	2.291	185	13.79	688	29.8	1.16	1.075	49.4	1010	420
430	5.699	1.099	0.331	2091	4.331	2.369	173	14.14	685	30.4	1.09	1.10	47.2		430

From this table, K_f can be found to be 0.664 W/m.K

Heat Transfer Coefficient $h = \frac{Nu\,.\,K_f}{D} = \frac{249.28\,.\,0.664}{0.02} = 8276.32$ W/m^2.K (5.17)

where K_f is the thermal conductivity in W/m. K

Air flowing in the tube

$V_{m,tube} = \frac{\dot{m}}{\rho\,.\,A_{tube}\,.\,N} = \frac{0.237}{3.48\,.\,\frac{\pi\,.\,0.02^2}{4}\,.\,32} = 6.77$ m/s (5.18)

where $V_{m,tube}$ is the velocity of the flue gas in the tube in m/s

N is the total number of the tube in the heat exchanger

$Re_D = \frac{\rho\,.\,V_{m,tube}\,.\,D}{\mu} = \frac{3.48\,.\,6.77\,.\,0.02}{23\,.\,10^{-6}} = 20510.24$

From the Prandtl number graph or table, Pr = 0.86

$Nu_D = 0.23\,.\,Re_D^{\frac{4}{5}}.Pr^n = 0.23\,.\,20510.24^{\frac{4}{5}}\,.\,0.86^3 = 411.9$ (5.19)

Table 6: Thermophysical Properties of Gases at Atmospheric Pressure [13]

T (K)	ρ (kg/m³)	c_p (kJ/kg · K)	μ · 10⁷ (N · s/m²)	ν · 10⁶ (m²/s)	k · 10³ (W/m · K)	α · 10⁶ (m²/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709

From this table, k_f can be found for $T_{avg} = 573$ K

Therefore, $K_f = 0.045$ W/m.K

Heat Transfer Coefficient $h = \frac{Nu\,.\,K_f}{D} = \frac{411.9\,.\,0.045}{0.02} = 926.79$ W/m^2.K

Overall Heat Transfer Coefficient

$$\frac{1}{U.A} = \frac{1}{h_1 A} + \frac{1}{h_2 A} \tag{5.20}$$

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2} = \frac{1}{8276.32} + \frac{1}{926.79}$$

where U is the overall heat transfer coefficient in $W/m^2.K$

$U = 833.46\ W/m^2.K$

Tube Length $L = \frac{q}{U\ .\ N\ .\ \pi .D .F .LMTD} = \frac{839000}{833.46\ .\ 32\ .\ 3.14\ .\ 0.02\ .\ 0.95\ .\ 226.33} = 2.32$ m (5.21)

No. of Baffles $m = \frac{L}{BF} - 1 = \frac{2.32}{0.146} = 14.88$ (This is not a whole number) (5.22)

In order to get the number of Baffles, number of iterations should be done by changing the dimensions.

After number of iterations, the values to get a whole number for Baffles are

$\dot{m} = 1.5$ kg/s

D = 0.025 m

$S_L = 0.035$ m

$S_T = 0.035$ m

W = 0.35 m

BF = 0.233 m

$A = 0.0816\ m^2$

For water flowing out of the tube

$V_{\infty} = 0.0183$ m/s

$V_{max} = 0.064$ m/s

$h = 1990.809\ W/m^2.K$

For air flowing inside the tube

$V_{m,tube} = 4.33$ m/s

$h = 620.21\ W/m^2.K$

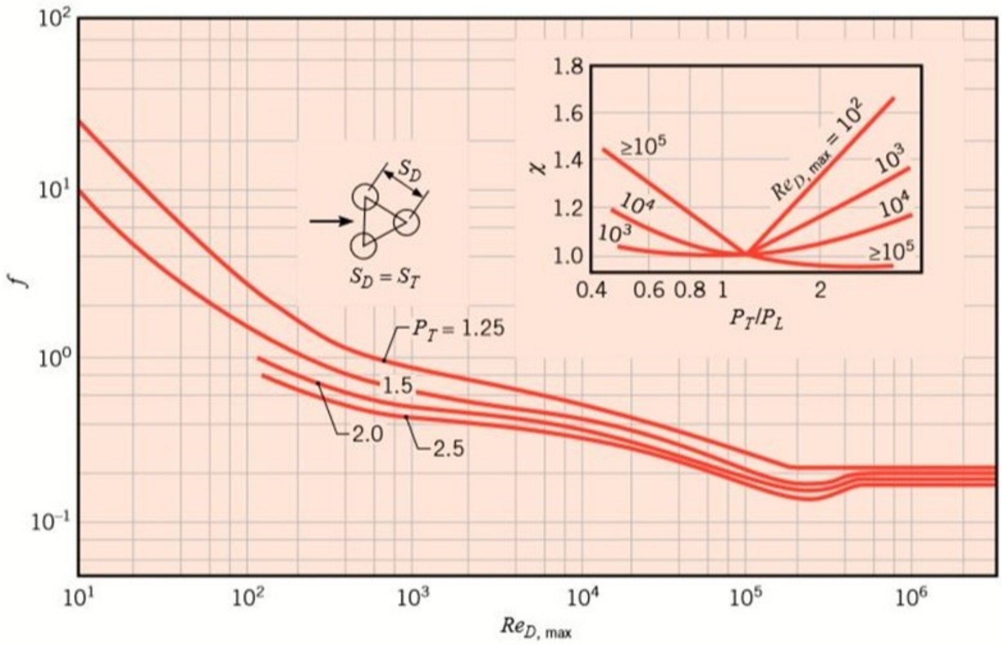
Overall heat transfer Coefficient $U = 472.89\ W/m^2.K$

L = 2.46 m

Number of Baffles m = 10

To find the power consumption, friction factor and correction factor should be found

Graph 2: Friction factor f and correction factor χ, Staggered tube bundle arrangement [13]



From this graph, χ (Correction factor) and f (friction factor) can be plotted

χ = 1

f = 0.55

$\Delta P = N \cdot \chi \cdot f \cdot \rho \cdot \frac{V_{max}^2}{2} = 32 \cdot 1 \cdot 0.55 \cdot 1000 \cdot \frac{0.064^2}{2} = 36.36 \text{ N/m}^2$ (5.23)

Power consumption P = V' . ΔP = 54551 W = 54.55 kW (5.24)

5.4. Design of the Universal Exhaust System

I propose an engine and the universal exhaust system to be inside a container. There is an original engine and its exhaust system. A flexible hose is attached to this exhaust system because the position of the engine and the exhaust system can vary. So, the exhaust system can be attached to the solid pipe of the Universal exhaust system using a flexible hose. According to the calculation, the diameter decided is 80 mm.

There is a sampling system used in the beginning which can be explained below in detail with a model. Now, the pressure and temperature sensor are used in order to maintain the mass flow, the pressure and the temperature of the flue gas. These sensors are connected to the control unit which is used to control the rpm of the blower. Therefore, these sensors are used to maintain the pressure inside the system and also if the temperature is more than it needs to be, the blower increases the rpm to maintain the temperature. The flow rate of the flue gas is 0.237 kg/s. But the maximum flow rate is assumed to be 0.5 kg/s. So, the centrifugal blower should have a specification of 0.2-0.5 kg/s. A Filter is used before the blower, so that the flue gas can pass through the blower without dust just in case.

The heat exchanger designed by me has a length of 2.46 m and width of 0.35 m. It is a tube and shell type Heat exchanger which is arranged as staggered with 4 rows of tube and 8 tubes in each row. The number of baffles is calculated to be 16. This heat exchanger has a power consumption of 54.55 kW. A cooler can be used in case if the water is not cold enough to treat the flue gas in the summer. The treated flue gas is taken to the silencer for noise reduction and then taken out of the container using a flexible hose.

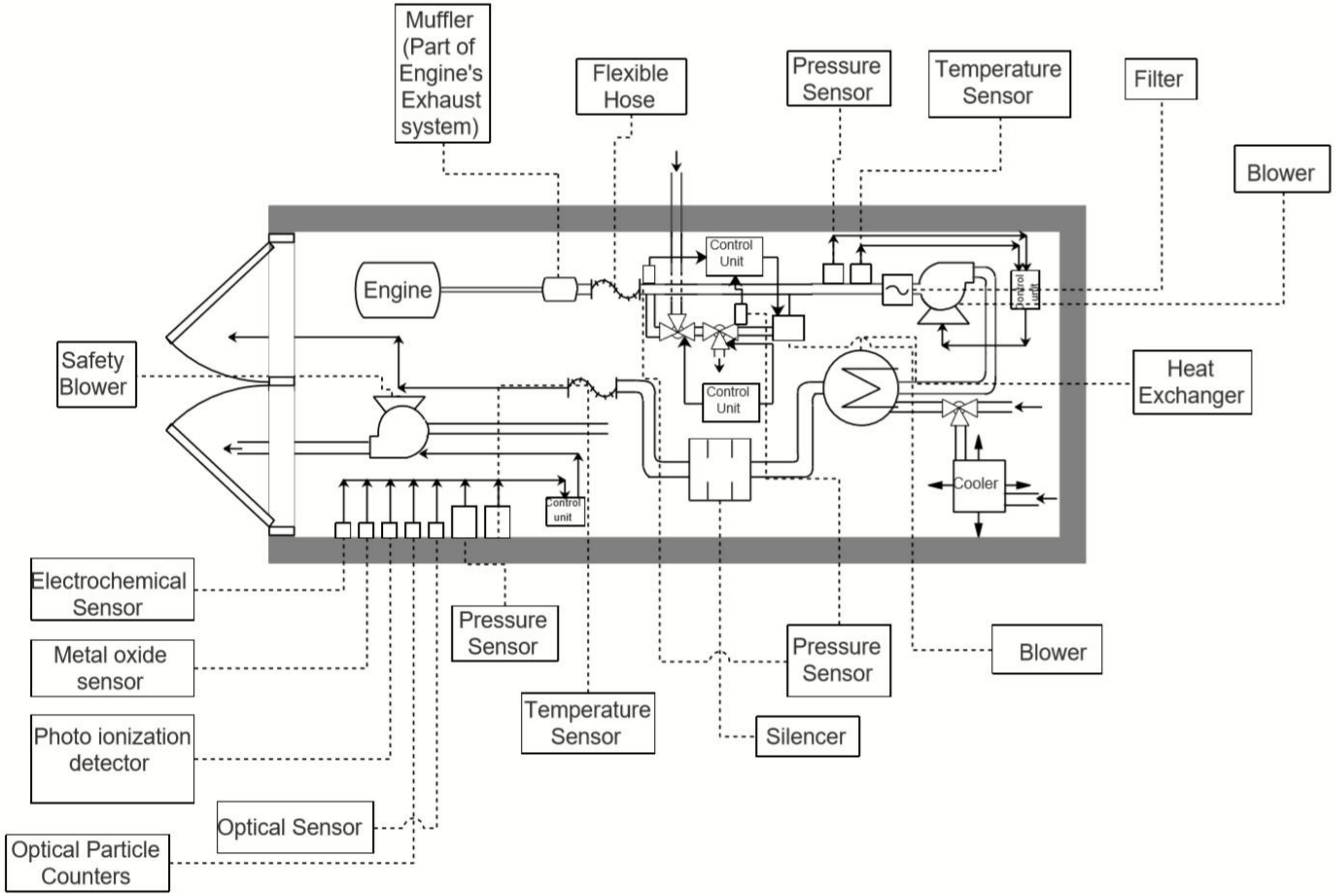


Figure 11: Design of the Universal Exhaust System (Author)

5.5. Pressure and Temperature sensors

The pressure and temperature sensors have a vital role in the safety and the efficiency of the system. The pressure sensor used for this place is KACISE GXPS series. The specification for this sensor can be seen below

Table 7: Specification of the pressure sensor [22]

Pressure range	0 ~ 2 bars……60 bars
Accuracy	±1%F.S, ±2%F.S, ±2.5%F.S
Operating temperature	-40 °C ~ 125 °C
Compensation temperature	-10 °C ~ 80 °C
Output signal	0 ~ 5V
Power supply	10 ~ 24 VDC
Pressure durable	2 . 10^6 pressure circle @25 °C

Figure 12 Pressure sensor [22]

The temperature sensor that is supposed to buy is Firstrate FST600-204.

Table 8: Specification of the temperature [23]

Voltage input	3 V to 30 VDC
Output range	0 V to 10 V
Temperature range	-50 °C to 400 °C

Figure 13: Temperature sensor [23]

5.6. Blower

The centrifugal blower used in this step is CXRT/4-500-1.5kW.

Table 9: Specification of the blower [24]

Motor Power (W)	1500
Supply (V)	230/400
Speed (RPM)	1420
Working point	Upto 5 kg/s @ 361 Pa
Diameter (mm)	500

Figure 14: Blower for the universal exhaust system [24]

5.7. Sampling System

The Sampling system is used to take samples of the flue gas more often. The analysers used by me are Brain bee Emission Analysers. There are 2 analysers which are used to analyse flue gas from petrol engine and diesel engine. For these analysers, some fresh air needs to be analysed first. I decided to make all the systems inside the container automatic so that no person needs to get inside. So, the analysers need to be sealed inside. This made me realise a Sampling system that can also take a fresh air, also take flue gas and then analyse automatically. The system consists of 3 sets of 3-way solenoidal valve. All these valves are connected to a control unit, so that it can be controlled remotely from outside.

The First valve blocks the flue gas and takes in fresh air. The second valve is the place where the Brain Bee AGS 200 (Petrol Engine Analyser) is sealed. In the third valve, the Brain Bee OPA 100 (Diesel Engine Analyser) is sealed. Depends on the type of engine using, the valves and the analyser can be controlled accordingly. The technical drawing for the sampling system can be seen in the Appendix B. The blower used for this system is SHYUAN YA CA120-98T. A blower is used so that there will be sufficient pressure to make the air flow in the sample system. There are 2 sensors used. One sensor is used to find the pressure of the incoming flue gas. Another sensor checks the pressure inside the sample system and operates the blower to maintain the flow inside.

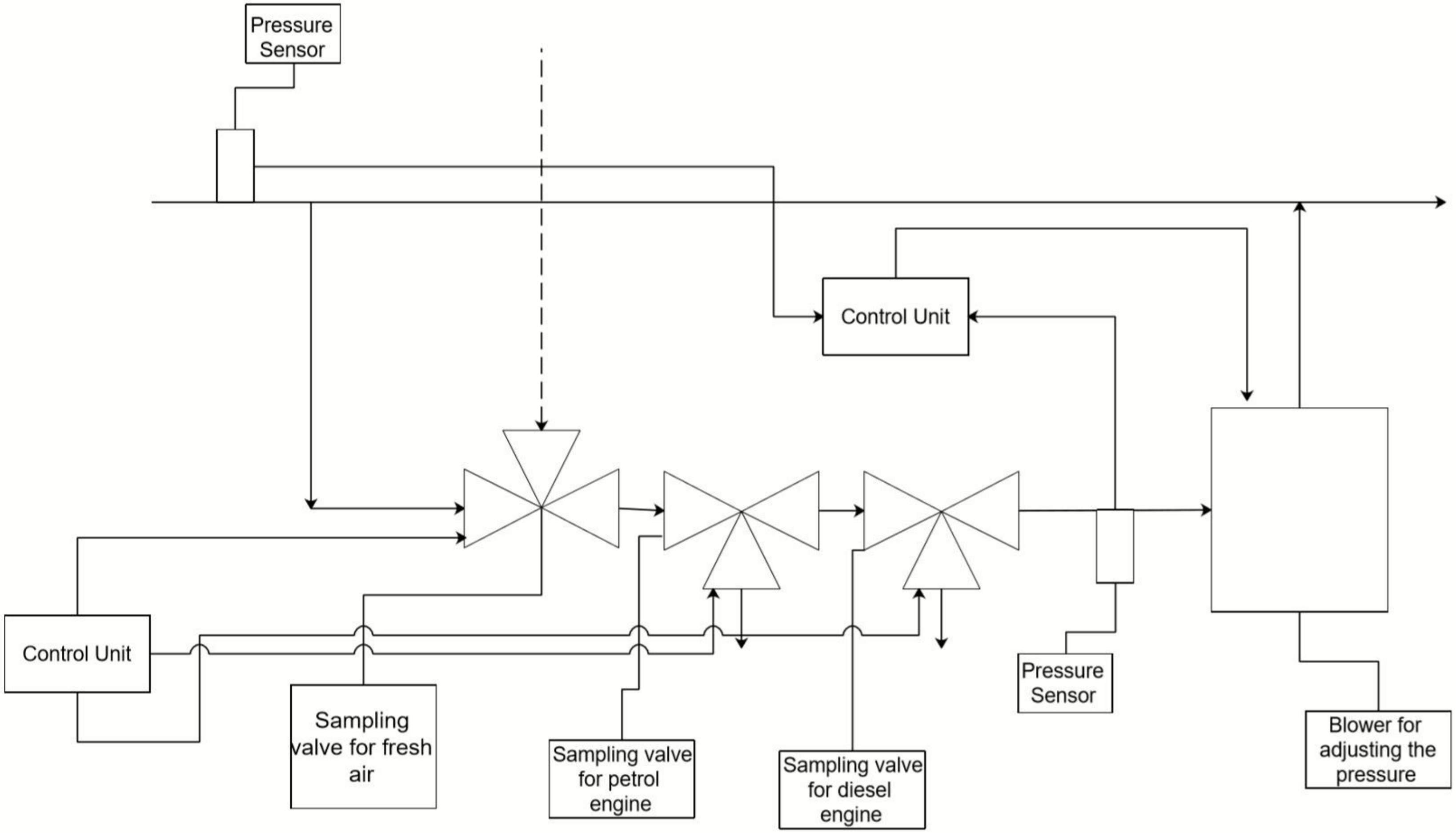


Figure 15: Sampling system (author)

Table 10: Specification for the pressure adjusting blower [25]

Type	Centrifugal fan
Blade material	Stainless steel
Mounting	Duct fan
Power	78 – 94 W
Voltage	115 V
Air flow	0.04 – 0.08 m^3/s

Figure 16: Pressure adjusting blower [25]

5.8. Safety System

A safety system is installed in order to reduce the temperature inside the room and also to detect the hazardous gas in the container and remove it by using a safety blower. The sensors used are listed as

- Electrochemical sensors
- Metal oxide sensor
- Photo ionization detector
- Optical particle counters
- Optical sensors

5.8.1. Electrochemical Sensors

The principle of this sensor depends on the chemical reaction between the electrode in a liquid inside the sensor and gases in the air. It is used to measure NO_2, SO_2, O_3, NO, CO. Depending on the electrolyte, it is highly sensitive to humidity variation and temperature [14].

The sensor to be bought is Aotoro FR12-2DO copper proximity sensor. The cost of this sensor is kc. 50 and has a specification of about 200 mA.

Figure 17: Electrochemical sensor [17]

5.8.2. Metal Oxide sensors

This sensor modifies its resistance when the gases in the air reacts to the sensor surface. The result can be affected by the variations of humidity and by temperature. It also varies depends on the past input history.

The sensor planned to buy is Alphasense P-type metal oxide VOC gas sensor. The specification can be seen in the table 7.

Table 11: Specification of Metal oxide sensor [18]

Model number	Measurement range (PPM)	EtOH sensitivity (PPM%)	C_3H_8 sensitivity (PPM%)	Operating temperature (°C)	Heater voltage (V)	Circuit voltage (VDC)
VOC-MF1	1-100	< 15	< 5	-20 to 120	2.7±0.2	24

Figure 18: Metal oxide sensor [18]

5.8.3. Photo ionization detector

This detector detects the resulting electric current by ionising the volatile organic compounds. It has good sensitivity and reacts to all volatile organic compounds that can be ionised by UV lamp, but the dependence on humidity effects and temperature is limited.

The product used for this process is VOC-TRAQ II from MOCON INC. The specification given for this detector is that it can remotely store up to 36,000 sample readings with the detector's internal memory with an optional rechargeable power supply or it can be connected to PC and take unlimited number of samples.

Figure 19: Photo ionization detector [19]

5.8.4. Optical Particle counters

This sensor basically measures the scattering of light by particles and detects the particulate pollution. It will be able to identify the particle size. The variety of parameters such as density, particle shape, colour, humidity, refractive index, all these affects the measured signals.

The product used for this process is Dekati DePS. The specification can be seen below

Table 12: Optical particle counter [20]

Sensitivity	Approx.. 1 µg/m^3
Saving interval	1 s
Operating condition	10-50 °C
Minimum particle size	Adjustable 4-15 nm
Maximum particle size	3 µm
Sample flow rate	0.5 lpm
Battery life	5-6 hours

Figure 20: Optical particle counter [20]

5.8.5. Optical sensors

This sensor measures the infrared light absorption and detects gases like carbon monoxide and carbon dioxide. The temperature, pressure and humidity affect the result of this sensor.

The brand name and model number for the used sensor is OEM OKY3105. The operating voltage is 3.3 -5 V and it weighs about 3 grams.

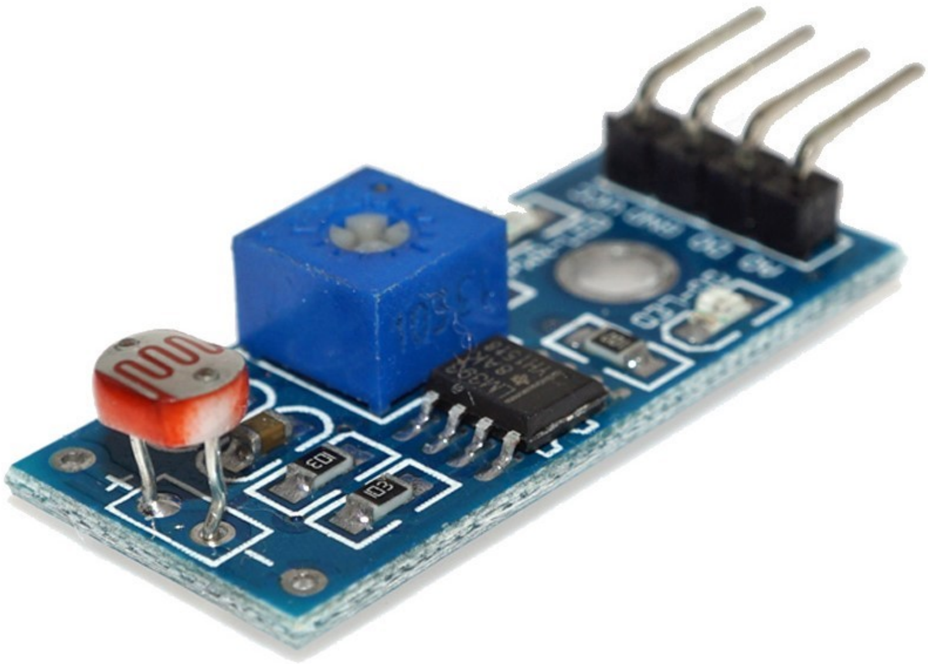


Figure 21: Optical sensor [21]

5.8.6. Safety Blower

Determination of Room Size (m)

= 2.43 . 2.59 . 6.06

Volume = 38.13 m^3

The necessary frequency for the ventilation of the given container is assumed to be 20.

Determination of Air Flow Required (m^3/s)

= Volume . Frequency / 60

= 38.13 . 20 / (60 . 60)

= 0.211 m^3/s

Therefore, the type of blower used as a safety blower is centrifugal blower with the air flow of 0.1 to 0.5 m^3/s.

The suitable blower for the safety system is SFD series from Chuan fan electric co.,ltd.

Figure 22: SFD series of Chuan fan electricals [16]

It has a specification which is as follows

Table 13: Specification of the Safety Blower [16]

Name	Output (kW)	Voltage (V)	Current (A)	Pressure (kPa)	Air flow (m^3/s)	Rotating speed (RPM)	Noise (dB)
SFD200-05AL	0.4	110/220	5/2.5	0.5/0.7	0.25/0.5	1400/1700	73/77

6. Modifications in the Proposed systems

My initial proposal doesn't have the sampling system which I have now. Since Brain bee analysers need the fresh air to be analysed first, the sampling system has been modified in the way it is now.

A filter is added in the system before the blower. This is used in case of the diesel engine where the whole system gets ash settled because of the smoke in the flue gas.

The Heat Exchanger calculated by me is itself a modification. I modified the mass flow and the diameter of the tubes in order to get an efficient heat exchanger.

The Safety system is added to the proposed system, so that no person should get harmed during the process. This system proposed by me is all about the safety inside the container. The planning layout can be seen in the Appendix A.

In my first proposed design, there was no water cooler for the heat exchanger. At normal times, the water from the outside is used, which has better effect on the flue gas. But at the time of summer, the water cannot be efficient for the heat exchanger. So, for this specific time, water cooler is used to cool inlet water to get a desired temperature. A solenoid valve is also added to it, so that it could be remotely operated.

The cooling system used for the heat exchanger is Tyrone TC-20WC. The specification for this cooler can be seen below.

Table 14: Specification of the cooler for the heat exchanger [26]

Flow rate	Upto 3 kg/s
Cooling capacity	233.4 MJ/h
Water tank capacity	510 L
Compressor power	15.68 kW
Voltage	380 V – 415 V/3 phase/50 Hz
Weight	750 kg

Figure 23: Cooler for the heat exchanger [26]

7. Conclusion

I have done some background research on the Combustion engine regarding co-generation units before the design of the Universal exhaust system. For the universal Exhaust System to be recognised technically, I have decided to take a real engine namely Skoda Octavia 1 1.8T 20V 110kW at 5700 rpm under consideration. With the known mass flow rate of this Engine, the diameter for the pipe of the Universal Exhaust system has been calculated. For the Sample to be taken efficiently and remotely, a sampling system has been designed.

For the temperature of the flue gas to be used efficiently, a heat exchanger was added. With the temperature, mass flow rate and few assumptions, the design of the heat exchanger is calculated. I chose to have a Shell and tube staggered Heat exchanger. According to the calculation, the designed heat exchanger has a dimension of 2.46 x 0.35 m^2 and has the Power consumption of about 54.55 kW.

The blower can be adjusted according to the incoming pressure using sensors. All the valves inside are solenoid and are connected to control units, so that it can be controlled remotely outside the room without the need of a person inside. A safety system installed inside has sensors that can detect air pollution, so that the safety blower starts working automatically in disposing the air outside. These are the precautions analysed for the safety of the system.

The planning layout of the proposed system's integration into the existing space proofs that the Universal exhaust system fits into a Standard container very well. Therefore, the task for designing the Exhaust system for the Experimental measuring stand equipped with an Internal Combustion Engine has been completed successfully.

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