ME-207L Thermodynamics Lab

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Experiment 0. Lab Guidelines

0.1 Course Learning Outcomes (CLOs)

The learning outcomes that are expected to be attained by the student at the end of the course are given in Table 0.1-1. The **CLO #3** is applicable only if lab is **Open Ended Lab (OEL)**. The List of **Program Learning Outcomes (PLOs)** of BS program of Mechanical Engineering Department are given in **Appendix A**.

Table 0.1-1: Course learning outcomes of ME-207L thermodynamics Lab

Sr. #	CLO Statement	Domain	Level	PLO
1	**DISPLAY** basic proficiency in operation of the apparatus and **PERFORM** the experiment to determine the solution of the engineering problems related to the subject.	Psychomotor	4	4
2	**Communicate** the learned concepts using different media i.e., verbal and written.	Affective	2	10
3	**Manifest** the professional responsibilities and norms of engineering practice.	Affective	3	8

The **Detail of Domains** and their Levels mentioned against each course learning outcome, is mentioned in **Appendix B**. The mapping of course learning outcomes with the program learning outcomes is given as in Table 0.1-2. The performance of you in course will be measured based on above learning outcomes using **Rubrics** mentioned in **Appendix C**.

Table 0.1-2: Relation of CLOs of thermodynamics Lab with PLOs

PLO #	PLO Statement	CLO1	CLO2	CLO3
PLO-1	**Engineering Knowledge**			
PLO-2	**Problem Analysis**			
PLO-3	**Design/Development of Solution**			
PLO-4	**Investigation**	✓		
PLO-5	**Modern Tool Usage**			
PLO-6	**The Engineer and Society**			
PLO-7	**Environment and Stability**			

PLO-8	**Ethics**			✓
PLO-9	**Individual and Team Work**			
PLO-10	**Communication**		✓	
PLO-11	**Project Management**			
PLO-12	**Life Long Learning**			

0.2 Guidelines for Lab Report

Lab report must be submitted/checked within **7 days effectively** after the experiment is conducted. Lab report may not be accepted/checked after due date and lab report marks may be deducted.

0.2.1 Content

The content contain guidelines about the report structure, the constituent headings and content to be written under the headings.

0.2.1.1 Cover Page

The cover page should contain the followings

- Lab Name
- Experiment Name
- Students' Name
- Group #
- Lab Instructor Name
- Date on which lab Experiment was conducted (See the Lab schedule for it)
- Submission date of Lab Report

The format and Alignment and arrangement of above mentioned is student's own choice.

0.2.1.2 Abstract

The abstract contains summary lab activity done and contains the following main points.

1. Purpose/ objective(s) of the experiment
2. Main results in the experiment
3. Main results of experiment
4. Main conclusion

The abstract should be of one paragraph with words not more than 200 words.

0.2.1.3 Introduction

This section is meant for describing the worth/importance/significance of your work. As a part of arguments for proving your work a useful one it is logical to briefly point out the similar work already done by others but a detailed literature review is not a part of introduction.

As a part of description of the importance of work you may also justify your choice of problem solution methodology. When there are potentially more than one approaches available for the solution of the same problem; it is logical to opt for the best available choice giving due regard to the resource constraints.

Through introduction of the report you try to convince the reader that your work is really useful. According to a researcher "Introduction is setting up the scene".

Wherever necessary there may be a separate section of theory but it must not be dragged into introduction.

0.2.1.4 Theory

It is an optional section and is included to appraise the reader the theory of your work. In the lab reports we normally do not recommend to include this section.

0.2.1.5 Procedure

In this section it is recommended to enlist the sequential steps for taking proper data. Wherever applicable a block diagram of the experimental set up is to be included. The diagrams should be properly labeled.

While writing a lab experiment procedure do not adopt the style of instructor. It is generally recommended to use past tense and passive voice. In technical writings the use of "I" and "We" is generally not appreciated.

0.2.1.6 Observations & calculations

It includes tabulation of observed data and calculations are required to be made for the meaningful analysis of results. Formulae involved in calculations need to be mentioned along with a sample of calculations. Graphical representation is a more effective way (than tabulation) of the presentation of results.

0.2.1.7 Discussion

In this section you are supposed to justify your results. The expected results need to be justified with the help of some standard references. Reasons should be mentioned for the unexpected results. In this case all possible sources of error need to be looked at while giving consideration to the individual contribution of each source of error towards the overall error in the final results. Comparison of results with similar investigations (already made using same or different technique) is an essential component of the discussion section of a report.

0.2.1.8 Conclusions

The conclusion expresses the main points (one or two) of the final results the lab.

0.2.1.9 References

Whatever information (other than own work of present report) has been used in writing of report needs to be properly referred (using a standard format of referring a book, a paper of a journal, a paper of a conference and information on a website). It is not sufficient to put a list of references at the end of a report. These references should also appear as numbers in square brackets in the main body of report.

0.2.2 Format

From **Semester 1** to **semester 4**, the report to be submitted containing the content as mentioned above, should be hand written. For **Semester 5 to Semester 8**, report to be submitted should be written on computer.

The following format should be followed for writing report on computer

Title page should always be documented on computer.

- **Font** should be **Times New Roman** (Whole Report)
- **Line Spacing** = 1.15 (whole report)
- **Title** should be of **font size = 16, Bold,**
- **Heading 1** should be of **font size = 14, Bold**
- **Heading 2** should be of **font size = 13, Bold**
- **Heading 3** should be of **font size = 12, Italic, Bold**
- **Page #** should be added.
- List of figure, List of table and Table of content**.**

0.2.3 Caption

For table: Above the Table aligned in center with table. **Font size: 10**

For Figure: Below the Figure aligned in center with figure. **Font size: 10**

0.2.4 References

Should be added in **IEEE format** using Endnote/word.

0.3 General Guidelines in a Lab for safety

The following guidelines are to be followed in a lab.

- No Laboratory work should be carried out without supervision of the Instructor or Lab technician.
- Do only experiment assigned to you and do not perform unauthorized experiment by yourself.
- Do not play with the equipment that are not part of experimental setup.
- Never leave an in-progress experiment unattended.
- Don not exceed voltage limits of devices when plugging them into electrical outlets.
- Do not try to repair or modify any lab equipment.
- Always wear a protective lab coat/overall and safety shoes. Long hair should be tied back.
- Be alert to unsafe conditions and actions and call them to the attention of the instructor immediately.
- Be careful not to touch any heated surfaces as they might cause a burn.
- Don't touch live conductor or wire with the bare hand.
- Don't work in lab all alone.
- Report all damages to lab instructor immediately.
- Leave equipment in proper places at the end of your experiments and cleanup.
- After completion of the experiments, return the items borrowed, if any.
- Don't run or paly in the lab.
- Eating drinking, smoking or chewing of gum is not permitted in the laboratory.
- Don't use cell phones inside the laboratory.
- Everyone is responsible for housekeeping and cleaning up after themselves. Aisles and doorways, including access to the service hallway and electrical boxes, are to be kept clear for purposes of safe passage.
- Report any cases of vandalism or theft to your instructor or staff member.
- Students should not perform any type of maintenance on equipment in the lab without prior authorization and direct supervision of the lab manager.
- Use appropriate safety equipment for the task at hand (i.e. safety glasses, ear protection, gloves). See your instructor or a staff member for guidance.
- In case of fire or hazardous chemical spill evacuate the premises immediately.

Experiment 1. Study of classification and working of internal combustion (IC) and External Combustion (EC) engines

1.1 Learning Objectives

i. Students will learn about different classifications of internal combustion (IC) and external combustion (EC) engines.
ii. In this experiment, students will be shown sectioned models of different IC and EC engines.
iii. Students will learn about working of steam engine, two-stroke and four-stroke engines.

1.2 Precautions

i. Use the sectioned models with care so as the finger(s) do not get caught in them.

1.3 Theory

The engine that produces mechanical work by combustion of fuel inside the engine is called internal combustion engine. There are two main types of engines based on their working principle i.e. rotary engines and reciprocating engines. In rotary engine, the combustion chambers and cylinders rotate with the driven shaft around a fixed control shaft to which pistons are affixed and the gas pressures of combustion are used to rotate the shaft. A reciprocating engine is an engine that uses one or more pistons in order to convert pressure into rotational motion. They use the reciprocating (up-and-down) motion of the pistons to translate this energy.

External combustion engines use their fuel to heat a gas or a vapor through the walls of an external chamber, and the heated gas or vapor is then transferred to the power cylinder. External combustion engines therefore require a heat exchanger or boiler to take in heat and as their fuels are burnt externally under steady conditions, they can in principle use any fuel. There are two main families of external combustion engines; steam engines which rely on expanding steam or occasionally some other vapor, to drive a mechanism, or Stirling engines which use hot air or some other hot gas.

Steam engine is based on Rankine cycle, which is also referred as the practical Carnot cycle, because when an efficient turbine is used, the T-s diagram begins to resemble the Carnot cycle.

1.4 Working Principle

Wankel engine uses eccentric rotary design to convert pressure into rotary motion. It has a triangular rotor which rotates and has combustion cavity on each side. It has three ports, one each for fuel inlet, fuel outlet and spark plug. Fuel enters one of the cavities and is compressed by the triangular rotor.

After compression, fuel is ignited by the spark plug and the burnt fuel is then exhausted out of the exhaust port.

Two-stroke and four-stroke engines are types of reciprocating engines. The two-stroke engine employs both the crankcase and the cylinder to achieve all the elements of the Otto cycle in only two strokes of the piston. The fuel/air mixture is first drawn into the crankcase by the vacuum that is created during the upward stroke of the piston. During the downward stroke, the inlet valve is forced closed by the increased crankcase pressure. The fuel mixture is then compressed in the crankcase during the remainder of the stroke. Toward the end of the stroke, the piston exposes the intake port, allowing the compressed fuel/air mixture in the crankcase to escape around the piston into the main cylinder. This expels the exhaust gasses out the exhaust port, usually located on the opposite side of the cylinder. Unfortunately, some of the fresh fuel mixture is usually expelled as well. The piston then rises, driven by flywheel momentum, and compresses the fuel mixture. At the same time, another intake stroke is happening beneath the piston. At the top of the stroke, the spark plug ignites the fuel mixture. The burning fuel expands, driving the piston downward, to complete the cycle. At the same time, another crankcase compression stroke is happening beneath the piston. Sectioned model of a two-stroke engine is shown in the Figure 1.

The four strokes of the cycle are intake, compression, power, and exhaust. Each corresponds to one full stroke of the piston and therefore, the complete cycle requires two revolutions of the crankshaft to complete. There are two types of four-stroke internal combustion engines i.e. spark ignition (SI) engines and compression ignition (CI) engines.

Spark ignition (SI) engines operate on Otto cycle and as the name suggests the fuel is ignited by the spark after the end of compression stroke. The spark plug is installed on the cylinder head and as soon as the fuel is compressed up to a certain point, the spark plug fires and the fuel is burnt pushing the piston downward and thus rotating the crankshaft for conversion of pressure into rotating motion. An example of spark ignition engine is the four-stroke gasoline engine whose sectioned model is shown in the Figure 2. Compression ignition (CI) engines operate on Diesel cycle and as the name suggests the fuel is ignited by the compression of the fuel only. No spark plug is required for a compression ignition engine. The compression ratio for this type of engine is higher than for a spark ignition engine which ignite the fuel, pushing the piston downward and thus rotating the crankshaft for conversion of pressure into rotating motion. An example compression ignition engine is a four-stroke diesel engine whose sectioned model is shown in the Figure 3.

Figure 1: Sectioned model of a two-stroke engine

Figure 2: Sectioned model of a four-stroke engine gasoline engine

Figure 3: Sectioned model of a four-stroke engine diesel engine

Since the two stroke engine fires on every revolution of the crankshaft, a two-stroke engine is usually more powerful than a four-stroke engine of equivalent size. This, coupled with their lighter, simpler construction, makes the two-stroke engine popular in chainsaws, line trimmers, outboard motors, snowmobiles, jet-skis, light motorcycles, and model airplanes. Unfortunately, most two stroke engines are inefficient and are terrible polluters due to the amount of unspent fuel that escapes through the exhaust port.

In a steam engine, fuel is burnt in a furnace and the hot gases usually pass through tubes surrounded by water i.e. fire tube boilers. Steam is generated under pressure. A safety valve is provided to release steam when the pressure becomes too high, to avoid the risk of an explosion. High pressure steam is admitted to a power cylinder through a valve, where it expands against a moving piston to do work while its pressure drops. The inlet valve closes at a certain point, but the steam usually continues expanding until it is close to atmospheric pressure, when the exhaust valve opens to allow the piston to push the cooled and expanded steam out to make way for a new intake of high-pressure steam. The valves are linked to the drive mechanism, to open or close automatically at the correct moment. The period of opening of the inlet valve can be adjusted by the operator to vary the speed and power of the engine. Sectioned model of a typical steam engine is shown in the Figure 4.

The most basic steam engine is about 5% efficient i.e. steam energy to mechanical shaft energy. However, with the addition of condenser, multiple expansions and high steam pressure and temperature, it may greatly be improved, but it is very difficult to achieve an efficiency beyond 20%.

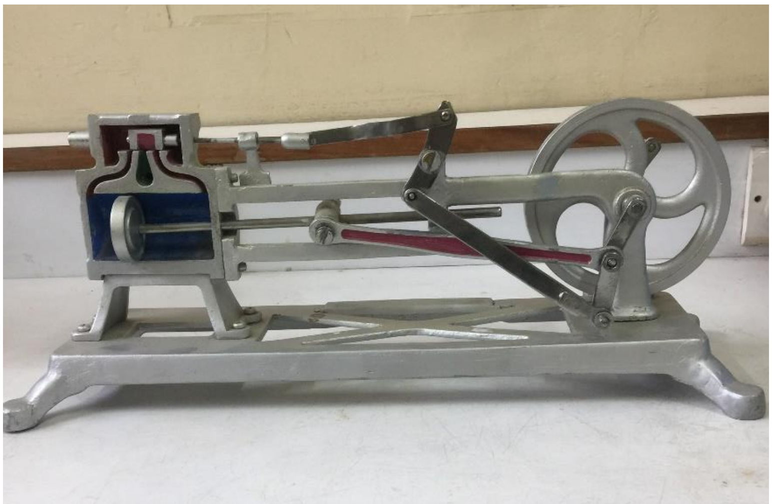

Figure 4: Sectioned model of a steam engine

1.5 Points of Discussion in the Lab Report

Classification of IC and EC engines and their working principle needs to be demonstrated in the lab reports.

Experiment 2. Study of Working Principle of Rotary Internal Combustion Engine

2.1 Learning Objectives

i. This experiment will be helpful in demonstration of governing principles for working of a Wankel engine

ii. The students will learn about the applications of steam engine

2.2 Precautions

i. Use the sectioned models with care so as the finger(s) do not get caught in them.

2.3 Theory

The engine that produces mechanical work by combustion of fuel inside the engine is called internal combustion engine. There are two main types of engines based on their working principle i.e. rotary engines and reciprocating engines. In rotary engine, the combustion chambers and cylinders rotate with the driven shaft around a fixed control shaft to which pistons are affixed and the gas pressures of combustion are used to rotate the shaft. A reciprocating engine is an engine that uses one or more pistons in order to convert pressure into rotational motion. They use the reciprocating (up-and-down) motion of the pistons to translate this energy.

Wankel engine is a type of rotary internal combustion engine which uses the rotating motion of the rotor to convert pressure into motion.

2.4 Working Principle of Wankel Rotary Engines

Wankel engine uses eccentric rotary design to convert pressure into rotary motion. It has a triangular rotor which rotates and has combustion cavity on each side. All parts of the engine rotate consistently in one direction, as opposed to common reciprocating piston engine. It has an advantage of simplicity, smoothness, compactness and greater revolutions per minute and a high power-to-weight ratio. This is because one revolution of Wankel engine contains three power pulses. Sectioned model of a typical Wankel engine is shown in the Figure 5.

In the Wankel engine, the four strokes of an Otto cycle occur in the space between a three-sided symmetric rotor and the inner boundary of the housing. In each rotor of the Wankel engine, the oval-shaped housing surrounds a rotor which is triangular with bow-shaped flanks. This shape helps in minimizing the wear and maximizing the compression ratio of the Wankel engine.

Figure 5: Sectioned model of a Wankel engine

Early engine designs had a high incidence of sealing loss, both between the rotor and the housing and also between the various pipes making up the housing. In earlier models, carbon particles could become trapped between the seal and the casing. The shape of the Wankel combustion chamber is more resistant to preignition operating at lower octane rating gasoline than a comparable piston engine. Sectioned model of a typical Wankel engine is shown in the Figure.

2.5 Points of Discussion in the Lab Report

To discuss the understanding of working principle of a Wankel engine.

Experiment 3. Study of performance characteristics of a 10hp horizontal water-cooled diesel engine

3.1 Learning Objectives

i. The students will learn about the working of a diesel engine
ii. This experiment will be helpful in in getting familiar with different parts of engine and understanding its working principle
iii. The students will learn about the effect of torque on different parameters like speed, power, efficiency and fuel consumption

3.2 Procedure

i. Make sure the engine has enough fuel for test.
ii. Open the water in dynamometer to avoid running dry.
iii. Note the pressure difference across air filter to calculate mass flowrate of air by using the formula:

$$m_a = C_d \times \frac{\pi d^2}{4} \sqrt{\frac{2P_a \Delta P}{RT_a}}$$

Where

P_a = Atmospheric pressure

ΔP = Air box differential pressure

T_a = Air inlet temperature

R = Gas constant, 287 J/Kg.K

iv. Measure the values of torque and rpm of engine by increasing the torque using dynamometer
v. Calculate the fuel flowrate by the following formula:

$$\dot{m}_f = \frac{\rho_f V_f}{t}$$

Where

ρ_f = Density of fuel

V_f = Fuel volume consumed

t = Time of fuel consumption

3.3 Precautions

i. Do not run the engine at load conditions without proper warmup
ii. Avoid touching heated parts of engine
iii. Do not turn off the water circulation until the engine has cooled down

3.4 Theory

Diesel engine is an internal combustion engine, in which ignition of fuel is caused by elevated temperature of air in the cylinder due to mechanical compression.

In diesel engine, inlet valves open and fuel enters the cavity while the piston descends on the intake stroke. An ignitable mixture of air is drawn into the cylinder by partial vacuum created. The air is compressed as the piston ascends on the compression stroke with both valves closed. As the end of the stroke is approached, fuel is injected into the combustion chamber. Temperature of air rises so high that fuel is burnt at this point, which pushes the piston. Power stroke follows with both valves still closed and gas pressure pushes on piston head. During the exhaust stroke, the piston ascends and pushes the exhaust gases out of the cylinder. Diesel engine used for experimentation is shown in Figure 6.

Figure 6: Kubota diesel Engine

3.5 Analysis of Data

Table 3: Effect of torque

Sr. No.	Torque (Nm)	Rotational Speed (rpm)	Fuel consumption rate (L/s)	Time (s)

Table 4: Change in efficiency with heat of combustion

Sr. No.	Heat of combustion (kW)	Air-to-Fuel ratio	Percentage efficiency

3.6 Graphs

Following four graphs are required:

- Torque vs. efficiency
- Torque vs. speed
- Torque vs. power
- Torque vs. fuel consumption

3.7 Points of Discussion in the Lab Report

Trend of the plots needs to be discussed to understand the effect of torque on different parameters.

Experiment 4. Study of Working of Stirling Engine

4.1 Learning Objectives

i. This experiment will be helpful in demonstration of governing principles for working of a Stirling engine
ii. The students will learn about the applications of Stirling engine

4.2 Apparatus Required

i. Stirling Engine
ii. Heat source with electrical input
iii. Torque meter
iv. Oscilloscope
v. Thermocouple
vi. Motor/generator unit
vii. Working fluid (Air for this case)

4.3 Procedure

i. Make sure that the load applied is zero on the torque meter and turn on the electrical input.
ii. Turn on the engine and this will start the working of the engine.
iii. Apply the load to determine the output power in the form of torque and velocity.
iv. Note down the values for input power, speed, weight, torque and output power.
v. Calculate the efficiency of the engine.

4.4 Precautions

i. Let the equipment running before measuring the mechanical output of the engine
ii. Keep cylindrical ports closed when operating on air
iii. Add weights gently to the pan
iv. Take all the general safety precautions related to electrical equipment

4.5 Theory

Stirling engine is a type of external combustion engine which uses hot air or a hot gas to drive a mechanism. It is a promising technology due to zero carbon emissions. It is an engine that derives its power from external heat source, assuming that there is a substantial temperature difference between engine and environment. These engines use pistons but the engine itself is sealed to the atmosphere. They can be supplied with heat from a variety of different sources including combustion fuels, waste heat and from solar heat energy. There are a range of different Stirling engine designs, but all rely on two pistons for each cylinder or unit. If a Stirling engine is driven mechanically it can act as a refrigerator. A free piston engine is another type of reciprocating engine, one that does not have a crankshaft of any mechanical constraint on the motion of its piston(s). The engines are often simple and potentially more efficient than crankshaft engines, but they are more difficult to engineer and exploit successfully. Stirling engine setup is shown in Figure 7.

Figure 7: Stirling engine setup

4.6 Working Principle of Stirling Engine

The Stirling engine operates with a closed system in which a working gas is successively heated and cooled. When the gas is heated, it expands. This is used to move a piston which rotates a crankshaft, which then will rotate. In this way, heat energy is converted to mechanical energy in the form of shaft power. The heat energy can be supplied to the working gas by a solar heater. This, of course, restricts operation to sunny days. The most commonly used method of heat supply is to collect the heat generated when some kind of fuel is burned and transfer this to the working gas via a heat exchanger. Air was used as working gas in the Stirling engines of the 19th century. Advanced designs of today use helium which gives improved performance but leads to much higher manufacturing requirements since helium may otherwise leak away from the system. There are three basic configurations of a Stirling engine. An alpha Stirling contains two power pistons in separate cylinders, one hot and one cold. The hot cylinder is situated inside the high temperature heat exchanger and the cold cylinder is situated inside the low temperature heat exchanger. This type of engine has a high power-to-volume ratio but has technical problems because of the usually high temperature of the hot piston and the durability of its seals. A beta Stirling has a single power piston arranged within the same cylinder on the same shaft as a displacer piston. The displacer piston is a loose fit and does not extract any power from the expanding gas but only serves to shuttle the working gas between the hot and cold heat exchangers. A gamma Stirling is simply a beta Stirling with the power piston mounted in a separate cylinder alongside the displacer piston cylinder, but still connected to the same flywheel. The gas in the two cylinders can flow freely between them and remains a single body.

4.7 Points of Discussion in the Lab Report

To discuss the understanding of working principle of Stirling engine.

Experiment 5. Study of performance characteristics of a 5.5hp gasoline engine

5.1 Learning Objectives

i. The students will learn about the working of a gasoline engine
ii. This experiment will be helpful in demonstration of governing principles for working of a gasoline engine
iii. The students will learn about the effect of torque on different parameters like speed, power, efficiency and fuel consumption

5.2 Procedure

i. Make sure the engine has enough fuel for test.
ii. Open the water in dynamometer to avoid running dry.
iii. Note the pressure difference across air filter to calculate mass flowrate of air by using the formula:

$$m_a = C_d \times \frac{\pi d^2}{4} \sqrt{\frac{2P_a \Delta P}{RT_a}}$$

Where

P_a = Atmospheric pressure

ΔP = Air box differential pressure

T_a = Air inlet temperature

R = Gas constant, 287 J/Kg.K

iv. Measure the values of torque and rpm of engine by increasing the torque using dynamometer
v. Calculate the fuel flowrate by the following formula:

$$\dot{m}_f = \frac{\rho_f V_f}{t}$$

Where

ρ_f = Density of fuel

V_f = Fuel volume consumed

t = Time of fuel consumption

5.3 Precautions

i. Do not run the engine at load conditions without proper warmup
ii. Avoid touching heated parts of engine
iii. Do not turn off the water circulation until the engine has cooled down

5.4 Theory

Gasoline engines are an important type of internal combustion engines and are used all around the world. They are mostly used for commercial purposes. Gasoline engines use gasoline as their fuel and a spark is required to burn the fuel, whereas a diesel engine uses mechanical compression to ignite the fuel.

In gasoline engine, the inlet valves open and the fuel enters while the piston descends on the intake stroke. An ignitable mixture of gasoline vapor and air is drawn into the cylinder by partial vacuum that was created because of the downward movement of the piston. The mixture is compressed as the piston ascends in the compression stroke with both valves closed. As the end the compression stroke approaches, the mixture is ignited by an electrical spark. The power stroke follows with both valves still closed and the gas pressure pushes against the piston head. The piston ascends again, and the exhaust valves are opened so that piston pushes the burnt fuel out of the exhaust valves. Gasoline engine setup is shown in Figure 8.

Figure 8: Gasoline engine

5.5 Analysis of Data

Table 5: Effect of torque on efficiency and heat of combustion, H_f

Sr. No.	Volume (mL)	Time (s)	Rotational Speed (rpm)	Torque (Nm)	Power (W)	$\dot{m}_f$ (kg/s) x10^{-4}	H_f	Efficiency

5.6 Graphs

Following four graphs are required:

- Torque vs. efficiency
- Torque vs. speed
- Torque vs. power
- Torque vs. fuel consumption

5.7 Points of Discussion in the Lab Report

Trend of the plots needs to be discussed to understand the effect of torque on different parameters.

Experiment 6. Study of working principle of a Marcet boiler

6.1 Learning Objectives

i. In this experiment, students will learn about the relationship between temperature and pressure using a Marcet boiler.
ii. The students will determine the vapor pressure curve

6.2 Procedure

i. Check all the valves in the water filled boiler.
ii. Turn on the electrical power to the boiler.
iii. Gradually increase the temperature of water and note down the temperature change vs. pressure change.
iv. Calculate the change and compare it with theoretical values.

6.3 Precautions

i. Do not open the valve at the water inlet port as it is at high temperature and pressure
ii. Never open the valve when boiler is heated as pressurized steam can cause severe injury

6.4 Theory

In this experiment a Marcet boiler was used to conduct the relationship between a saturated pressure. When the temperature increases pressure also increases in this case the relationship between pressure and temperature is directly proportional. Theoretically, the values from the steam table should almost be the same with the recorded values. In this case, if the values are not the same then this is due to error that was made in the experiment. Marcet reboiler unit is shown in the Figure 9.

Figure 9: Marcet boiler unit

6.5 Analysis of Data

Table 6: Experimental vs. theoretical comparison of dT/dP

Sr. No.	T (K)	P (psi)	P (kPa)	dT (K)	dP (Pa)	dT/dP (Exp.)	$\frac{T_{v_{fg}}}{h_{fg}}$	% age Error

6.6 Graphs

- Temperature vs. absolute pressure
- $(\frac{dT}{dP})_{sat}$ vs. Pressure
- $\frac{T_{v_{fg}}}{h_{fg}}$ vs. Pressure

6.7 Points of Discussion in the Lab Report

Trend of the plots needs to be discussed to understand the relation between temperature and pressure inside a Marcet boiler.

Experiment 7. Study of exhaust gas calorimeter to find exhaust gas flow rate and determination of heat carried by gas

7.1 Learning Objectives

i. Students will determine the exhaust gas flow rate
ii. This experiment will be helpful for students to determine the heat carried by the exhaust gas

7.2 Apparatus Required

i. Single piston horizontal cylinder diesel engine
ii. Finned tube calorimeter

7.3 Procedure

i. Run the engine and let it run for about five minutes
ii. Note the calorimeter readings for T_1, T_2, T_3 and T_4, where:

   T_1 = Inlet temperature of water

   T_2 = Outlet temperature of water

   T_3 = Inlet temperature of exhaust gas

   T_4 = Outlet temperature of exhaust gas

iii. Note the water volumetric flowrate, V, by calorimeter
iv. Now, calculate the mass flowrate of exhaust gas using energy balance equation.

$$\dot{m}_w = \dot{V} \times \rho$$

   According to energy balance:

$$\dot{Q}_{in} = \dot{Q}_{out}$$

$$\dot{m}_w C_{p1,w} T_1 + \dot{m}_{exh} C_{p1,exh} T_3 = \dot{m}_w C_{p2,w} T_2 + \dot{m}_{exh} C_{p1,exh} T_4$$

v. Calculate the heat content carried by the exhaust gas using the formula:

$$Q_{exh} = \dot{m}_{exh} C_{p,out} T_{exh}$$

vi. Repeat the procedure to get multiple readings

7.4 Precautions

i. If the test set has not been in use for a long period of time, drain all the water by opening the drain valve at the bottom

7.5 Theory

Determination of the thermal exhaust gas losses is essential when calculating an energy balance for internal combustion engines. Calorimetric measurement is an established method of doing this. It involves a largely complete and loss-free heat exchange between the exhaust gas and a cooling medium, water in this case.

A single piston horizontal cylinder was used for measuring of heat content of exhaust gases. Engine speed could be varied. It is important to find the energy losses in the engine to enhance the performance of the engine. The calorimeter used for measuring the heat content of exhaust gases is a shell and tube heat exchanger that consists of a series of tubes. One set of these tubes contains the cooling fluid that must be either heated or cooled. The second fluid runs over these tubes so that heat could be provided to or absorbed form the fluid inside the tubes. Finned tubes calorimeter is used for this experiment shown in Figure 10.

Figure 10: Exhaust gas calorimeter

7.6 Analysis of Data

Table 7: Values of temperatures at inlet and outlet

Sr. No.	Volume (mL)	Time (s)	$\Delta P_{orifice}$ (Pa)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)

Table 8: Determination of heat content of exhaust gas

Sr. No.	$\dot{Q}_{w,in}$ (kJ/s)	$\dot{Q}_{w,out}$ (kJ/s)	$\dot{m}_{exh}$ (kg/min)	$\dot{Q}_{exh}$ (kJ/s)

7.7 Points of Discussion in the Lab Report

To discuss the understanding of concept of measuring heat content of exhaust gas.

Experiment 8. Study of change of state of ideal gases

8.1 Learning Objectives

i. The students will study Boyle's Law at moderate pressures

8.2 Procedure

8.2.1 Boyle's Law

1. Check that the unit and all instruments are in proper condition
2. Make sure that the glass vessel is empty i.e. there is no oil in the glass chamber
3. If there is oil in glass chamber, then evacuate it by first turning on the pump and adjusting the handle on filling valve so that it starts evacuating the chamber.
4. Now turn on the pump and make sure that the control valve is open. Adjust the filling speed by pump speed control knob. Make sure the filling speed should be slow.
5. Fill the glass chamber with oil meanwhile observe the pressure gauge and height of air column.
6. As soon as the pressure increases, volume of air will begin to reduce in a hyperbolic manner.
7. Draw PV diagram of the observed values.

8.3 Precautions

i. Pressure inside the chamber should not exceed 3 bars
ii. If the pressure exceeds 3 bars, immediately turn off the control valve and pump

8.4 Theory

The experimental setup is shown in the Figure 11.

Figure 11: Experimental setup for Boyle's law and Gay-Lussac's law

8.4.1 Boyle's Law

The relation existing between the pressure exerted by a confined gas and its volume is given by what is usually known as Boyle's law, namely: The temperature remaining constant, the volume V occupied by a given mass of gas is inversely proportional to the pressure P to which it is subjected. In symbols:

$V \propto 1/P$

or

$V = k \times 1/P$

So,

$PV = k$

Where k is (numerically) a constant under given conditions.

8.5 Analysis of Data

Diameter = 0.1m

Total height of chamber = 0.25m

Table 9: Study of Boyle's Law

Sr. No.	Gauge Pressure (bar)	Absolute Pressure (bar)	Height (m)	Diameter (m)	Area (m^2)	Volume of air (m^3)

8.6 Graphs

- Pressure vs. volume
- Temperature vs. pressure

8.7 Points of Discussion in the Lab Report

Trend of the plots needs to be discussed to understand the Boyle's Law.

Experiment 9. Study of change of state of ideal gases

9.1 Learning Objectives

i. The students will study Gay-Lussac’s Law at moderate pressures

9.2 Procedure

9.2.1 Gay-Lussac’s Law

1. Check that the unit and all instruments are in proper condition.
2. Attach the hand air pump with the degassing valve
3. Fill up the chamber with air unless it reaches 10 psi gauge pressure.
4. Switch on heater and start noting values of pressure rise with temperature rise until temperature inside the chamber reaches 150^{o}C.
5. Draw pressure vs. temperature curve.

9.3 Precautions

iii. Pressure inside the chamber should not exceed 3 bars

iv. If the pressure exceeds 3 bars, immediately turn off the control valve and pump

9.4 Theory

The experimental setup is shown in the Figure 12.

Figure 12: Experimental setup for Boyle's law and Gay-Lussac's law

9.4.1 Gay-Lussac’s Law

Gay-Lussac's law states that:

The pressure of a gas of fixed mass and fixed volume is directly proportional to the gas' absolute temperature. Simply put, if a gas' temperature increases then so does its pressure, if the mass and volume of the gas are held constant. The law has a particularly simple mathematical form if the temperature is measured on an absolute scale, such as in Kelvin. The law can then be expressed mathematically as:

$P \propto T$

Or

$P/T = k$

Where:

P is the pressure of the gas (measured in atm).

T is the temperature of the gas (measured in Kelvin).

k is a constant.

9.5 Analysis of Data

Diameter = 0.1m

Total height of chamber = 0.25m

Table 10: Study of Gay-Lussac’s Law

Sr. No.	Gauge Pressure (bar)	Temperature (°C)

9.6 Graphs

- Pressure vs. volume
- Temperature vs. pressure

9.7 Points of Discussion in the Lab Report

Trend of the plots needs to be discussed to understand the Gay-Lussac’s Law.

Experiment 10. Expansion process of a perfect Gas

Study behaviour of a perfect gas and calculate properties of perfect gases like volume ratio, adiabatic ratio and specific heat.

10.1 Apparatus

10.2 Experiment 1

To find the adiabatic ratio of the ideal gas under consideration

10.2.1 Procedure

1. Check that equipment and connecting lines are in proper working condition.
2. Follow the general startup procedure.
3. Make sure that pressure in the tanks A and B is at atmospheric pressure or 0bar.
4. Turn the compressor on.
5. Increase the pressure in tank A/B by the pressurized air upto 160kpa. Then turn off the control valve. Turn off the compressor.
6. Note the reading of the temperate and pressure in the tank A/B.
7. Open the valve slightly to allow air flow out of the cylinder slowly, until it reaches atmospheric pressure.
8. Note down the pressure and temperature reading after the expansion.
9. Use the formula provided below to calculate the k.

10.2.2 Observations

Table 11: Adiabatic ratio of Ideal gas

Sr. No.	Temperature before expansion (°C)	Pressure (gauge) before expansion (bar)	Temperature after expansion (°C)	Pressure (gauge) after expansion (bar)
1.				
2.				
3.				
4.				

10.2.3Formulas

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

Appendix

Appendix A

Program Learning Outcomes (PLOs)

On the basis of the Knowledge Attributes defined in the Washington Accord, twelve (12) Program Learning Outcomes, also known as Graduate Attributes, are listed below:

(i) **Engineering Knowledge**: An ability to apply knowledge of mathematics, science and engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

(ii) **Problem Analysis**: An ability to identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

(iii) **Design / Development of Solutions**: An ability to design solutions for complex engineering problems and design systems, components, or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.

(iv) **Investigation**: An ability to investigate complex engineering problems in a methodical way including literature survey, design and conduct of experiments, analysis and interpretation of experimental data, and synthesis of information to derive valid conclusions.

(v) **Modern Tool Usage**: An ability to create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering activities, with an understanding of the limitations.

(vi) **The Engineer and Society**: An ability to apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solution to complex engineering problems.

(vii) **Environment and Sustainability**: An ability to understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.

(viii) **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

(ix) **Individual and Team Work**: An ability to work effectively, as an individual or in a team, on multifaceted and/or multidisciplinary settings.

(x) **Communication**: An ability to communicate effectively, orally as well as in writing on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentations, make effective presentations, and give and receive clear instructions.

(xi) **Project Management**: An ability to demonstrate management skills and apply engineering principles to one's own work, as a member and/or leader in a team to manage projects in a multidisciplinary environment.

(xii) **Lifelong Learning**: An ability to recognize importance of, and pursue lifelong learning in the broader context of innovation and technological developments.

Appendix B

Details of Domains

Cognitive		Affective		Psychomotor	
Level 1	Knowledge	Level 1	Receiving	Level 1	Perception
Level 2	Comprehension	Level 2	Responding	Level 2	Set
Level 3	Application	Level 3	Valuing	Level 3	Guided Response
Level 4	Analysis	Level 4	Organization	Level 4	Mechanism
Level 5	Synthesis	Level 5	Characterization by value or value complex	Level 5	Complex over response
Level 6	Evaluation			Level 6	Adaption
				Level 7	Organization

Appendix C

Lab Rubrics for ME-207L thermodynamics Lab

CLOs	Criteria	Poor (0 to 4)	Satisfactory (5-6)	Good (7-8)	Excellent (9-10)
CLO-1	**Apparatus Handling, Experiment Performance and Calculations**	No knowledge of apparatus, experiment not performed, nor any calculations done	Knows basic operation of the apparatus, performed the experiment with major errors in calculations	Can handle the apparatus well, experiment completely performed, and calculations have few mistakes	Fully understands the complete operation of the apparatus, experiment performed, and all calculations are correct
	Planning and Execution of an Experiment [OEL]	Experiment not planned for proper execution	Experiment planned but not executed properly	Experiment planned and executed but slight omissions	Experiment correctly planned and executed
CLO-2	**Communication [Report]**	Report neither covers technical details of experiment nor according to format	Correct report submitted according to format but not covering essential technical details	Report well written technically but format not completely followed / slight mistakes	Well-composed flawless report covering technical aspects of experiment
	Communication [Viva]	Either does not understand or cannot communicate concepts related to experiment	Understands the concepts related to experiment but does not communicate in technical terms	Understands and able to communicate the learned concepts but with slight mistakes	Fully understands all the concepts and can express them technically
CLO-3	**Punctuality, Teamwork and Safety**	Arrives too late for experiment with disregard to teamwork or safety	Arrives little late for experiment, somewhat adheres to teamwork and safety	Punctual but slightly lacking in teamwork and safety consciousness	Punctual, works as a team and adheres to safety instructions