**AGNEL INSTITUTE OF TECHNOLOGY AND DESIGN**

**ASSAGAO, BARDEZ, GOA- 403507**



**LAB MANUAL**

**APPLIED THERMODYNAMICS**

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**Introduction**

This course is intended to enhance the learning experience of the student in topics encountered in Applied Thermodynamics. In this lab, students are expected to practically observe the concepts in Applied Thermodynamics. How the student performs in the lab depends on his/her preparation, participation, and teamwork. Each team member must participate in all aspects of the lab to ensure a thorough understanding of the devices and concepts. The student, lab teaching assistant, and faculty coordinator all have certain responsibilities toward successful completion of the lab's goals and objectives.

**DO’s:**-

1. Students should carry observation notes and record completed in all aspects.
2. Students should be at their concerned experiment table, unnecessary movement is restricted.
3. Student should follow the indent procedure to receive and deposit the equipment to the Lab Assistant.
4. The readings must be shown to the Faculty In-Charge for verification.

**DON’Ts:-**

1. Don’t come late to the Lab.
2. Don’t leave the lab without the permission of the Faculty In-Charge.

### EXPERIMENT NO. 1 DATE:

### CONFORMANCE TO I LAW BY PETROL ENGINE

1. **Aim:** To investigate I law on a single cylinder CI (Diesel engine).
2. **Apparatus Required:**
3. Engine test rig with following specification,

Engine specifications:

* Type : 4-Stroke, Single cylinder Petrol Engine
* Make : Honda GX160
* Rated power output : 3.6 kW @ 3600 RPM
* Bore diameter ‘D’ : 0.068 m
* Stroke length ‘L’ : 0.045 m
* Compression ratio : 8.5:1
* Cylinder capacity : 256 cc
* Starting : Manual cranking
* Cooling system : Air cooled
* Dia of orifice : 0.016 m
* Loading : Eddy current loading

1. Stopwatch & scale.
2. **Practical Significance:** To investigate and ascertain the conformance of: the first law of thermodynamics on petrol engine
3. **Competency/Skill:** Investigation skill
4. **Objective:** To conduct the experiment for the,
   * + - 1. Conformance of I law
         2. Application of I law on a prime-mover
5. **Prerequisites:** Testing & performance, measurement and knowledge on I Law
6. **Concept/ Principle:** I Law of Thermodynamics
7. **Theory:**

### 8.1 First Law Conformance

James Prescott Joule (1818-1889) was working very sincerely in establishing the fact of conservation of energy. Though it was stated by Leibnitz in 1693, the international community did not accept his claim as he had not considered thermal energy. In fact this gave motivation to J. P. Joule to carry out the research in that direction involving heat. His constant work during 1843-1850 made him realize the fact that in a cycle heat and work are mutually convertible. This fact came as First law of thermodynamics. There are many interpretations and statements on first law, of which the following one is being used more commonly.

**8.1.1 Statement**

Whenever any closed system is taken through a cycle, the net work transfer taken place is proportional to the net heat transfer taken place with the surroundings. where, J is Joule’s constant which is taken as unity in SI units.

**8.1.2. Test**

During the engine operation the thermodynamic cycle is executed numerous amount of time. Therefore to investigate the conformance of the first law of thermodynamics by petrol engine, a single cycle is picked from these thermodynamic cycles and the net heat and work transfer during the selected cycle is determined by performing the experiment on the engine. According to the first law of thermodynamics, where, J is Joule’s constant which is taken as unity in SI units. Hence the above relation becomes

(8.1)

Thus the aim of the experiment is to show that the net heat transfer during each cycle is equal to the net work transfer and hence conformance of first law of thermodynamics to petrol engine

Equation (8.1) represents net heat and work interaction per cylinder per cycle. If we want the total heat interaction for all the cylinders of the engine and for all the cycles executed during the engine operation, equation (8.1) is multiplied by the number of cylinders pertaining to the engine (K=1, for the current case) and the number of cycles executed (n) during the engine operation. Where K is number of cylinders pertaining to the engine and n is the number of cycles executed during engine operation. For four stroke engine n= N/2, where N is the engine speed. Hence the equation (8.1) becomes

(8.2)

The L.H.S. of above equation represents total heat transfer during all the cycles in all the cylinders and is represented by. Whereas, the R.H.S of equation (8.2) represents the Indicated power (IP). For the present case K=1. To simplify the investigation by eliminating the detailed and elaborated calculation, first law conformance on SI engine is shown by showing for all cycles in all cylinders,

OR (8.3)

The L.H.S. of the above equation gives the net heat transfer for all the cycles in all cylinders. This net heat transfer is composed of the heat added during the heat addition or combustion process, heat rejected during the constant volume heat rejection process of the thermodynamic cycle and heat carried away by the exhaust gases. Hence these quantities are formulated as follows,

(8.4)

Where the rate of heat added during the combustion process and is the total heat rejected rate.

* + - 1. The rate of heat added during the combustion process is given by(,

where, the mass of the fuel consumed per cycle per cylinder and is the calorific value of the fuel which is fixed for Petrol (48000kJ/Kg-K).

Now,

where is the density of the fuel and is the volume of fuel consumed per unit time.

* + - 1. The total rate of Heat Lost (

is the heat given away during exhaust process occurring during the mechanical cycle which is taken as heat rejected at constant pressure.

Heat rejected is calculated without accounting for the heat lost to the cooling system since the engine is air cooled and no provision is made to calculate the heat rejected to air.

,

is the rate at which mass of air is consumed in the engine.

is the density of air

is the area of orifice

Where , the diameter of orifice.

is the velocity of the air across the orifice

is density of water in the manometer

is the difference in height of water column in manometer (manometer reading)

Now, ,

is the temperature of the exhaust gases.

is the ambient temperature (NTP), 27˚C

Where is the specific heat of exhaust at constant pressure. It is assumed to be that of air (1 KJ/Kg-K) as the facility for measuring Cp of exhaust is not provided in the test rig.

Considering the right hand side of the equation 8.3 which is the Indicated power (IP) and is given by relation,

*BrP* is the Brake power.

Now,

Where,

‘*N*’ is engine speed in rpm, ‘*F*’ is load indicator reading in kg, ‘*r*’ is radius of brake drum= 0.34m.

Where is the mechanical efficiency of the engine and is assumed to be 80%.

is the Brake power produced by the engine as shown in Figure-1.

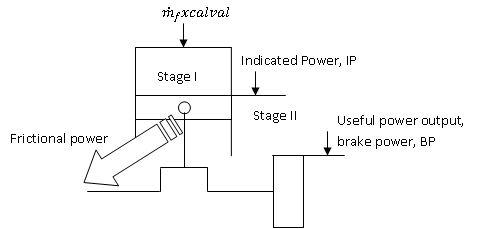


Figure-1 Power transmission to the generator

To summarize, the net heat interaction for all the cylinders and for all the executed cycles has been calculated which the L.H.S. of equation (8.3). Even the R.H.S. of equation has been found out. If we could plot a graph of IP vs and show that they are proportional by obtaining a straight line from which we can infer that single cylinder four stroke SI engine conforms to I law.

1. **Precautions:**
2. Do not run the engine without water supply.
3. Do not shut down the engine when maximum load applied to engine.
4. Engage clutch after the engine maintains speed.
5. After completion of experiment, turn OFF the fuel supply valve.
6. Do not turn off water supply immediately when experiment completes, wait for some time to maintain the engine temperature cool.
7. Remove one line of the battery wire after experiment is completed.
8. Do not cut off more than one cylinder at a time.
9. Change engine oil when oil turns to black colour.
10. Frequently, at least once in three months, grease all visual moving parts.
11. At least every week, operate the unit for five minutes to prevent any clogging of the moving parts.
12. **Procedure:**
13. Check the petrol in petrol storage tank.
14. Allow water to flow through the dynamometer
15. Put ‘ON’ ignition on button (spark plug NO) and start the engine by hand cranking.
16. Set the engine speed to 3000 rpm.
17. Keep the throttle position constant.
18. Applying load by rotating the regulator of eddy current dynamometer provided on the control penal.
19. Load applied is 0kg. Now take down the reading, air flow across orifice .
20. Note down time taken for particular quantity of fuel (10ml) consumed by the engine from the pipette and also note down the temperature from the temperature indicator.
21. For the next set of reading, gradually increased the load by 1 kg i.e. 1kg, 2kg, 3kg, 4kg and 5kg.
22. Read the required parameters for those various load.
23. Tabulate the readings.
24. After the experiment is over, unload the engine and put OFF the engine.
25. After a while stop the water flow by operating the values.
26. **Observation:**

Refer Table 1 for observation

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Load (kg) | Engine speed  N (rpm) | Brake Power  BrP in (kW) | Indicated power IP in (kW) | Time taken for 10 ml of fuel consumption  (sec) | Manometer reading in mm of water  (mm) | Mass flow rate of fuel  sec) | Mass flow rate of air  (sec) | Total Heat input  (kW) | Total Heat rejected  (kW) | Net heat interaction  (kW) | Exhaust temperature, Te (oC) |
| 0 |  |  |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |  |  |  |

**Table 1**

Te  is the temperature of exhaust gases.

CV=48000 kJ/kg

Orifice diameter d=0.016 m

1. **Model Calculation:**

**List of formulae**

* + - 1. Mass of fuel consumed per sec () :

= kg/sec

Where,

Pipette reading= Fixed volume of fuel consumed (10ml)

= Density of petrol

= 740 kg/m3

*t* = Time taken for 10 ml of fuel consumption.

* + - 1. Heat input (HI)

HI= CVin kW

CV=Calorific value of petrol= 48,000 kJ/kg (approx.)

* + - 1. Mass of air consumed per sec() :

= in kg/sec

i.e. m/sec

=0.62,

in m2 , d=0.016 m

in mm of water from manometer reading

g= 9.81 m/s2

= Density of air

= 1.16 kg/m3

Density of water

= 1000 kg/m3

* + - 1. Mass of exhaust per sec :

* + - 1. Total heat rejected per sec (

Where, is the heat given away during exhaust process occurring during the mechanical cycle which is taken as heat rejected at constant pressure.

Now,

*,*

Whereis the specific heat of exhaust at constant pressure and is assumed to be equal to that of an ideal gas (Cp =1.005kJ/kg-K).

is the temperature of the exhaust gases.

is the ambient temperature (NTP)(270C)

1. Brake Power (*BrP*)
2. Indicated power (IP):
3. **Graphs:**

A graph of Indicated power (IP) vs Net heat interaction for all the cycles in all cylinders () is plotted as shown in Figure-2. The graph is seen to be of straight line nature which indicates IP is directly proportional to net heat interaction for all cycles in all cylinders. Thus it conforms to I law of thermodynamics.

Figure-2 Graph of IP vs

IP (kW)

(kW)

1. **Conclusion:**

The graph obtained by plotting Indicated power versus net heat interaction for all cycles in all cylinders is a straight line graph which indicates that the indicated power is directly proportional to the Net heat interaction in the engine. Thus I law is conformed by four stroke single cylinder SI engine.

EXPERIMENT NO.2 DATE:

**CONFORMANCE TO II LAW BY PETROL ENGINE**

1. **Aim:** To investigate II law on a single cylinder SI (Petrol engine).
2. **Apparatus required:**
3. Engine test rig with following specification,

Engine specifications:

* Type : 4-Stroke, Single cylinder Petrol Engine
* Make : Honda GX160
* Rated power output : 3 kW @ 3600 RPM
* Bore diameter ‘D’ : 0.068 m
* Stroke length ‘L’ : 0.045 m
* Compression ratio : 8.5:1
* Cylinder capacity : 256 cc
* Starting : Manual cranking
* Cooling system : Air cooled
* Dia. of orifice : 0.016 m
* Loading : Eddy current loading

1. Stopwatch & scale.
2. **Practical Significance:** To investigate and ascertain the conformance of the second law of thermodynamics on petrol engine.
3. **Competency/Skill:** Investigation skill
4. **Objective:** To conduct the experiment for the,
5. Conformance of II law
6. Application of II law on a prime-mover
7. **Prerequisites:** Testing & performance, measurement and knowledge on II Law
8. **Concept/ Principle:** II Law of Thermodynamics
9. **Theory:**

**8.1 Second Law of Thermodynamics**

The first-law thermodynamics gave impetus to almost all the developments in thermal engineering. As a statement it means energy heat which can be converted into work in a cyclic device or process. The first corollary derived out of first law reduced down the facts to a process, in which heat at one side will be equal to the sum of work transfer and change in internal energy in the other side. It is just the energy balance, without regard to their nature and direction of energy flow. Moreover, the first law does not categorically say how to apply in the situation wherein irreversibility is involved. It does not quantify irreversibility. These are the major shortcomings of I-law.

Second law works on this direction of assigning direction constraint to a process. It introduces a concept of Thermal Energy Reservoir (TER). Along with TER we have to have a cyclic device to convert the heat received form the source and to complete the cycle it has to reject heat to the sink. Thus the second law projects the requirement of a source, a cyclic device which can either a power producing or power consuming and a sink.

**8.1.1 Kelvin-Planck Statement**

It is impossible to construct a device that will operate in a cycle and produce no effect other than the raising of a weight and the exchange of heat with a single reservoir.

 (8.1)

As QH>QL, η<1.

* + 1. **Test**

Conformance of second law of thermodynamics on engine is investigated in two steps,

1. *By investigating the I law conformance on single cylinder SI (Petrol engine).*

This is done by performing an experiment on single cylinder petrol engine and showing that with the help a graph of net heat interaction ( versus indicated power (*IP*). The graph should be an increasing curve as shown in figure 2 which proves the I law conformance of single cylinder SI engine.

(kW)

IP (kW)

Figure 2 : Graph of IP vs

1. *By computing different efficiencies and showing a particular relation between them.*

Here we compute three different efficiencies namely the brake thermal efficiency, Carnot efficiency and the air standard efficiency comparing which we can show that the II law is conformed as detailed below.

1. Brake thermal efficiency,

It is the ratio of brake power to the net heat input i.e.

(8.3)

Where is the brake power for this particular engine given by,

is the heat input to the engine given by,

CV (8.4)

is fuel consumption per unit time.

CV=Calorific value of petrol= 48,000 kJ/kg (approx.)

We show here that which shows that Kelvin-Plank statement of second law is not violated .However, its learnt from Carnot theorem that this is supposed to less than the Carnot efficiency and also lesser than the air standard efficiency.

1. Carnot efficiency,

It depends on the lower and higher temperature limits the engine is undergoing and is given by,

(8.5)

Where, is the lowest temperature in the thermodynamic cycle,

, is the maximum temperature in the thermodynamic cycle.

To find and the engine assumed to be following air standard Otto cycle as shown below,

3

P

4

2

1

V

Figure 3: PV diagram for Otto cycle

In the above graph is assumed to be at NTP condition i.e. 270c or 300K. Considering process 1-2 which is the reversible adiabatic process, we can state the relation as,

(8.6)

From the engine specification we get the value of compression ratio (r) to be 6.5. Hence we can calculate temperature at the end of compression by,

(8.7)

Our target is to get maximum temperature which is in this cycle. From this we can calculate Carnot efficiency. We use the energy balance equation during combustion process as given below,

) (8.8)

Where as it assumed that the air fuel mixture will behave like air owing to containing greater portion of air.

is the mass flow rate of air.

The only unknown in the above equation is which can be found by rearranging the terms.

1. Air standard efficiency

It is the theoretical efficiency of the SI engine which depends on only single parameter i.e. the compression ratio (r=6.5 of this SI engine) and is formulated as,

(8.9)

Having calculated the three efficiencies, we can show that the following relation is strictly followed,

(8.10)

The above relation can be represented in graphical manner. Thus the second law of thermodynamics is conformed by 4-S SI engine.

1. **Precautions:**
2. Do not run the engine without water supply.
3. Do not shut down the engine when maximum load applied to engine.
4. Engage clutch after the engine maintains speed.
5. After completion of experiment, turn OFF the fuel supply valve.
6. Do not turn off water supply immediately when experiment completes, wait for some time to maintain the engine temperature cool.
7. Remove one line of the battery wire after experiment is completed.
8. Do not cut off more than one cylinder at a time.
9. Change engine oil when oil turns to black colour.
10. Frequently, at least once in three months, grease all visual moving parts.
11. At least every week, operate the unit for five minutes to prevent any clogging of the moving parts.
12. **Procedure:**
13. Check the petrol in petrol storage tank.
14. Allow water to flow through the dynamometer
15. Put ‘ON’ ignition on button (spark plug NO) and start the engine by hand cranking.
16. Set the engine speed to 3000 rpm.
17. Keep the throttle position constant.
18. Applying load by rotating the regulator of eddy current dynamometer provided on the control penal.
19. Load applied is 0kg. Now take down the reading, air flow across orifice.
20. Note down time taken for particular quantity of fuel (10ml) consumed by the engine from the pipette and also note down the temperature from the temperature indicator.
21. For the next set of reading, gradually increased the load by 1 kg i.e. 1kg, 2kg, 3kg, 4kg and 5kg.
22. Read the required parameters for those various load.
23. Tabulate the readings.
24. After the experiment is over, unload the engine and put OFF the engine.
25. After a while stop the water flow by operating the values.
26. **Observation**

For observation, refer Table 1

**Table 1**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sr. no. | Load , F  (kg) | N (rpm) | BrP  ( kW) | (%) | *TH*  (K) | ( %) | (%) |
| 1 | 1 |  |  |  |  |  |  |
| 2 | 2 |  |  |  |  |  |  |
| 3 | 3 |  |  |  |  |  |  |
| 4 | 4 |  |  |  |  |  |  |
| 5 | 5 |  |  |  |  |  |  |

1. **Sample Calculation**

**Note.**

**Step1** of the experiment is similar to experiment no.1 **“Conformance of engine to I law”** in which a graph of **IP v/s**  is plotted which comes to be a **linearly increasing graph**. Therefore the calculations carried out in the **experiment 1 should be referred**.

**Step2:**

1. Brake thermal efficiency,

Where

= 75 %

Kelvin-Plank statement)

1. Carnot efficiency ,

, *r=*6.5;

)

Where

is the mass flow rate of air.

1. Air standard efficiency,

It is to be noted that the following relation should be strictly followed,

1. **Graph**

To show the above relation i.e. equation (8.10) graphically we plot the three efficiency values versus A/F ratio. The nature of the three curves is indicated in Figure 4.

A/F

Figure 4: Graph of vs. A/F

From the graph it is clear that the Carnot efficiency is maximum amongst all the efficiencies. Further we see that the efficiency of Otto cycle is constant for the given engine as it depends on the compression ratio which is fixed for a given engine. The brake thermal efficiency is lowest among all the efficiency values.

1. **Conclusion**

* The graph of IP v/s comes out to be a linearly increasing curve which proves that I law is conformed by single cylinder 4-S SI engine.
* It was observed that which follows Kelvin-Plank statement of second law.
* The efficiencies were also seen to follow the relation ,

, strictly which clearly proves the Carnot theorem i.e. Carnot efficiency is the maximum efficiency among all efficiencies calculated for the engine operating between the two given constant temperature reservoirs.

Considering the above statements we can say that the SI engine under investigation is conforming to the second law of thermodynamics.

### EXPERIMENT NO. 3 DATE:

### CONFORMANCE TO I LAW BY DIESEL ENGINE

1. **Aim:** To investigate I law on a multi-cylinder CI (Diesel engine).
2. **Apparatus Required:**
3. Engine test rig with following specification,

Engine specifications:

* Type : 4-Stroke, 4-cylinder Diesel Engine (Water cooled)
* Make : Hindustan Motors
* Rated power output : 26 HP @ 4000 RPM
* Bore diameter ‘D’ : 0.070 m
* Stroke length ‘L’ : 0.089 m
* Compression ratio : 17.5:1
* Starting : Ignition starting
* Cooling system : Water cooled
* Dia. of orifice : 0.016 m

1. Loading : Eddy current loading
2. Stopwatch & scale.
3. **Practical Significance:** To investigate and ascertain the conformance of: the first law of thermodynamics on diesel engine
4. **Competency/Skill:** Investigation skill
5. **Objective:** To conduct the experiment for the,
   * + - 1. Conformance of I law
         2. Application of I law on a prime-mover
6. **Prerequisites:** Testing & performance, measurement and knowledge on I Law
7. **Concept/ Principle:** I Law of Thermodynamics
8. **Theory:**

### 8.1 First Law Conformance

James Prescott Joule (1818-1889) was working very sincerely in establishing the fact of conservation of energy. Though it was stated by Leibnitz in 1693, the international community did not accept his claim as he had not considered thermal energy. In fact this gave motivation to J. P. Joule to carry out the research in that direction involving heat. His constant work during 1843-1850 made him realize the fact that in a cycle heat and work are mutually convertible. This fact came as First law of thermodynamics. There are many interpretations and statements on first law, of which the following one is being used more commonly.

**8.1.1 Statement**

Whenever any closed system is taken through a cycle, the net work transfer taken place is proportional to the net heat transfer taken place with the surroundings. where, J is Joule’s constant which is taken as unity in SI units.

**8.1.2. Test**

During the engine operation the thermodynamic cycle is executed numerous amount of time. Therefore to investigate the conformance of the first law of thermodynamics by diesel engine, a single cycle is picked from these thermodynamic cycles and the net heat and work transfer during the selected cycle is determined by performing the experiment on the engine. According to the first law of thermodynamics, where, J is Joule’s constant which is taken as unity in SI units. Hence the above relation becomes

(8.1)

Thus the aim of the experiment is to show that the net heat transfer during each cycle is equal to the net work transfer and hence conformance of first law of thermodynamics to diesel engine

Equation (8.1) represents net heat and work interaction per cylinder per cycle. If we want the total heat interaction for all the cylinders of the engine and for all the cycles executed during the engine operation, equation (8.1) is multiplied by the number of cylinders pertaining to the engine (K=1, for the current case) and the number of cycles executed (n) during the engine operation. Where K is number of cylinders pertaining to the engine and n is the number of cycles executed during engine operation. For four stroke engine n= N/2, where N is the engine speed. Hence the equation (8.1) becomes

(8.2)

The L.H.S. of above equation represents total heat transfer during all the cycles in all the cylinders and is represented by. Whereas, the R.H.S of equation (8.2) represents the Indicated power (IP). For the present case K=1. To simplify the investigation by eliminating the detailed and elaborated calculation, first law conformance on SI engine is shown by showing for all cycles in all cylinders,

OR (8.3)

The L.H.S. of the above equation gives the net heat transfer for all the cycles in all cylinders. This net heat transfer is composed of the heat added during the heat addition or combustion process, heat rejected during the constant volume heat rejection process of the thermodynamic cycle and heat carried away by the exhaust gases. Hence these quantities are formulated as follows,

(8.4)

Where the rate of heat added during the combustion process and is the total heat rejected rate.

* + - 1. The rate of heat added during the combustion process is given by(,

where, the mass of the fuel consumed per cycle per cylinder and is the calorific value of the fuel which is fixed for Diesel (40000kJ/Kg-K).

Now,

where is the density of the fuel and is the volume of fuel consumed per unit time.

* + - 1. The total rate of Heat Lost (

Where

is the rate of heat lost to the water flowing in the water jacket surrounding the cylinder.

is the heat given away during exhaust process occurring during the mechanical cycle which is taken as heat rejected at constant pressure.

Now, ,

is specific heat of water at constant pressure = 4.2 kJ/kg-K (Constant).

is mass flow rate of water flowing in the water jacket in kg/s.

is the temperature of water entering the water jacket.

is the temperature of water leaving the water jacket.

,

is the rate at which mass of air is consumed in the engine.

is the density of air

is the area of orifice

Where , the diameter of orifice.

is the velocity of the air across the orifice

is density of mercury in the manometer.

is the difference in height of mercury column in manometer (manometer reading)

Now, ,

is the temperature of the exhaust gases before calorimeter.

is the ambient temperature (NTP)(270C)

Where is the specific heat of exhaust at constant pressure. This is found using the heat exchanged at the calorimeter by the exhaust gases. The calorimeter is insulated at the walls and hence all the heat rejected by the exhaust gases is taken away by the coolant flowing through the calorimeter. In this case the coolant used is the water whose specific heat is known. Hence the heat balance equation at the calorimeter is given as,

Heat lost by exhaust gases = Heat gained by cooling water

Where is the mass flow rate of water which is measured at the calorimeter outlet coolant line by measuring the time required to collect fixed quantity of coolant water (500 ml).

= Mass flow rate of water.

= Volume flow rate of coolant (water)

are the temperature of exhaust before calorimeter, the temperature of exhaust after calorimeter, the temperature of coolant water before calorimeter, the temperature of coolant water after calorimeter and are measured on the temperature indicator.

is the specific heat at constant pressure of coolant water and is constant = 4.2 kJ/kg-K.

Considering the right hand side of the equation 8.3 which is the Indicated power (IP) and is given by relation,

*BrP* is the Brake power.

Now,

Where,

‘*N*’ is engine speed in rpm, ‘*F*’ is load indicator reading in kg, ‘*r*’ is radius of brake drum= 0.34m.

Where is the mechanical efficiency of the engine and is assumed to be 80%.

is the Brake power produced by the engine as shown in Figure-1.

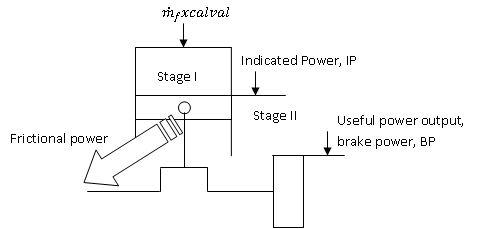


Figure-1 Power transmission to the generator

To summarize, the net heat interaction for all the cylinders and for all the executed cycles has been calculated which the L.H.S. of equation (8.3). Even the R.H.S. of equation has been found out. If we could plot a graph of IP vs and show that they are proportional by obtaining a straight line from which we can infer that single cylinder four stroke SI engine conforms to I law.

1. **Precautions:**
2. Do not run the engine without water supply.
3. Do not shut down the engine when maximum load applied to engine.
4. Engage clutch after the engine maintains speed.
5. After completion of experiment, turn OFF the fuel supply valve.
6. Do not turn off water supply immediately when experiment completes, wait for some time to maintain the engine temperature cool.
7. Remove one line of the battery wire after experiment is completed.
8. Do not cut off more than one cylinder at a time.
9. Change engine oil when oil turns to black colour.
10. Frequently, at least once in three months, grease all visual moving parts.
11. At least every week, operate the unit for five minutes to prevent any clogging of the moving parts.
12. **Procedure:**
13. Check the diesel in diesel tank.
14. Allow water to flow through the calorimeter.
15. Allow diesel, start the engine by key provided without engaging the clutch.
16. Engage the clutch, set the engine speed, by adjusting the speed regulator (throttle)provided at the control panel.
17. Apply load by rotating the regulator of Eddy current dynamometer provided on the control panel.
18. Now adjust the speed using speed regulator.
19. Now take down the load reading shown on the load indicator (Dial gauge).
20. Note down water flow rate (rotameter) reading and time for water meter reading, different temperatures, speed, fuel consumption (TFC) and air flow across orifice ( measured using manometer).
21. Repeat the procedure 5 to 8 for different loads.
22. Tabulate the readings.
23. After the experiment is over, disengage the clutch, put off the engine and keep the diesel control valve at off position.
24. Stop the water flow after a while by operating the valves.
25. **Observation:**

Refer Table 1 for observation

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Load meter reading (kg) | Engine speed  (RPM) | Brake Power  BrP in (kW) | Indicated power IP in (kW) | Fuel consumed TFC  (kg/hr.) | Mass flow rate of fuel  sec) | Manometer reading in mm of Hg  (mm) | Total Heat input  (kW) | Total Heat rejected  (kW) | Net heat interaction  (kW) | Temperature Points (oC) | | | | | |
| T2 | T3 | T4 | T5 | T6 | T7 |
| 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1.5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2.5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Table 1**

T2= Engine water inlet temperature; T3= Engine water outlet temperature;

T4= Exhaust gas temperature before calorimeter; T5=Calorimeter water inlet temperature; T6= Calorimeter water outlet temperature ;T7= Exhaust gas temperature after calorimeter

Specific heat of water= 4.2 kJ/kg-K

CV=40000kJ/kg; Orifice diameter d=0.016 m

1. **Model Calculation:**

**List of formulae**

* + - 1. Mass of fuel consumed per sec () :

= kg/sec

Where,

TFC is fuel consumed in kg/hr.

* + - 1. Heat input (HI)

HI= CVin kW

CV=Calorific value of Diesel = 40,000 kJ/kg (approx.)

* + - 1. Mass of air consumed per sec() :

= in kg/sec

i.e. m/sec

=0.62,

in m2 , d=0.016 m

is manometer difference in mm of mercury.

g= 9.81 m/s2

= Density of air = 1.10 kg/m3

Density of mercury = 13600 kg/m3

* + - 1. Mass of exhaust per sec :

* + - 1. Total heat rejected per sec (

Where,

is the rate of heat lost to the water flowing in the water jacket surrounding the cylinder.

is the heat given away during exhaust process occurring during the mechanical cycle which is taken as heat rejected at constant pressure.

Now, ,

is specific heat of water at constant pressure = 4.2 kJ/kg-K (Constant).

is mass flow rate of water flowing in the water jacket in kg/s.

is the temperature of water entering the water jacket.

is the temperature of water leaving the water jacket.

*,*

Whereis the specific heat of exhaust at constant pressure.

is the temperature of the exhaust gases before calorimeter.

is the ambient temperature (NTP)(270C)

* + - 1. Specific heat of exhaust ()

is the mass flow rate of water which is measured at the calorimeter outlet coolant line by measuring the time required to collect fixed quantity of coolant water (500 ml).

= Mass flow rate of water.

= Volume flow rate of coolant (water)

1. Brake Power *(BrP)*

Where,

‘*N*’ is engine speed in rpm, ‘*F*’ is load indicator reading in kg, ‘*r*’ is radius of brake drum= 0.34m.

1. Indicated power (IP):
2. **Graphs:**

A graph of Indicated power (IP) vs. Net heat interaction for all the cycles in all cylinders () is plotted as shown in Fig 2. The graph is seen to be of straight line nature which indicates IP is directly proportional to net heat interaction for all cycles in all cylinders. Thus it conforms to I law of thermodynamics.

Fig. 2 Graph of IP vs

(kW)

IP (kW)

1. **Conclusion:**

The graph obtained by plotting Indicated power versus net heat interaction for all cycles in all cylinders is a straight line graph which indicates that the indicated power is directly proportional to the Net heat interaction in the engine. Thus I law is conformed by four stroke multi-cylinder CI engine.

EXPERIMENT NO.4 DATE:

**CONFORMANCE TO II LAW BY DIESEL ENGINE**

1. **Aim:** To investigate II law on a multi-cylinder CI (Diesel engine).
2. **Apparatus required:**
3. Engine test rig with following specification,

Engine specifications:

* Type : 4-Stroke, 4-cylinder, Diesel Engine (Water cooled)
* Make : Hindustan Motors
* Rated power output : 26.5 HP @ 4000 RPM
* Bore diameter ‘D’ : 0.073 m
* Stroke length ‘L’ : 0.089 m
* Compression ratio : 17.5:1
* Starting : Ignition starting
* Cooling system : Water cooled
* Diameter of orifice : 0.016 m
* Loading : Eddy current loading

1. Stopwatch & scale.
2. **Practical Significance:** To investigate and ascertain the conformance of the second law of thermodynamics on diesel engine.
3. **Competency/Skill:** Investigation skill
4. **Objective:** To conduct the experiment for the,
5. Conformance of II law
6. Application of II law on a prime-mover
7. **Prerequisites:** Testing & performance, measurement and knowledge on II Law
8. **Concept/ Principle:** II Law of Thermodynamics
9. **Theory:**

**8.1 Second Law of Thermodynamics**

The first-law thermodynamics gave impetus to almost all the developments in thermal engineering. As a statement it means energy heat which can be converted into work in a cyclic device or process. The first corollary derived out of first law reduced down the facts to a process, in which heat at one side will be equal to the sum of work transfer and change in internal energy in the other side. It is just the energy balance, without regard to their nature and direction of energy flow. Moreover, the first law does not categorically say how to apply in the situation wherein irreversibility is involved. It does not quantify irreversibility. These are the major shortcomings of I-law.

Second law works on this direction of assigning direction constraint to a process. It introduces a concept of Thermal Energy Reservoir (TER). Along with TER we have to have a cyclic device to convert the heat received form the source and to complete the cycle it has to reject heat to the sink. Thus the second law projects the requirement of a source, a cyclic device which can either a power producing or power consuming and a sink.

**8.1.1 Kelvin-Planck Statement**

It is impossible to construct a device that will operate in a cycle and produce no effect other than the raising of a weight and the exchange of heat with a single reservoir.

 (8.1)

As QH>QL, η<1.

* + 1. **Test**

Conformance of second law of thermodynamics on engine is investigated in two steps,

1. *By investigating the I law conformance on multi-cylinder CI (Diesel engine).*

This is done by performing an experiment on multi-cylinder diesel engine and showing that with the help a graph of net heat interaction ( versus indicated power (*IP*). The graph should be an increasing curve as shown in figure 2 which proves the I law conformance of multi-cylinder CI engine.

(kW)

IP (kW)

Figure 2 : Graph of IP vs

1. *By computing different efficiencies and showing a particular relation between them.*

Here we compute three different efficiencies namely the brake thermal efficiency, Carnot efficiency and the air standard efficiency comparing which we can show that the II law is conformed as detailed below.

1. Brake thermal efficiency,

It is the ratio of brake power to the net heat input i.e.

(8.3)

Where is the brake power for this particular engine given by,

= 75 %

is the heat input to the engine given by,

CV (8.4)

is fuel consumption per unit time.

CV=Calorific value of diesel= 40,000 kJ/kg (approx.)

We show here that which shows that Kelvin-Plank statement of second law is not violated .However, its learnt from Carnot theorem that this is supposed to less than the Carnot efficiency and also lesser than the air standard efficiency.

1. Carnot efficiency,

It depends on the lower and higher temperature limits the engine is undergoing and is given by,

(8.5)

Where, is the lowest temperature in the thermodynamic cycle,

, is the maximum temperature in the thermodynamic cycle.

To find and the engine assumed to be following air standard Diesel cycle as shown below,

2

3

P

4

1

V

Figure 3: PV diagram for Diesel cycle

In the above graph is assumed to be at NTP condition i.e. 270c or 300K. Considering process 1-2 which is the reversible adiabatic process, we can state the relation as,

(8.6)

From the engine specification we get the value of compression ratio (r) to be 6.5. Hence we can calculate temperature at the end of compression by,

(8.7)

Our target is to get maximum temperature which is in this cycle. From this we can calculate Carnot efficiency. We use the energy balance equation during combustion process as given below,

) (8.8)

Where as it assumed that the air fuel mixture will behave like air owing to containing greater portion of air.

is the mass flow rate of air.

The only unknown in the above equation is which can be found by rearranging the terms.

1. Air standard efficiency

It is the theoretical efficiency of the CI engine which depends on only single parameter i.e. the compression ratio (r=17.5 of this CI engine) and is formulated as,

(8.9)

Having calculated the three efficiencies, we can show that the following relation is strictly followed,

(8.10)

The above relation can be represented in graphical manner. Thus the second law of thermodynamics is conformed by 4-S CI engine.

1. **Precautions:**
2. Do not run the engine without water supply.
3. Do not shut down the engine when maximum load applied to engine.
4. Engage clutch after the engine maintains speed.
5. After completion of experiment, turn OFF the fuel supply valve.
6. Do not turn off water supply immediately when experiment completes, wait for some time to maintain the engine temperature cool.
7. Remove one line of the battery wire after experiment is completed.
8. Do not cut off more than one cylinder at a time.
9. Change engine oil when oil turns to black colour.
10. Frequently, at least once in three months, grease all visual moving parts.
11. At least every week, operate the unit for five minutes to prevent any clogging of the moving parts.
12. **Procedure:**
    * + 1. Check the diesel in diesel tank.
        2. Allow water to flow through the calorimeter.
        3. Allow diesel, start the engine by key provided without engaging the clutch.
        4. Engage the clutch, set the engine speed, by adjusting the speed regulator (throttle) provided at the control panel.
        5. Apply load by rotating the regulator of Eddy current dynamometer provided on the control panel.
        6. Now adjust the speed using speed regulator.
        7. Now take down the load reading shown on the load indicator (Dial gauge).
        8. Note down water flow rate (rotameter) reading and time for water meter reading, different temperatures, speed, fuel consumption (TFC) and air flow across orifice ( measured using manometer).
        9. Repeat the procedure 5 to 8 for different loads.
        10. Tabulate the readings.
        11. After the experiment is over, disengage the clutch, put off the engine and keep the diesel control valve at off position.
        12. Stop the water flow after a while by operating the valves.
13. **Observation**

For observation refer Table 1

**Table 1**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sr. no. | Load  (kg) | Engine speed  (RPM) | BrP  ( kW) | (%) | *TH*  (K) | ( %) | Cut-off ratio  *rc* | (%) |
| 1 |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |

1. **Sample Calculation**

**Note. Step1** of the experiment is similar to experiment no.3 **“Conformance of diesel engine to I law”** in which a graph of **IP v/s**  is plotted which comes to be a **linearly increasing graph**. Therefore the calculations carried out in the **experiment 3 should be referred**.

**Step2:**

1. Brake thermal efficiency,

,

Where,

*‘N’* is engine speed in rpm, ‘*F’* is load indicator reading in kg, ‘*r*’ is radius of brake drum= 0.34 m.

Kelvin-Plank statement)

1. Carnot efficiency ,

, r*=*17.5;

)

Where

is the mass flow rate of air.

1. Air standard efficiency,

Where, is called the cut-off ratio which is given by,

It is to be noted that the following relation should be strictly followed,

1. **Graph**

To show the above relation i.e. equation (8.10) graphically we plot the three efficiency values versus A/F ratio. The nature of the three curves is indicated in Figure 4.

A/F

Figure 4: Graph of vs. A/F

From the graph it is clear that the Carnot efficiency is maximum amongst all the efficiencies. Further we see that the efficiency of Diesel cycle is constant for the given engine as it depends on the compression ratio which is fixed for a given engine. The brake thermal efficiency is lowest among all the efficiency values.

1. **Conclusion**

* The graph of IP v/s comes out to be a linearly increasing curve which proves that I law is conformed by multi-cylinder 4-S CI engine.
* It was observed that which follows Kelvin-Plank statement of second law.
* The efficiencies were also seen to follow the relation ,

, strictly which clearly proves the Carnot theorem i.e. Carnot efficiency is the maximum efficiency among all efficiencies calculated for the engine operating between the two given constant temperature reservoirs. Considering the above statements we can say that the CI engine under investigation is conforming to the second law of thermodynamics.

EXPERIMENT NO. 5 DATE:

**DETERMINATION OF EXHAUST GAS PROPERTIES**

1. **Aim:** To investigate exhaust gas properties on petrol engine.
2. **Apparatus Required:**
3. Exhaust gas analyzer.
4. SI engine test rig.
5. **Practical Significance:** To investigate the exhaust gas composition emitted by petrol engine.
6. **Competency/Skill:** Investigation skill
7. **Objective:** To conduct the experiment for determination of exhaust gas mixture properties.
8. **Prerequisites:** Testing & performance, measurement and knowledge on exhaust emissions.
9. **Concept/ Principle:** Volumetric to gravimetric analysis.
10. **Theory:**

**8.1 Introduction to Engine Emissions**

Internal combustion engines generate undesirable emissions during the combustion process. In this, both SI and CI engines are equally responsible for the same. The emissions exhausted into the surroundings pollute the atmosphere and causes the problems such as global warming, acid rain, smog, odours, respiratory and other health hazards. The major causes of these emissions are non-stoichiometric combustion, dissociation of nitrogen and impurities in the fuel and air. The emissions of concern are: unburnt Hydrocarbons (HC), oxides of Carbon (CO, CO2), oxides of Nitrogen (NOX), oxides of Sulphur (SO2) and solid Carbon particulates which constitute exhaust emission. Moreover, these emissions also include non-exhaust emissions such as unburnt hydrocarbon from the fuel tank and crankcase blowby.

**8.1.1. Mixture Properties**

In real life we deal with mixture of gases that constitute the system. Molecules of the system are independent of the behaviour of other molecules at relatively low temperature. In such cases, the properties of the mixture can be obtained from their constituents. It is quite obvious to know that the total number of molecules of the mixture is the sum of the molecules of the individual constituents. Similarly for mass of the mixture the same thing can be extended. Thus the following expressions are quite obvious.

Where n is no. of molecules.

Dividing by n which is fixed both sides we get

Where is a mole fraction. Similarly for the mass,

Where *m* is mass

Dividing by *m* which is fixed both sides we get

Where is mass fraction.

The composition of exhaust gas is found by using an exhaust gas analyzer which gives the percentages of various constituents of exhaust i.e. CO, CO2, and O2 etc These percentages represent the volume fraction or molar fraction of different constituents of exhaust. But mixture properties of exhaust are determined using mass fraction of exhaust. Therefore volumetric to gravimetric analysis is required to be performed which is explained in the next section.

**8.1.2 Volumetric to gravimetric analysis.**

We want finally mass fraction but the exhaust gas analyzer gives the compositions in terms of mole (volume) fraction, that is we will express required quantity in terms of given quantity.

Dividing by *n* in numerator and denominator, we get

Where molecular weight of *i*th constituent is, is number of moles of *i*th constituent, *n* is total number of moles of exhaust, is volume fraction of *i*th constituent, is mass fraction of *i*th constituent.

1. **Precautions:**

* During the measurements, care has to be taken to avoid probe contact to metallic parts of the exhaust.
* Please note that water particles should not come in contact with the probe.
* Machine cable should be kept away from automobile motorial parts and don’t touch these parts optionally when you do the measurement, in order to avoid burning human body.
* Do not touch the sample gun after removing from exhaust as it will be hot.
* The measurements should be performed in well-ventilated area, because CO, NO etc. of automobile emission which has been absorbed by human may result in suffocation.
* Strong magnet is one composition of composite sensor. Note that the strong magnetic field can affect or damage electronic and mechanical equipment.
* Don’t open or repair this machine optionally, there is tip-and-run danger probably and it will cause machine unworkable.

1. **Procedure:**

* Start the petrol engine as usual with initial checks made.
* Start the exhaust gas analyser by putting “ON” the switch provided on the backside of the analyser.
* Wait for 10 minutes which is warm up time for the analyzer. This is displayed on the front panel by showing a countdown timer.
* Start the test by pressing the enter button provided on the panel. Various compositions (CO, CO2, O2 etc.) are displayed on the panel.
* Wait for 20 seconds, then insert the sample gun in the exhaust and hold it, avoid contact with metallic parts of the exhaust and water particles.
* Note down the readings (percentage of CO, CO2 and O2) after the values get stabilized.
* Remove the sample gun and keep it in a safe position. Do not touch the sample gun as it will be still hot.
* Stop the engine and switch “OFF” the exhaust gas analyzer.

1. **Observation:**

Refer Table 1 for observation

**Note:** It is to be noted that the three main compositions (CO, CO2, and O2) are noted from the analyzer and the remaining composition of exhaust is assumed to be constituted by N2 only as it does not participate in the chemical reactions being an inert gas.

Table 1: Volumetric to gravimetric analysis

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Constituent no. *i*** | **Constituents** | **Mole fraction, *x*i** | **Molecular weight, *Mi*** | ***x*i .*Mi*** | ***y*i** |
| 1 | CO |  | 28 |  |  |
| 2 | CO2 |  | 44 |  |  |
| 3 | O2 |  | 32 |  |  |
| 4 | N2 |  | 28 |  |  |
| **Total/Sum,** | |  |

1. **Model Calculation:**

Mass fraction,

Where is molecular weight of *i*th constituent is, is volume fraction of *i*th constituent.

1. **Conclusion:**

The properties of exhaust were determined using exhaust gas analyzer in terms of percentage of constituents. These volume fractions of the constituents were converted to their mass fractions and thus the investigation is performed successfully.

EXPERIMENT NO. 6 DATE:

**DETERMINATION OF EXHAUST GAS PROPERTIES**

1. **Aim:** To investigate exhaust gas properties on diesel engine.
2. **Apparatus Required:**
3. Exhaust gas analyzer.
4. CI engine test rig.
5. **Practical Significance:** To investigate the exhaust gas composition emitted by diesel engine.
6. **Competency/Skill:** Investigation skill
7. **Objective:** To conduct the experiment for determination of exhaust gas mixture properties.
8. **Prerequisites:** Testing & performance, measurement and knowledge on exhaust emissions.
9. **Concept/ Principle:** Volumetric to gravimetric analysis.
10. **Theory:**

**8.1 Introduction to Engine Emissions**

Internal combustion engines generate undesirable emissions during the combustion process. In this, both SI and CI engines are equally responsible for the same. The emissions exhausted into the surroundings pollute the atmosphere and causes the problems such as global warming, acid rain, smog, odours, respiratory and other health hazards. The major causes of these emissions are non-stoichiometric combustion, dissociation of nitrogen and impurities in the fuel and air. The emissions of concern are: unburnt Hydrocarbons (HC), oxides of Carbon (CO, CO2), oxides of Nitrogen (NOX), oxides of Sulphur (SO2) and solid Carbon particulates which constitute exhaust emission. Moreover, these emissions also include non-exhaust emissions such as unburnt hydrocarbon from the fuel tank and crankcase blowby.

**8.1.1. Mixture Properties**

In real life we deal with mixture of gases that constitute the system. Molecules of the system are independent of the behaviour of other molecules at relatively low temperature. In such cases, the properties of the mixture can be obtained from their constituents. It is quite obvious to know that the total number of molecules of the mixture is the sum of the molecules of the individual constituents. Similarly for mass of the mixture the same thing can be extended. Thus the following expressions are quite obvious.

Where n is no. of molecules.

Dividing by n which is fixed both sides we get

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The composition of exhaust gas is found by using an exhaust gas analyzer which gives the percentages of various constituents of exhaust i.e. CO, CO2, and O2 etc These percentages represent the volume fraction or molar fraction of different constituents of exhaust. But mixture properties of exhaust are determined using mass fraction of exhaust. Therefore volumetric to gravimetric analysis is required to be performed which is explained in the next section.

**8.1.2 Volumetric to gravimetric analysis.**

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Dividing by *n* in numerator and denominator, we get

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1. **Precautions:**

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* Please note that water particles should not come in contact with the probe.
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* Do not touch the sample gun after removing from exhaust as it will be hot.
* The measurements should be performed in well-ventilated area, because CO, NO etc. of automobile emission which has been absorbed by human may result in suffocation.
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* Note down the readings (percentage of CO, CO2 and O2) after the values get stabilized.
* Remove the sample gun and keep it in a safe position. Do not touch the sample gun as it will be still hot.
* Stop the engine and switch “OFF” the exhaust gas analyzer.

1. **Observation:**

Refer Table 1 for observation

**Note:** It is to be noted that the three main compositions (CO, CO2, and O2) are noted from the analyzer and the remaining composition of exhaust is assumed to be constituted by N2 only as it does not participate in the chemical reactions being an inert gas.

Table 1: Volumetric to gravimetric analysis

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
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| 4 | N2 |  | 28 |  |  |
| **Total/Sum,** | |  |

1. **Model Calculation:**

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Where is molecular weight of *i*th constituent is, is volume fraction of *i*th constituent.

1. **Conclusion:**

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