UNIT - 7

PERFORMANCE OF IC ENGINES

7.0 Introduction:

The performance of an Engine is an indication of the degree of success with which the conversion of chemical energy contained in the fuel is done into useful mechanical work.

Performance Parameters of an IC Engine:

An internal combustion Engine generally operates at high speeds. Some Engines are made to run at fixed speed by means of a speed governor which is its rated speed. At each speed within the useful range the variations in the power output may differ.

While evaluating the performance of an IC Engine few factors have to be considered.

1. Max power available at each speed within the useful range of speed.
2. The range of power output at constant speed for stable operation is needed.
3. The different speeds should be selected at definite and equal intervals within the range of operation.

Here are listed few performance parameters of the Engine.

1. Compression ratio
2. Swept volume
3. Clearance volume
4. Indicated power
5. Brake power
6. Friction power
7. Indicated thermal efficiency
8. Brake thermal efficiency
9. Mechanical efficiency
10. Indicated & brake mean effective pressure
11. Specific fuel consumption
12. Volumetric efficiency
13. Heat balance sheet.

1. Compression Ratio (r):

It is the ratio of total cylindrical volume (V_T) to the clearance volume (V_C) of the cylinder.

Compression Ratio(r) = V_T/V_C

$V_T = V_s + V_C$

Where **V_T** = Total volume, **V_s** = Swept volume, **V_C** = Clearance volume.

2. Swept Volume (V_s):

The nominal volume swept by the working piston between two dead centers is known as swept volume.

3. Clearance Volume (V_C):

The nominal volume of the cylinder above the piston, when the piston is at top dead center.

4. Indicated Power (IP):

The power actually produced inside the Engine cylinder is called indicated power.

$IP= (P_m*L*A*n*K) / 60$ kwatts

P_m = Indicated Mean effective pressure

L = Length of stroke.

A = Area of the piston

n = N- for 2-s, n=N/2 for 4-s Engines

K = No of cylinders.

For four-stroke Engine speed = N/2. For two-stroke Engine speed = N.

5. Brake Power (BP):

The power output at the crank shaft is called brake power.

$BP= (2*\pi*N*T) / 60$ kwatts

Where N = Speed in RPM

T= Torque developed in N-m

6. Friction Power (FP):

The difference between the indicated horse power and brake horse power is called Friction Horse Power. This power is wasted due to Friction.

$$\mathbf{FP = IP - BP}$$

7. Indicated Thermal Efficiency ($\eta_{\text{Indicated Thermal}}$):

It is the ratio of indicated power obtained to the energy supplied by fuel.

$$\eta_{\text{Indicated Thermal}} = ((IP)/ (\dot{m}_f * CV))*100$$

where $\dot{m}_f$ = Fuel Consumption Kg/hr

CV = Calorific Value

8. Brake Thermal Efficiency ($\eta_{\text{Brake Thermal}}$):

It is the ratio of brake or shaft work obtained to the energy supplied by fuel.

$$\eta_{\text{Brake Thermal}} = ((BP)/ (\dot{m}_f * CV))*100$$

where $\dot{m}_f$ = Fuel Consumption Kg/hr

CV= Calorific Value

9. Mechanical Efficiency ($\eta_{\text{mechanical}}$):

It is the ratio of power obtained at shaft to the indicated power.

$$\eta_{\text{mechanical}} = (BP/IP)* 100$$

10. Indicated & Brake mean effective pressure:

It is the algebraic sum of the mean pressures on the face of the piston during each stroke over one complete cycle.

$$P_m = (a/l)*s \text{ kg/cm}^2$$

Where p = Mean effective pressure in kg/cm^2

a = Area of the indicator diagram in cm^2

l = Length of the indicator diagram in cm

s = Spring number or spring strength in $kg/cm^2/cm$

11. Specific fuel consumption:

It is defined as the amount of fuel consumed per unit of power developed per hour

$$\text{Specific Fuel Consumption} = \frac{\text{Fuel Consumption in Kg/h}}{\text{Power Developed}}$$

12. Volumetric efficiency:

The volumetric efficiency is defined as the ratio of actual volume flow rate of air into the cylinder to the swept volume of the cylinder.

13. Heat Balance Sheet:

S. No	Item	KW	Percentage
1	Heat supplied by Fuel	X	100%
2	Heat absorbed in IP	$a=m_f {}^{*}C_v$	a/x*100
3	Heat taken away by Cooling Water	$b=m_w C_{pw}(t_2-t_1)$	b/x*100
4	Heat carried away by Exhaust Gases	$c=m_g C_{pg} (t_e-t_r)$	c/x*100
5	Heat uncountable for	X-(a+b+c)	{x-(a+b+c)}/X*100

7.2 Sankey Diagram:

Sankey diagrams are named after Irish Captain Matthew Henry Phineas Riall Sankey, who used this type of diagram in 1898 in a classic figure ,showing the energy efficiency of a steam Engine.

Sankey diagrams are a type of flow diagram in which the width of the arrows is proportional to the flow rate. The illustration shows a Sankey diagram that represents all the primary energy flows into a factory. The widths of the bands are linearly proportional to energy production, utilization and loss.

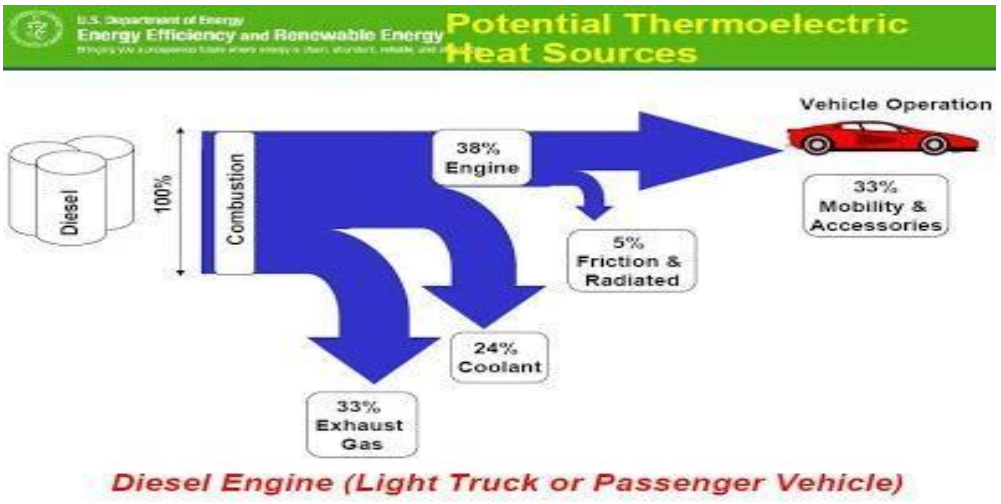

Fig 7.1 Sankey Diagram for a Diesel Engine

7.3. Performance Curves:

The word performance for an Engine is generally used for designating the relationship between power, speed and fuel consumption. For variable speed Engines the rated horse power at a certain speed does not given enough information. The performance curve helps to obtain necessary information.

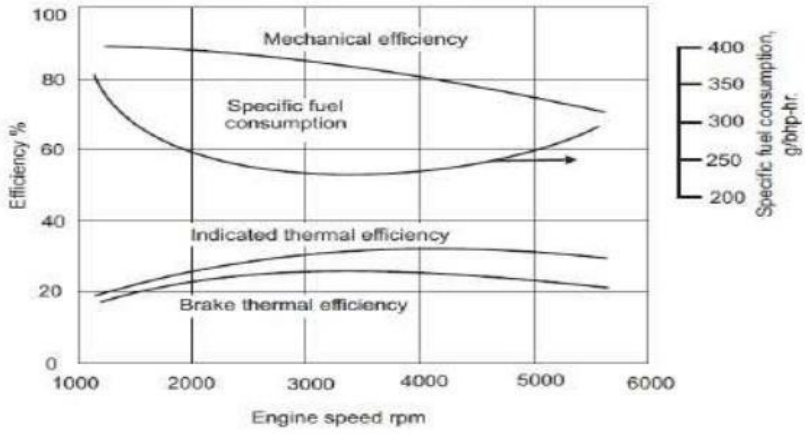

Fig 7.2 Performance Curves

Methods to improve the Performance of an IC Engine:

1. Increasing the compression ratios.
2. Providing better lubricating system.
3. Providing the low friction causing mechanism
4. By maintaining moderate running speeds.
5. By maintaining perfect spark timing.
6. By preventing the excessive heat losses.

Sources of Automobile Emissions:

1. Hydrocarbons:

In automobile of burned or partially burned fuel, hydrocarbons are toxins and are a major contributor to smog, which can be a major problem in urban areas.

2. Carbon Monoxide (CO):

A product of incomplete combustion, carbon monoxide reduces the blood's ability to carry oxygen.

3. Nitrogen Oxides (NOx):

Generated when nitrogen in the air reacts with oxygen at the high temperature and pressure inside the engine.

4. Particulate Matter:

Soot or smoke made up of particles in micrometers size range

5. Sulfur Oxide (SOx):

A general term for oxides of sulphur, which are emitted from motor vehicles burning fuel containing a high concentration of sulphur**.**

Effect of Automobile Pollutants:

1. Prolonged exposure to hydrocarbons contributes to asthma, liver disease, and cancer, overexposure of carbon monoxide poisoning may be fatal.
2. NOx is a precursor to smog and acid rain. NOx is a mixture of NO and NO2. NO2 destroys resistance to respiratory infection.

3. Particulate matter causes negative health effects, including but not limited to respiratory disease.

4. Oil, petroleum products and other toxins from automobiles kill fish, plants, aquatic life and even people. One quart of oil will contaminate thousands of gallons of water because it doesn't dissolve. These toxins as well as trace metals and degreasing agents used on automobiles contaminate drinking water and can cause major illness. Some of these toxins and metals are absorbed in various sea life and cause medical problems to people when eaten.

Control of Automobile Pollution:

1. Engine efficiency has been steadily improved with improved engine design.

2. One of the first-developed exhaust emission control systems is secondary air injection. Originally, this system was used to inject air into the engine's exhaust ports to provide oxygen so unburned and partially-burned hydrocarbons in the exhaust would finish burning.

3. Air injection is now used to support the catalytic converters oxidation reaction, and to reduce emissions when an engine is started from cold. After a cold start, an engine needs a fuel-air mixture richer than what it needs at operating temperature, and the catalytic converter does not function efficiently until it has reached its own operating temperature.

The air injected upstream of the converter supports combustion in the exhaust head pipe, which speeds catalyst warm up and reduces the amount of unburned hydrocarbon emitted from the tailpipe.

4. Converter does not function efficiently until it has reached its own operating temperature. The air injected upstream of the converter supports combustion in the exhaust head pipe, which speeds catalyst warm up and reduces the amount of unburned hydrocarbon emitted from the tailpipe.

SI Engine Emissions:

The gaseous and particulate pollutants to which motor vehicles contribute include carbon monoxide (CO), ozone through its atmospheric precursors volatile organic compounds and nitrogen oxides [NOx], fine particulate matter PM10 and PM2.

CI Engine Emissions:

The four main pollutant emissions from diesel engines (carbon monoxide-CO, hydrocarbons-HC, particulate matter-PM and nitrogen oxides-NOx) and control systems for these emissions.

Emission Standards:

Emission standards are the legal requirements governing air pollutants released into the atmosphere. These emission standards set quantitative limits on the permissible amount of specific air pollutants that may be released from specific sources over specific timeframes. These emission norms gives detailed information of modifications to be done to every automobile before it is released into environment.

7.10.1 Bharat Stage Emission Standards (BSEC):

These are the standards set up by the Indian government which specify the amount of air pollutants from internal combustion engines, including those that vehicles can emit. If these emit more pollutants than the prescribed limit, they don't get a clearance to be sold in an open market. Bharat Stage Emission Standards have been instituted by the Central Pollution Control Board (CPCB), instituted within the Ministry of Environment Forests and Climate Change.

History of BSES:

The first emission norms were introduced in India in 1991 for petroleum distillate, and 1992 for diesel vehicles. These were followed by making the Catalytic converter mandatory for petrol vehicles and the introduction of unleaded petrol in the market.

On 29 April 1999, the Supreme Court of India ruled that all vehicles in India have to meet Euro I or India 2000 norms by 1 June 1999 and Euro II will be imperative in the Delhi by 1 April 2000. Car makers were not prepared for this transition and in a subsequent judgement the implementation date for Euro II was not enforced.

In 2002, the Indian government proposed a road map for the roll-out of Euro based emission norms for India. Based on the recommendations of the committee, the National Auto Fuel policy was announced officially in 2003.

Present BSES:

To regulate the pollution emitted by cars and two-wheelers, the government of Asian nation has placed forth regulations known as Bharat Stage Emission Standards (BSES). The Central government has mandated that every vehicle manufacturer, each two-wheels and four-wheels, ought to manufacture, sell and register solely BS6 (BSVI) vehicles from 1 April 2020.

Both BSIV and BSVI area unit emission norms that set the most permissible levels for pollutants emitting from a automotive or a two-wheeler exhaust. Compared to the BS4, BS6 emission standards area unit stricter, whereas makers use this variation to update their

vehicles with new options and safety standards, the largest or the numerous modifications comes within the type of stricter permissible emission norms.

Permissible Limits of BSES VI &IV for Automobiles:

Fuel Type	Pollutant Gases	BS - VI	BS - IV
Gasoline Vehicle	Nitrogen Oxide Limit (NO_x)	60 mg	80 mg
	Particulate Matter (PM)	4.5 mg/km	
Diesel Vehicle	Nitrogen Oxide Limit (NO_x)	80 mg	250 mg
	Particulate Matter (PM)	4.5 mg/km	25 mg
	HC+ NOx	170 mg/km	300 mg

European Emission Standards (EURO):

European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in the European Union and European Economic Area(EEA) member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.

In the European Union, emissions of nitrogen oxides (NOx), total hydrocarbon (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types, including cars, trucks (lorries), locomotives, tractors and similar machinery, barges, but excluding seagoing ships and aeroplanes. For each vehicle type, different standards apply. Compliance is determined by running the engine at a standardised test cycle. Non-compliant vehicles cannot be sold in the EU, but new standards do not apply to vehicles already on the roads. No use of specific technologies is mandated to meet the standards, though available technology is considered when setting the standards.

Diesel Cars					
Standards	**Date of approval**	**CO**	**NOx**	**HC+NOx**	**PM**
Euro 1	July 1992	2.73	-	0.97	0.14
Euro 2	January 1996	1.0	-	0.7	0.08
Euro 3	January 2000	0.64	0.50	0.56	0.05
Euro 4	January 2005	0.50	0.25	0.30	0.025
Euro 5	September 2009	0.50	0.18	0.230	0.005
Euro 6	September 2014	0.50	0.80	0.170	0.005
Euro 6D	January 2020	0.50	0.80	0.170	0.005
Petrol Cars					
Standards	**Date of Approval**	**CO**	**NOx**	**HC+NOx**	**PM**
Euro 1	July 1992	2.72	-	0.97	-
Euro 2	January 1996	2.2	-	0.5	-
Euro 3	January 2000	2.3	-	-	-
Euro 4	January 2005	1.0	-	-	-
Euro 5	September 2009	1.0	0.068	-	0.005
Euro 6	September 2014	1.0	0.068	-	0.005
Euro 6D	January 2020	1.0	0.068		0.045

Pollution Under Control Certificate (PUC):

A Pollution Under Control Certificate is an approval that emission from your vehicle is under control and as per the pollution norms. It is an official document issued by the government after the thorough verification of the vehicle's emission levels.

As per the Motor Vehicle Act, like a motor insurance policy, registration certificate, and driving license, a PUC certificate is now mandatory to carry while driving.

The Non Polluting Vehicle mark is a mandatory certification mark required on all new motor vehicles sold in India. The mark certifies that the motor vehicle conforms to the relevant version of the Bharat Stage emission standards. This certification for a brand new vehicle has a limited validity of 6 months from the date of sale of the vehicle. After this, the vehicle has to be tested afresh. The vehicle is tested in the car companies' garage during the

year's maintenance and a renewed certificate has to be obtained. The certificate thus issued on a used vehicle is the Pollution under Control certificate.

PUC Certificate Validity:

By now the importance of getting a PUC test is crucial. The person who is supposed to be driving the vehicle must carry the certificate either in soft or hard copy while driving..

The validity of the PUC Certificate for the new car or a bike is 1 year. The certificate will be renewed at regular intervals. The validity of the renewed certificate is 6 months for both cars and bikes. In case, the reading is adverse, the validity of the certificate will depend on the reading.

The cost to obtain the Pollution Under Control Certificate varies from Rs.60/- to Rs.100/-. The cost also depends on the fuel type.

Penalties for not obtaining a PUC Certificate:

According to motor insurance policy, people will have to pay a fine for not carrying a PUC Certificate. And under section 190 (2) of the Motor Vehicle Act, you will be liable for prosecution.

Other than this, a fine of Rs.1000/- will be charged for the first time offence. If it is repeated a fine of Rs.2000/- is to be paid.

Short Answer Questions

1. How do we measure the performance of an engine?
2. What are the performance parameters of an IC engine?
3. Write the sources of auto emissions.
4. Why an automobile is causes air pollution.
5. With a neat diagram explain sankey diagram.
6. What is PUC certificate?

Long Answer Questions

1. Explain the following terms.
    a. Indicated power.
    b. Brake power
    c. Friction power
2. Write the methods to the performance of an IC engine.
3. Explain BS & EURO standards of vehicle emissions.
4. Explain the following.
    a. Mechanical efficiency
    b. Indicated thermal efficiency
    c. Brake thermal efficiency
    d. Volumetric efficiency.