Certification Course on **COMBUSTION AND EMISSION IN ENGINES**

Resource Person: Sri K. Suresh Kumar

Co-ordinator: Sri. R. Rama Krishna Reddy

Date(s) of Event: 24/08/2020 to 11/09/2020

Organizing department:

Mechanical Engineering

K.S.R.M.COLLEGEOFENGINEERING

(UGC-AUTONOMOUS)

Kadapa,Andhra Pradesh,India–516 005
ApprovedbyAICTE,NewDelhi&AffiliatedtoJNTUA,Ananthapuramu.

Cr./KSRMCE/(Department of ME)/2020-2021

Date: 17/08/2020

To

The Principal,

KSRM College of Engineering,

Kadapa.

Respected Sir

Sub: KSRMCE-(Department of ME) permission to conduct certification course on "**Combustion and Emission in Engines**"-Request-Reg.

It is brought to your kind notice that, with reference to the cited, the ME department is planning to conduct Certification Course on "**Combustion and Emission in Engines**" for B.Tech, III Sem Students from **24 Aug 2020 to 11 Sep 2020.**

In this regard I kindly request you to grant permission to conduct the certification course. This is submitted for your kind perusal.

Thanking you sir,

Yours Faithfully

Sri. R. Rama Krishna
Reddy

Asso.Prof,Dept.ME

KSRMCE,Kadapa.

Forwarded to principal sir

Permitted
V.S.S. Murthy

To the Director for Information

To All Deans/HoD's/IQAC

K.S.R.M.COLLEGE OF ENGINEERING
(UGC-AUTONOMOUS)
Kadapa,Andhra Pradesh,India–516 005
ApprovedbyAICTE,NewDelhi&AffiliatedtoJNTUA,Ananthapuramu

Cr./KSRMCE/(Department of ME)/2020-2021

Date: 17/08/2020

Circular

All the B.Tech VI Sem ME students are here by informed that department of **MECHANICAL** is going to conduct certificate course on **Combustion and Emission in Engines**" interested students may register their names on or before **22-08-2020, 5 PM**

For any queries contact faculty coordinator:

Sri. R. Rama Krishna Reddy, Asso.Prof,Dept.ME, KSRMCE, Kadapa.

Hod

Professor & Head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

K.S.R.M.COLLEGE OF ENGINEERING

(UGC-AUTONOMOUS)

Kadapa,Andhra Pradesh,India–516 005
ApprovedbyAICTE,NewDelhi&AffiliatedtoJNTUA,Ananthapuramu

Department of Mechanical Engineering

Certification Course on **Combustion and Emission in Engines**

List of Participants

S.No	Roll No	Name of the student	Email id's
1	199Y1A0301	AKULA SREEDHAR	199Y1A0301@ksrmce.ac.in
2	199Y1A0302	B SRINIDHI SAI	199Y1A0302@ksrmce.ac.in
3	199Y1A0303	BANDI SHIVA REDDY	199Y1A0303@ksrmce.ac.in
4	199Y1A0304	CHAGANTI SUNIL KUMAR REDDY	199Y1A0304@ksrmce.ac.in
5	199Y1A0305	CHEPPALI AMATHYA	199Y1A0305@ksrmce.ac.in
6	199Y1A0306	CHIRUCHAPALA ABDUL SUBAHAN	199Y1A0306@ksrmce.ac.in
7	199Y1A0307	DEVAPATLA BHARATH SIMHA REDDY	199Y1A0307@ksrmce.ac.in
8	199Y1A0308	DUDIMANI SAI SRUJAN KUMAR	199Y1A0308@ksrmce.ac.in
9	199Y1A0309	GADIKOTA MURALIDHAR REDDY	199Y1A0309@ksrmce.ac.in
10	199Y1A0310	GANGALA VENKATA PRATHAP	199Y1A0310@ksrmce.ac.in
11	199Y1A0311	GANUGAPENTA BHARATH	199Y1A0311@ksrmce.ac.in
12	199Y1A0312	GODDENDLA ASHOK KUMAR	199Y1A0312@ksrmce.ac.in
13	199Y1A0313	GUDURU SUBHAN	199Y1A0313@ksrmce.ac.in
14	199Y1A0315	KAPURAM VAMSINATH REDDY	199Y1A0315@ksrmce.ac.in
15	199Y1A0316	KETHIREDDY NAVEEN KUMAR REDDY	199Y1A0316@ksrmce.ac.in
16	199Y1A0317	KONANGI SUBBANNA	199Y1A0317@ksrmce.ac.in
17	199Y1A0318	KONERU SAI KARTHIK	199Y1A0318@ksrmce.ac.in
18	199Y1A0319	KOTHAPALLE VAMSIDHAR REDDY	199Y1A0319@ksrmce.ac.in
19	199Y1A0320	KUMMARI MANJUNATH	199Y1A0320@ksrmce.ac.in
20	199Y1A0321	KUMMETHA SAI KUMAR REDDY	199Y1A0321@ksrmce.ac.in

21	199Y1A0322	L M VINAY KUMAR	199Y1A0322@ksrmce.ac.in
22	199Y1A0324	MALEPATI SIVA SAI REDDY	199Y1A0324@ksrmce.ac.in
23	199Y1A0325	MANJUNATHA DINESH KUMAR	199Y1A0325@ksrmce.ac.in
24	199Y1A0326	MARKAPURAM MYSORA REDDY	199Y1A0326@ksrmce.ac.in
25	199Y1A0327	MEDIMALA KIRAN KUMAR	199Y1A0327@ksrmce.ac.in
26	199Y1A0328	MOGHAL JUNAID BAIG	199Y1A0328@ksrmce.ac.in
27	199Y1A0329	MOLAKALA SREEKANTH REDDY	199Y1A0329@ksrmce.ac.in
28	199Y1A0330	MOYILLA CHARAN REDDY	199Y1A0330@ksrmce.ac.in
29	199Y1A0331	NADIMINTI NAVANEETH KUMAR	199Y1A0331@ksrmce.ac.in
30	199Y1A0332	NAGULAGARI VENKATA SANDEEP KUMAR REDDY	199Y1A0332@ksrmce.ac.in
31	199Y1A0333	PAGIDIPALEM VAMSI ACHARI	199Y1A0333@ksrmce.ac.in
32	199Y1A0334	PALLETI VAMSIDHAR REDDY	199Y1A0334@ksrmce.ac.in
33	199Y1A0335	PASUPALA RAVI KUMAR	199Y1A0335@ksrmce.ac.in
34	199Y1A0336	PATHAN KHALEELULLA KHAN	199Y1A0336@ksrmce.ac.in
35	199Y1A0337	PULAKONDAM BHEEMAIAH	199Y1A0337@ksrmce.ac.in
36	199Y1A0338	REDDAM VEERA TEJASWAR REDDY	199Y1A0338@ksrmce.ac.in
37	199Y1A0339	S K RAJESH	199Y1A0339@ksrmce.ac.in
38	199Y1A0340	SAGIRAJU DILLI VARMA	199Y1A0340@ksrmce.ac.in
39	199Y1A0341	SHAIK ABDUL RASHEED	199Y1A0341@ksrmce.ac.in
40	199Y1A0343	SHAIK GHOUSE BASHA	199Y1A0343@ksrmce.ac.in
41	199Y1A0344	SHAIK KURNOOL DADA KHALANDAR	199Y1A0344@ksrmce.ac.in
42	199Y1A0345	SHAIK MAHAMMED MANSOOR	199Y1A0345@ksrmce.ac.in
43	199Y1A0346	SHAIK MOHAMMED GHOUSE	199Y1A0346@ksrmce.ac.in
44	199Y1A0347	SHAIK MOHAMMED SAJID	199Y1A0347@ksrmce.ac.in
45	199Y1A0348	SHAIK MOHAMMED SHOAIB AKTHAR	199Y1A0348@ksrmce.ac.in
46	199Y1A0349	SHAIK NAYEEMUR RAHMAN	199Y1A0349@ksrmce.ac.in
47	199Y1A0350	SHAIK ZABEEULLA	199Y1A0350@ksrmce.ac.in
48	199Y1A0352	SUDA ABHILASH KUMAR REDDY	199Y1A0352@ksrmce.ac.in
49	199Y1A0353	SUNKESULA BABA SAB	199Y1A0353@ksrmce.ac.in
50	199Y1A0354	SYED ASLAM	199Y1A0354@ksrmce.ac.in
51	199Y1A0355	TAMMINENI SURENDRA NAIDU	199Y1A0355@ksrmce.ac.in
52	199Y1A0356	VANGALA BHARGAVA KUMAR REDDY	199Y1A0356@ksrmce.ac.in
53	199Y1A0357	VENKATAGIRI BHARGAV	199Y1A0357@ksrmce.ac.in

54	199Y1A0358	VUTUKURU HITESH REDDY	199Y1A0358@ksrmce.ac.in
55	199Y1A0359	YANDAPALLI SAI KUMAR REDDY	199Y1A0359@ksrmce.ac.in
56	199Y1A0360	YARRAPUREDDY HARSHAVARDHAN REDDY	199Y1A0360@ksrmce.ac.in

Coordinator

HOD

Professor & Head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

Syllabus

COMBUSTION AND EMISSION IN IC ENGINES

COURSE OBJECTIVES

1. To make the students familiar with the engine fuel and air supply systems, electronic injection systems used in modern automotive engines.
2. To make the students understand about the combustion phenomenon of SI and CI engines , engine pollutants.
3. To teach the students on production and utilization of alternative solid, liquid and gaseous fuels.
4. To teach modern trends in IC engines.

UNIT –I

COMBUSTION PRINCIPLES

Combustion equations, heat of combustion - chemical equilibrium and dissociation – Theories of combustion – flammability Limits – Reaction rates – Laminar and Turbulent Flame propagation in engines.

UNIT –II

Combustion in in SI engines,

Stages of combustion, normal abnormal , knocking , variables affecting knock, features and design consideration of combustion chambers. Lean burn combustion, Stratified charge combustion systems. Heat release relation

UNIT – III

Stages of combustion, vaporisation of fuel droplets and spray formation , air motion, swirl measurement , knock and engine variables, features and design considerations of combustion chambers, delay period correlations, heat release correlations, influence of the injection system on combustion, direct and indirect injection systems.

UNIT – IV

Flame stability , Re circulation zone and requirement - Combustion chamber configurations, cooling, Materials.

UNIT –V

Carbon Monoxide, Unburnt Hydrocarbons, Oxides of Nitrogen , particulate Matter and Smoke – sources. Emission control measures for SI and CI engines. Effect of emissions on environment and human beings.

OUTCOMES

1. Can explain fuel supply systems, combustion and emission aspects of IC engines and recent developments in IC engines.
2. Able to design fuel and air supply systems and combustion and after treatment systems Able to apply knowledge in developing engine combustion and exhaust treatment models
3. Can explain advanced engine technologies such MPFI, GDI, HCCI: Calculate the stoichiometric air fuel ratio, enthalpy of combustion that is applied in IC engines.
4. Apply concepts of different alternate fuels used for SI and CI engines.

Text Book :

1. B. P Pundir engine combustion and emission , Narosa publishing House, 2011
2. Cohen, H, Roggers , G,E,C, and saravanamuttoo, H.I.H.. Gas Turbine Theory, Longman.

Department of Mechanical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

K.S.R.M.COLLEGE OF ENGINEERING

(UGC-AUTONOMOUS)

Kadapa,Andhra Pradesh,India–516 005
ApprovedbyAICTE,NewDelhi&AffiliatedtoJNTUA,Ananthapuramu

Department of MECHANICAL ENGINEERING

Certification Course on Combustion and Emission in Engines

Schedule

Timing: 4:00pm – 6:00pm

S.No	Date	Course Coordinator	Topic Coverd
1	24/08/2020	Sri K. Suresh Kumar	Combustion equations, heat of combustion — chemical equilibrium and Dissociation
2	25/08/2020	Sri. R.Rama Krishna Reddy	Theories of Combustion – Flanun ability Limits - Reaction rates - Laminar
3	26/08/2020	Sri K. Suresh Kumar	Turbulent Flame Propagation in Engines. Introduction to spray formation and characterization
4	27/08/2020	Sri. R.Rama Krishna Reddy	combustion. Normal and abnormal combustion. knocking. variables affecting knock
5	28/08/2020	Sri K. Suresh Kumar	Features and design consideration of combustion chambers. Flame structure and speed.
6	29/08/2020	Sri. R.Rama Krishna Reddy	Lean burn combustion. Stratified charge combustion systems. I cat release correlations.
7	31/08/2020	Sri K. Suresh Kumar	Influence of the injection system on combustion. Direct and indirect injection systems.
8	02/09/2020	Sri. R.Rama Krishna Reddy	Vaporization of fuel droplets and spray formation, air motion
9	03/09/2020	Sri K. Suresh Kumar	Features and design considerations of combustion chambers
10	05/09/2020	Sri. R.Rama Krishna Reddy	Heat release correlations. Influence of the injection system on combustion. Direct and indirect injection systems
11	07/09/2020	Sri K. Suresh Kumar	Flame stability, Re-circulation zone and requirements - Combustion chamber configurations. Cooling. Materials.
12	08/09/2020	Sri. R.Rama Krishna Reddy	Unburnt Hydrocarbons. Oxides of Nitrogen.
13	09/09/2020	Sri K. Suresh Kumar	Particulate Matter and Smoke — sources.
14	10/09/2020	Sri. R.Rama Krishna Reddy	Emission control measures for SI and CI engines
15	11-09-2020	Sri K. Suresh Kumar	Effect of emissions on environment and human beings.

Coordinator

HoD

Professor & head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

K.S.R.M.COLLEGE OF ENGINEERING

(UGC-AUTONOMOUS)

Kadapa, Andhra Pradesh, India–516 005
Approved by AICTE, New Delhi & Affiliated to JNTUA, Ananthapuramu

---

Department of Mechanical Engineering

Activity Report

Name of the Event : Certification Course on COMBUSTION AND EMISSION IN ENGINES

Duration of the Event : 24-08-2020 to 11-09-2020

Scheduled Time : 4.00 to 6.00PM

Target Audience : B.Tech V Sem Students

Course Coordinator : R. Rama Krishna Reddy

Activity Description:

COMBUSTION AND EMISSION IN ENGINES is one of the important subject for Mechanical students to learn the COMBUSTION AND EMISSION IN ENGINES. Department of Mechanical organized a certification course on "**COMBUSTION AND EMISSION IN ENGINES**". Head of the Department, faculty & participants inaugurated with all good spirit. Resource persons began with the Introduction to **COMBUSTION AND EMISSION IN ENGINES** followed by Combustion equations, heat of combustion – chemical equilibrium and Dissociation, finally valedictory. Students were issued participation certificates by the Head of the Department.

Coordinator

HOD
Professor & Head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

V.S.S. Murty
Principal
PRINCIPAL
K.S.R.M. COLLEGE OF ENGINEERING
KADAPA - 516 003. (A.P.)

K.S.R.M. COLLEGE OF ENGINEERING

UGC - Autonomous
Approved by AICTE, New Delhi & Affiliated to JNTUA, Ananthapuramu.
Kadapa, Andhra Pradesh, India– 516 003

Certificate Course on

Combustion & Emission in Engines

24/08/2020 to 11/09/2020

Organized by

**DEPARTMENT
OF
MECHANICAL ENGINEERING**

K.S.R.M.COLLEGEOFENGINEERING

(UGC-AUTONOMOUS)

Kadapa, Andhra Pradesh, India–516 005.

ApprovedbyAICTE, New Delhi&AffiliatedtoJNTUA, Ananthapuramu.

Department of Mechanical Engineering

Certification Course on **Combustion & Emission in Engines**

Attendance Sheet

S.No	Name of the Student	Roll List	24/08	25/08	26/08	27/08	28/08	29/08	31/08	02/09	03/09	05/09	07/09	08/09	09/09	10/09	11/09
1	AKULA SREEDHAR	199Y1A0301	A	A	✓	✓	A	✓	✓	✓	A	✓	✓	✓	✓	A	✓
2	B SRINIDHI SAI	199Y1A0302	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓
3	BANDI SHIVA REDDY	199Y1A0303	✓	✓	✓	✓	A	✓	✓	A	✓	✓	✓	✓	✓	✓	✓
4	CHAGANTI SUNIL KUMAR REDDY	199Y1A0304	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
5	CHEPPALI AMATHYA	199Y1A0305	A	A	✓	✓	✓	✓	✓	✓	A	✓	✓	A	✓	✓	✓
6	CHIRUCHAPALA ABDUL SUBAHAN	199Y1A0306	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	DEVAPATLA BHARATH SIMHA REDDY	199Y1A0307	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	DUDIMANI SAI SRUJAN KUMAR	199Y1A0308	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓

9	GADIKOTA MURALIDHAR REDDY	199Y1A0309	A	✓	A	A	✓	✓	✓	A	A	✓	✓	✓	✓	✓	✓
10	GANGALA VENKATA PRATHAP	199Y1A0310	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓
11	GANUGAPENTA BHARATH	199Y1A0311	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12	GODDENDLA ASHOK KUMAR	199Y1A0312	✓	✓	✓	✓	A	A	A	✓	✓	✓	✓	✓	✓	✓	✓
13	GUDURU SUBHAN	199Y1A0313	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓
14	KAPURAM VAMSINATH REDDY	199Y1A0315	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓
15	KETHIREDDY NAVEEN KUMAR REDDY	199Y1A0316	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	KONANGI SUBBANNA	199Y1A0317	✓	✓	✓	✓	✓	✓	✓	A	✓	A	✓	A	✓	✓	✓
17	KONERU SAI KARTHIK	199Y1A0318	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓
18	KOTHAPALLE VAMSIDHAR REDDY	199Y1A0319	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
19	KUMMARI MANJUNATH	199Y1A0320	✓	A	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	KUMMETHA SAI KUMAR REDDY	199Y1A0321	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
21	L M VINAY KUMAR	199Y1A0322	A	✓	✓	A	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
22	MALEPATI SIVA SAI REDDY	199Y1A0324	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
23	MANJUNATHA DINESH KUMAR	199Y1A0325	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓
24	MARKAPURAM MYSORA REDDY	199Y1A0326	✓	✓	✓	✓	✓	✓	A	✓	A	✓	✓	A	✓	✓	✓
25	MEDIMALA KIRAN KUMAR	199Y1A0327	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓
26	MOGHAL JUNAID BAIG	199Y1A0328	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓
27	MOLAKALA SREEKANTH REDDY	199Y1A0329	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓
28	MOYILLA CHARAN REDDY	199Y1A0330	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓
29	NADIMINTI NAVANEETH KUMAR	199Y1A0331	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓

30	NAGULAGARI VENKATA SANDEEP KUMAR REDDY	199Y1A0332	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓	✓	✓	✓	✓
31	PAGIDIPALEM VAMSI ACHARI	199Y1A0333	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	A	✓
32	PALLETI VAMSIDHAR REDDY	199Y1A0334	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	A	✓	✓	✓	✓
33	PASUPALA RAVI KUMAR	199Y1A0335	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
34	PATHAN KHALEELULLA KHAN	199Y1A0336	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
35	PULAKONDAM BHEEMAIAH	199Y1A0337	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓
36	REDDAM VEERA TEJASWAR REDDY	199Y1A0338	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
37	S K RAJESH	199Y1A0339	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	A	✓	✓
38	SAGIRAJU DILLI VARMA	199Y1A0340	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A
39	SHAIK ABDUL RASHEED	199Y1A0341	✓	A	✓	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓	✓
40	SHAIK GHOUSE BASHA	199Y1A0343	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
41	SHAIK KURNOOL DADA KHALANDAR	199Y1A0344	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	A	✓	✓
42	SHAIK MAHAMMED MANSOOR	199Y1A0345	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
43	SHAIK MOHAMMED GHOUSE	199Y1A0346	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓
44	SHAIK MOHAMMED SAJID	199Y1A0347	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	A	✓	✓	✓	✓
45	SHAIK MOHAMMED SHOAIB AKTHAR	199Y1A0348	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓
46	SHAIK NAYEEMUR RAHMAN	199Y1A0349	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓
47	SHAIK ZABEEULLA	199Y1A0350	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	A
48	SUDA ABHILASH KUMAR REDDY	199Y1A0352	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	A	✓	✓
49	SUNKESULA BABA SAB	199Y1A0353	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
50	SYED ASLAM	199Y1A0354	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	A	✓	✓	✓	✓
51	TAMMINENI SURENDRA NAIDU	199Y1A0355	✓	A	A	✓	A	A	✓	✓	✓	✓	A	✓	✓	A	✓

52	VANGALA BHARGAVA KUMAR REDDY	199Y1A0356	✓	✓	✓	✓	✓	A	✓	✓	✓	✓	✓	✓	✓	✓	✓
53	VENKATAGIRI BHARGAV	199Y1A0357	✓	✓	A	✓	A	✓	✓	✓	✓	✓	✓	A	✓	✓	✓
54	VUTUKURU HITESH REDDY	199Y1A0358	✓	✓	✓	A	✓	A	A	A	A ✓	✓	✓	A	✓	A	A
55	YANDAPALLI SAI KUMAR REDDY	199Y1A0359	✓	✓	✓	✓	A	A	A	A	A	A	A	✓	✓	✓	✓
56	YARRAPUREDDY HARSHAVARDHAN REDDY	199Y1A0360	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Coordinator

HOD

Professor & Head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.

15

ENGINE EMISSIONS AND THEIR CONTROL

15.1 INTRODUCTION

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 following problems

(i) global warming

(ii) acid rain

(iii) smog

(iv) odours

(v) 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_x), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), and solid carbon particulates.

It is the dream of engineers and scientists to develop engines and fuels such that very few quantity of harmful emissions are generated, and these could be let into the surroundings without a major impact on the environment. However, with the present technology this is not possible, and after-treatment of the exhaust gases as well as in-cylinder reduction of emissions are very important. In case of after-treatment it consists mainly of the use of thermal or catalytic

Combustion & emission
in Engines

converters and particulate traps. For in-cylinder reduction, exhaust gas recirculation (EGR) and some fuel additives are being tried. In addition to exhaust emissions non-exhaust emissions also play a part. In this chapter we will look into the details of these emissions and their control.

15.2 AIR POLLUTION DUE TO IC ENGINES

Until the middle of the 20th century the number of IC engines in the world was so small that the pollution they caused was tolerable. During that period the environment, with the help of sunlight, stayed relatively clean. As world population grew, power plants, factories, and an ever-increasing number of automobiles began to pollute the air to the extent that it was no longer acceptable. During the late 1940s, air pollution as a problem was first recognized in the Los Angeles basin in California. Two causes of this were the large population density and the natural weather conditions of the area. Smoke and other pollutants from many factories and automobiles combined with fog that was common in this ocean area, and smog resulted. During the 1950s, the smog problem increased along with the increase in population density and automobile density. At this stage it was realized that the automobile was one of the major contributors to the problem. By the 1960s emission standards were beginning to be enforced in California.

During the next decade, emission standards were adopted in the rest of the United States and in Europe and Japan. By making engines more fuel efficient, and with the use of exhaust after-treatment, emissions per vehicle of HC, CO, and NO_x were reduced by about 95% during the 1970s and 1980s. Lead, one of the major air pollutants, was phased out as a fuel additive during the 1980s. More fuel-efficient engines were developed, and by the 1990s the average automobile consumed less than half the fuel used in 1970. However, during this time the number of automobiles greatly increased, resulting in no overall decrease in fuel usage.

Further reduction of emissions will be much more difficult and costly. As world population grows, emission standards have become more stringent out of necessity. The strictest laws are generally initiated in California, with the rest of the United States and world following. Although air pollution is a global problem, some regions of the world still have no emission standards or laws. However, many countries have started following Euro I and Euro II norms.

15.3 EURO I AND EURO II NORMS

As we know, the exhaust gas sent into the atmosphere by the engine contains hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxide (NO_x) which are mainly responsible for air pollution. These pollutants are known to cause serious health problems. Therefore there are laws on emission standards, which limit the amount of each pollutant in the exhaust gas emitted by an automobile engine.

Emission standards have been followed for some time in the developed countries. These include U.S.A., Europe, and Japan which have their own emission standards. India is in favour of the "European Model" developed by the European countries. The European emission norms are called 'Euro Norms',

In India, automobile industries have developed the "Euro" norms. Euro I emission norms were enforced in the New Delhi Capital Region from June 1999 and Euro II norms have taken effect from April 2000 throughout India.

The details of Euro I and Euro II norms adapted to Indian conditions are given in Table 15.1.

Table 15.1 Euro I and Euro II norms for new petrol and diesel cars followed in India

Norms	CO gm/km		HC + NO gm/km		PM gm/km	
	Petrol	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*
1996	8.68 – 12.40	5.7	3.00 – 4.36	2.2	–	–
Euro I	3.16	3.16	1.13	1.13	–	0.18
Euro II	2.20	1.00	0.50	0.70 – 0.90	–	0.080 – 0.10

gm/km – gram per kilometre
HC – Hydrocarbons
PM – Particulate Matter
CO – Carbon Monoxide
NO – Nitrogen Oxides

15.4 ENGINE EMISSIONS

Engine emissions can be classified into two categories:

(i) exhaust emissions and

(ii) non-exhaust emissions.

15.4.1 Exhaust Emissions

As already mentioned major exhaust emissions are

(i) unburnt hydrocarbons, (HC)

(ii) oxides of carbon, (CO and CO_2),

(iii) oxides of nitrogen, (NO and NO_2)

(iv) oxides of sulphur, (SO_2 and SO_3)

(v) particulates

(vi) soot and smoke.

The first four are common to both SI and CI engines and the last two are mainly from CI engines. The main non-exhaust emission is the unburn hydrocarbons from fuel tank and crankcase blowby.

Figure 15.1 shows the variation of HC, CO and NO_x emissions as a function of equivalence ratio for an SI engine. It is clearly seen that all the three emissions are a strong function of equivalence ratio.

As can be noticed from the Fig.15.1 that a rich mixture does not have enough oxygen to react with all the carbon and hydrogen, and both HC and CO emissions increase. For $\phi < 0.8$, HC emissions also increase due to poor combustion and misfire. The generation of nitrogen oxide emissions is a function of the combustion temperature, highest near stoichiometric conditions when temperatures are at the peak value. Maximum NO_x emissions occur at slightly lean conditions, where the combustion temperature is high and there is an excess of oxygen to react with the nitrogen.

Figure 15.2 shows a qualitative picture of HC, CO and NO_x emissions with respect to equivalence ratio, ϕ for a four-stroke DI Diesel engine. As can be seen HC will decrease slightly with increase in ϕ due to higher cylinder temperatures making it easier to burn up any over-mixed (very lean) or under-mixed (rich) fuel-air mixture. At high loads, however, HC may increase again if the amount of fuel

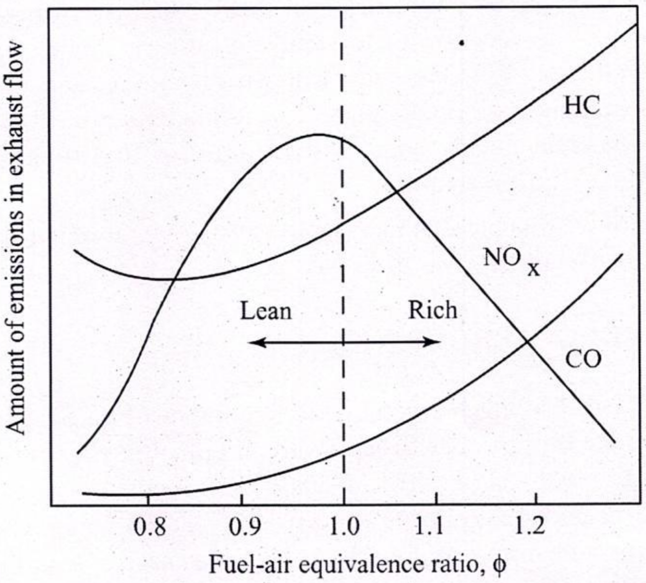


Fig. 15.1 Emissions as a Function of Equivalence Ratio for an SI Engine

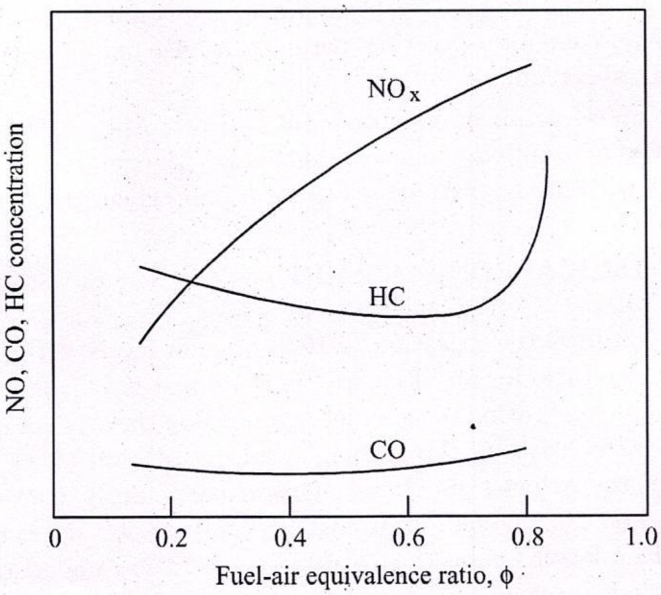


Fig. 15.2 Emissions as a Function of Equivalence Ratio for a CI Engine

in regions too rich to burn during primary combustion process. CO emissions will be very low at all equivalence ratio since excess air is always available. NO_x emission will steadily increase as ϕ increase due to increasing fraction of cylinder contents being burnt gases close to stoichiometric during combustion, and also due to higher peak temperatures and pressures.

In the following sections the causes for these emissions and their controls will be dealt with in detail.

15.5 HYDROCARBONS (HC)

Exhaust gases leaving the combustion chamber of an SI engine contain up to 6000 ppm of hydrocarbon components, the equivalent of 1-1.5% of the fuel. About 40% of this is unburned components of the fuel. The other 60% consists of partially reacted components that were not present in the original fuel. These consist of small nonequilibrium molecules, which are formed when large fuel molecules break up (thermal cracking) during the combustion reaction. It is often convenient to treat these molecules as if they contained one carbon atom, as CH_1.

Hydrocarbon emissions will be different for each gasoline blend, depending on the original fuel components. Combustion chamber geometry and engine operating parameters also influence the HC component spectrum.

When hydrocarbon emissions get into the atmosphere, they act as irritants and odorants; some are carcinogenic. All components except CH_4 react with atmospheric gases to form photochemical smog.

15.6 HYDROCARBON EMISSION

Figure 15.1 shows the variation of HC emission levels with respect to equivalence ratio for an SI engine. It is evident that it is a strong function of air-fuel ratio. With a fuel-rich mixture there is not enough oxygen to react with all the carbon, resulting in high levels of HC and CO in the exhaust products. This is particularly true during starting, when the air-fuel mixture is purposely made very rich. It is also true to a lesser extent during rapid acceleration under load. If air-fuel ratio is too lean poorer combustion occurs, again resulting in HC emissions. The extreme of poor combustion for a cycle is total misfire. This occurs more often as air-fuel ratio is made leaner. One misfire out of 1000 cycles gives exhaust emissions of 1 gm/kg of fuel used.

The causes for hydrocarbon emissions from SI engine are:

(i) Incomplete combustion

(ii) Crevice volumes and flow in crevices

(iii) Leakage past the exhaust valve

(iv) Valve overlap

(v) Deposits on walls

(vi) Oil on combustion chamber walls

We will discuss in details the various causes listed above.

15.6.1 Incomplete Combustion

Even when the fuel and air entering an engine are at the ideal stoichiometric condition, perfect combustion does not occur and some HC ends up in the exhaust. There are several reasons for this. Complete and homogeneous mixing of fuel and air is almost impossible. The incomplete combustion is due to:

(i) *Improper mixing*: Due to incomplete mixing of the air and fuel some fuel particles do not find oxygen to react with. This causes HC emissions.

(ii) *Flame quenching*: As the flame goes very close to the walls it gets quenched at the walls leaving a small volume of unreacted air-fuel mixture. The thickness of this unburned layer is of the order of 100 microns. However, it may be noted that some of this mixture near the wall that does not originally get burned as the flame front passes will burn later in the combustion process due to additional mixing, swirl and turbulence.

Another reason for flame quenching is the expansion of gases, which occurs during combustion and power stroke. As the piston moves down from TDC to BDC during power stroke, expansion of the gases lowers both pressure and temperature within the cylinder. This makes combustion slow and finally quenches the flame somewhere late in the expansion stroke. This leaves some fuel particles unreacted and causes HC emissions.

High exhaust gas contamination causes poor combustion and which in turn causes quenching during expansion. This is experienced at low load and idle conditions. High levels of EGR will also cause quenching of flame and will result in HC emission.

It has been found that HC emissions can be reduced by incorporating an additional spark plug at appropriate locations in the engine combustion chamber. By starting combustion at two points, the flame travel distance and total reaction time are both reduced, and less expansion quenching will result.

15.6.2 Crevice Volumes and Flow in Crevices

The volumes between the piston, piston rings, and cylinder wall are shown schematically in Fig.15.3. These crevices consist of a series of volumes (numbered 1 to 5) connected by flow restrictions such as the ring side clearance and ring gap. The geometry changes as each ring moves up and down in its ring groove, sealing either at the top or bottom ring surface. The gas flow, pressure distribution, and ring motion are therefore coupled.

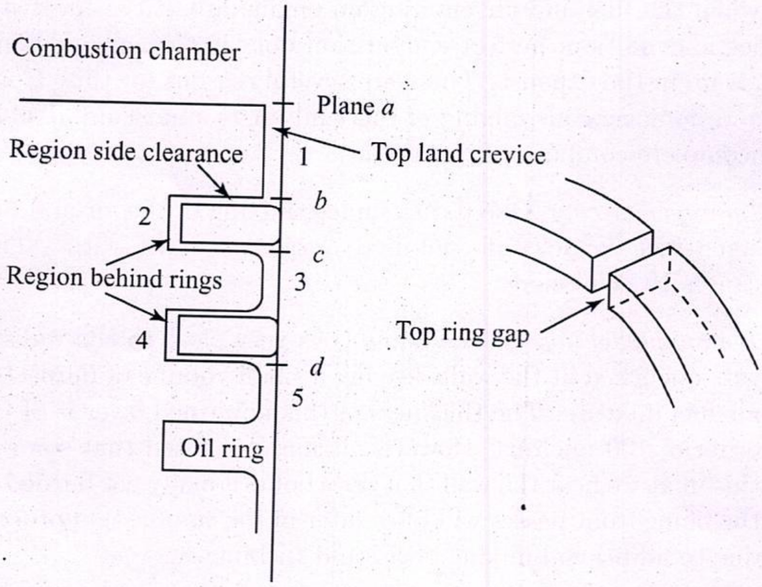


Fig. 15.3 Schematic of Piston and Ring Assembly in Automotive Spark-Ignition Engine Showing Various Crevice Volume

During the compression stroke and early part of the combustion process, air and fuel are compressed into the crevice volume of the combustion chamber at high pressure. As much as 3.5% of the fuel in the chamber can be forced into this crevice volume. Later in the cycle during the expansion stroke, pressure in the cylinder is reduced below crevice volume pressure, and reverse blow-by occurs. Fuel and air, flow back into the combustion chamber, where most of the mixture is consumed in the flame. However, before the last elements of reverse blow-by occurs flame will be quenched and unreacted fuel particles come out in the exhaust. Location of the spark plug relative to the top compression ring gap will affect the amount of HC in engine exhaust. The farther the spark plug is from the ring gap, the greater is the HC in the exhaust. This is because more fuel will be forced into the gap before the flame front passes.

Crevice volume around the piston rings is greatest when the engine is cold, due to the differences in thermal expansion of the various materials. Up to 80% of all HC emissions can come from this source.

15.6.3 Leakage Past the Exhaust Valve

As pressure increases during compression and combustion, some amount of air-fuel mixture is forced into the crevice volume around the edges of he exhaust valve and between the valve and valve seat. A small amount even leaks past the valve into the exhaust manifold. When the exhaust valve opens, the air-fuel mixture which is still in this crevice volume gets carried into the exhaust manifold. This causes a momentary increase in HC concentration at the start of blowdown process.

15.6.4 Valve Overlap

Valve overlap is a must to obtain satisfactory performance from the engine. During valve overlap, both the exhaust and intake valves are open, simultaneously creating a path where the fresh air-fuel mixture can flow directly into the exhaust. A well-designed engine minimizes this flow, but a small amount of fresh fuel-air mixture escape is inevitable. The worst condition for this is at idle and low speed, when the overlap in terms of time (milliseconds) is the largest.

15.6.5 Deposits on Walls

Gas particles, including those of fuel vapor, are absorbed by the deposits on the walls of the combustion chamber. The amount of absorption is a function of gas pressure. The maximum absorption occurs during compression and combustion. Later in the cycle, when the exhaust valve opens and cylinder pressure gets reduced, absorption capacity of the deposit material becomes lower. Gas particles are desorbed back into the cylinder. These particles, including some HC, comes out from the cylinder during the exhaust stroke. This problem is greater in engines with higher compression ratios due to the higher pressure these engines generate. More gas absorption occurs as pressure goes up. Clean combustion chamber walls with minimum deposits will reduce HC emissions in the exhaust. Most gasoline blends include additives to reduce deposit buildup in engines.

Older engines will typically have a greater amount of wall deposit buildup. This increases HC emissions correspondingly. This is due to age and to less swirl that was generally found in earlier engine design. High swirl helps to keep wall deposits to a minimum. When unleaded gasoline is used HC emissions from wall deposits becomes more severe. When leaded gasoline is burned the lead compounds make the walls harder and less porous to gas absorption.

15.6.6 Oil on Combustion Chamber Walls

A very thin layer of oil gets deposited on the cylinder walls to provide lubrication between the walls and the moving piston. During the intake and compression strokes, the incoming air and fuel comes in contact with this oil film. In the same way as wall deposits, this oil film absorbs and desorbs gas particles, depending on gas pressure.

During compression and combustion, when cylinder pressure is high, gas particles, including fuel vapor, are absorbed into the oil film. When pressure is later reduced during expansion and blowdown, the absorption capability of the oil is reduced and fuel particles are desorbed back into the cylinder. Some of this fuel ends up in the exhaust.

As an engine ages, the clearance between piston rings and cylinder walls becomes greater, and a thicker film of oil is left on the walls. Some of this oil film is scraped off the walls during the compression stroke and gets burned during combustion. Oil is a high-molecular-weight hydrocarbon compound that does not burn as readily as gasoline. Some of it comes out as HC emissions. This happens at a very slow rate with a new engine but increases with engine age and wear.

Figure 15.4 shows how HC emissions go up as oil consumption increases. Oil consumption increases as the piston rings and cylinder walls wear. In older engines, oil being burned in the combustion chamber is a major source of HC emissions. In addition to oil consumption going up as piston rings wear, blowby and reverse blowby also increase. The increase in HC emissions is therefore both from combustion of oil and from the added crevice volume flow.

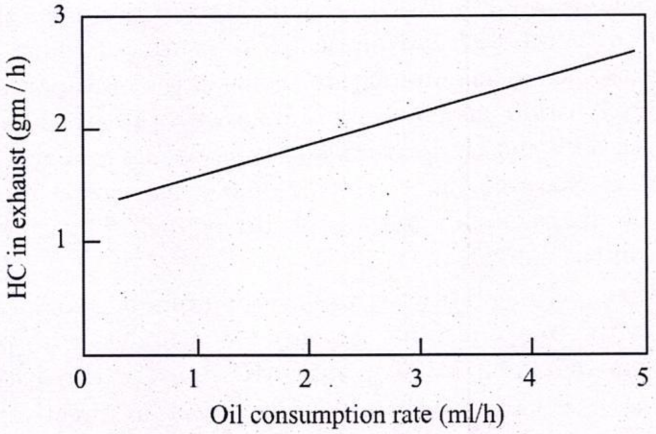


Fig. 15.4 HC Exhaust Emissions as a Function of Engine Oil Consumption

Often as an engine ages, due to wear, clearance between the pistons and cylinder walls increases. This increases oil consumption contributes to an increase in HC emissions in three ways:

(i) there is added crevice volume,

(ii) there is added absorption-desorption of fuel in the thicker oil film on cylinder walls, and

(iii) there is more oil burned in the combustion process.

15.7 HYDROCARBON EMISSION FROM TWO-STROKE ENGINES

Older two-stroke SI engines and many modern small two-stroke SI engines add HC emissions to the exhaust during the scavenging process. The intake air-fuel mixture is used to push exhaust residual out of the open exhaust port which is called scavenging. When this is done, some of the air and fuel mix with the exhaust gases and are expelled out of the cylinder before the exhaust port closes. This can be a major source of HC in the exhaust and is one of the major reasons why there have been no modern two-stroke cycle automobile engines.

Some experimental automobile two-stroke cycle engines and just about all small engines use crankcase compression, and this is a second source of hydrocarbon emissions. The crankcase area and pistons of these engines are lubricated by adding oil to the fuel. The oil is vaporized with the fuel and lubricates the surfaces which come in contact with the air-fuel-oil mixture. Some of the oil vapor is carried into the combustion chamber and burned with the air-fuel mixture. Lubricating oil is mostly hydrocarbon components and acts like additional fuel. However, due to the high molecular weight of its components, oil does not fully burn as readily as fuel. This adds to HC emissions in the exhaust.

Modern experimental two-stroke cycle automobile engines do not add fuel to the intake air, but scavenge the cylinders with pure air. This to a great extent avoid putting HC into the exhaust. After the exhaust port closes, fuel is added by injection directly into the cylinder. This creates a need for very fast and efficient vaporization and mixing of the air and fuel, but it eliminates a major source of HC emissions. Some automobile engines use superchargers instead of crankcase compression, and this eliminates HC pollution from that source.

15.8 HYDROCARBON EMISSION FROM CI ENGINES

Because CI engines operate with an overall fuel-lean equivalence ratio, CI engines have only about one-fifth the HC emissions of an SI engine.

The components in diesel fuel have higher molecular weights on average than those in a gasoline blend, and this results in higher boiling and condensing temperatures. Therefore, soot formation is more in CI engines. Some HC particles condenses onto the surface of the solid carbon soot that is generated during combustion. Most of this is burned as mixing continues and the combustion process proceeds. Only a small percentage of the original carbon soot that is formed comes out of the cylinder. The HC components condensed on the surface of the carbon particles, in addition to the solid carbon particles themselves, contribute to the HC emissions of the engine.

In general, a CI engine has combustion efficiency of about 98%. This means that only about 2% of the HC fuel being emitted. Because of the non-homogeneity of fuel-air mixture some local spots in the combustion chamber will be too lean to combust properly. Other spots may be too rich, with not enough oxygen to burn all the fuel. Local spots range from very rich to very lean, and many flame fronts exist at the same time. With undermixing, some fuel particles in fuel-rich zones never react due to lack of oxygen. In fuel-lean zones, combustion is limited and some fuel does not get burned. With overmixing, some fuel particles will be mixed with already burned gas and will therefore not combust totally.

It is important that injectors be constructed such that when injection stops there is no dribble. However, a small amount of liquid fuel will be trapped on the tip of the nozzle. This very small volume of fuel is called sac volume, its size depending on the nozzle design. This sac volume of liquid fuel evaporates very slowly because it is surrounded by a fuel rich zone and, once the injector nozzle closes, there is no pressure pushing it into the cylinder. Some of this fuel does not evaporate until combustion has stopped, and this increases HC emissions.

CI engines also have HC emissions for some of the same reasons as SI engines do (i.e., wall deposit absorption, oil film absorption, crevice volume, etc).

15.9 CARBON MONOXIDE (CO) EMISSION

Carbon monoxide is a colorless and odorless but a poisonous gas. It is generated in an engine when it is operated with a fuel-rich equivalence ratio, as shown in Fig.15.1. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Typically the exhaust of an SI engine will be about 0.2 to 5% carbon monoxide. Not only is CO considered an undesirable emission, but it also represents lost chemical energy. CO is a fuel that can be combusted to supply additional thermal energy:

$$\mathrm{CO} + \frac{1}{2}\,\mathrm{O_2} \rightarrow \mathrm{CO_2} + \text{ heat} \tag{15.1}$$

Maximum CO is generated when an engine runs rich. Rich mixture is required during starting or when accelerating under load. Even when the intake air-fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will also be the source for CO emissions.

A well-designed SI engine operating under ideal conditions can have an exhaust mole fraction of CO as low as 0.001. CI engines that operate overall lean generally have very low CO emissions [Fig.15.2].

15.10 OXIDES OF NITROGEN (NO_x)

Exhaust gases of an engine can have up to 2000 ppm of oxides of nitrogen. Most of this will be nitrogen oxide (NO), with a small amount of nitrogen dioxide (NO_2). There will also be traces of other nitrogen-oxygen combinations. These are all grouped together NO_x, with x representing some suitable number. NO_x is very undesirable. Regulations to reduce NO_x emissions continue to become more and more stringent year by year. Released NO_x reacts in the atmosphere to form ozone and is one of the major causes of photochemical smog.

NO_x is created mostly from nitrogen in the air. Nitrogen can also be found in fuel blends. Further, fuel may contain trace amounts of NH_3, NC, and HCN, but this would contribute only to a minor degree. There are a number of possible reactions that form NO. All the restrictions are probably occurring during the combustion process and immediately after. These include but are not limited to:

$$O + N_2 \rightarrow NO + N \tag{15.2}$$

$$N + O_2 \rightarrow NO + O \tag{15.3}$$

$$N + OH \rightarrow NO + H \tag{15.4}$$

NO, in turn, can further react to form NO_2 by various means, including

$$NO + H_2O \rightarrow NO_2 + H_2 \tag{15.5}$$

$$NO + O_2 \rightarrow NO_2 + O \tag{15.6}$$

At low temperatures, atmospheric nitrogen exists as a stable diatomic molecule. Therefore, only very small trace amounts of oxides of nitrogen are found. However, at very high temperatures that occur in the combustion chamber of an engine, some diatomic nitrogen (N_2) breaks down to monatomic nitrogen (N) which is reactive:

$$N_2 \rightarrow 2N \tag{15.7}$$

It may be noted that the chemical equilibrium constant for Eq.15.7 is highly dependent on temperature. Significant amount of N is generated in the temperature range of 2500-3000 K that can exist in an engine. Other gases that are stable at low temperatures but become reactive and contribute to the formation of NO_x at high temperatures include oxygen and water vapor, which break down as follows:

$$O_2 \rightarrow 2O \tag{15.8}$$

$$H_2O \rightarrow OH + \frac{1}{2} H_2 \tag{15.9}$$

If one goes a little deep into combustion chemistry it can be understood that chemical Eqs.15.7 to 15.9 all react much further to the right as high combustion chamber temperatures are reached. The higher the combustion reaction temperature, the more diatomic nitrogen, N_2, will dissociate to monatomic nitrogen, N, and the more NO_x will be formed. At low temperatures very little NO_x is created.

Although maximum flame temperature will occur at a stoichiometric air-fuel ratio ($\phi = 1$), Fig.15.1 shows that maximum NO_x is formed at a slightly lean equivalence ratio of about $\phi = 0.95$. At this condition flame temperature is still very high, and in addition, there is an excess of oxygen that can combine with the nitrogen to form various oxides.

In addition to temperature, the formation of NO_x depends on pressure and air-fuel ratio. Combustion duration plays a significant role in NO_x formation within the cylinder. Figure 15.5 shows the NO_x versus time relationship and supports the fact that NO_x is reduced in modern engines with fast-burn combustion chambers. The amount of NO_x generated also depends on the location of spark plug within the combustion chamber. The highest concentration is formed around the spark plug, where the highest temperatures occur.

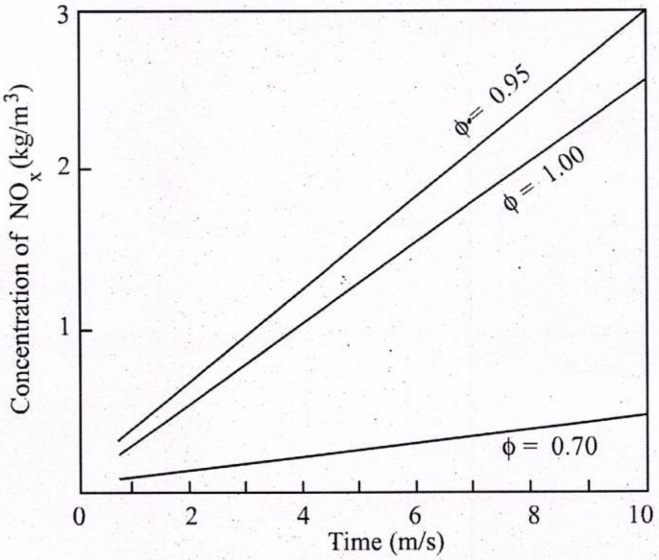


Fig. 15.5 Generation of NO_x as a Function of Combustion Time in an Engine

Figure 15.6 shows how NO_x can be correlated with ignition timing. If spark is advanced, the cylinder temperature will be increased and more NO_x will be created. Because CI engines have higher compression ratios and higher temperatures and pressure, they with divided combustion chambers and indirect injection (IDI) tend to generate higher levels of NO_x.

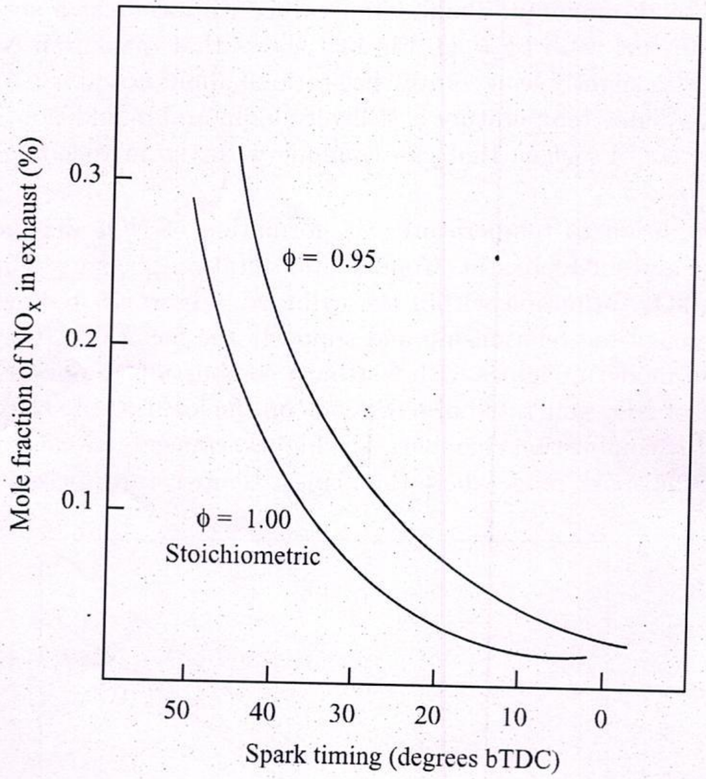


Fig. 15.6 Generation of NO_x in an SI Engine as a Function of Spark Timing

15.10.1 Photochemical Smog

NO_x is one of the primary causes of photochemical smog, which has become a major problem in many large cities of the world. Smog is formed by the photochemical reaction of automobile exhaust and atmospheric air in the presence of sunlight. NO_2 decomposes into NO and monatomic oxygen:

$$NO_2 + \text{energy from sunlight} \rightarrow NO + O + \text{smog} \qquad (15.10)$$

Monatomic oxygen is highly reactive and initiates a number of different reactions, one of which is the formation of ozone:

$$O + O_2 \rightarrow O_3 \tag{15.11}$$

Ground-level ozone is harmful to lungs and other biological tissue. It is harmful to plants and trees and causes very heavy crop losses each year. Damage is also caused through reaction with rubber, plastics, and other materials. Ozone also results from atmospheric reactions with other engine emissions such as HC, aldehydes, and other oxides of nitrogen.

15.11 PARTICULATES

The exhaust of CI engines contains solid carbon soot particles that are generated in the fuel-rich zones within the cylinder during combustion. These are seen as exhaust smoke and cause an undesirable odorous pollution. Maximum density of particulate emissions occurs when the engine is under load at WOT. At this condition maximum fuel is injected to supply maximum power, resulting in a rich mixture and poor fuel economy. This can be seen in the heavy exhaust smoke emitted when a truck or railroad locomotive accelerates up a hill or from a stop.

Soot particles are clusters of solid carbon spheres. These spheres have diameters from 9 nm to 90 nm (1 nm = 10^{-9} m). But most of them are within the range of 15-30 nm. The spheres are solid carbon with HC and traces of other components absorbed on the surface. A single soot particle may contain up to 5000 carbon spheres.

Carbon spheres are generated in the combustion chamber in the fuel-rich zones where there is not enough oxygen to convert all carbon to CO_2 :

$$C_x\,H_y + z\,O_2 \rightarrow a\,CO_2 + b\,H_2\,O + c CO + d C(s) \tag{15.12}$$

Then, as turbulence and mass motion continue to mix the components in the combustion chamber, most of these carbon particles $[C(s)]$ find sufficient oxygen to further react and are converted to CO_2:

$$C(s) + O_2 \rightarrow CO_2 \tag{15.13}$$

More than 90 to 95% of carbon particles originally generated within an engine are thus converted to CO_2 and never comes out as carbon particles. It should be remembered that if CI engines are made to operate with an overall stoichiometric air-fuel mixture, instead of overall lean as they do, particulate emissions in the exhaust would far exceed acceptable levels.

Up to about 25% of the carbon in soot comes from lubricating oil components which vaporize and then react during combustion. The rest comes from the fuel and amounts to 0.2-0.5% of the fuel. Because of the high compression ratios of CI engines, a large expansion occurs during the power stroke. This makes the gases within the cylinder cooled to a relatively low temperature. This causes the remaining high-boiling-point components found in the fuel and lubricating oil to condense on the surface of the carbon soot particles. This absorbed portion of the soot particles is called the soluble organic fraction (SOF), and the amount is highly dependent on cylinder temperature.

At light loads, cylinder temperatures are reduced and can drop to as low as 200 °C during final expansion and exhaust blow-down. Under these conditions, SOF can be as high as 50% of the total mass of soot. Under other operating conditions when temperatures are not so low, very little condensing occurs and SOF can be as low as 3% of total soot mass. SOF consists mostly of hydrocarbon components with some hydrogen, NO, NO_2, SO_2 and trace amounts of calcium, chromium, iron, phosphorus, silicon, sulphur and zinc. Diesel fuel contains calcium, chromium, iron, silicon, and sulphur, while lubricating oil additives contain calcium, phosphorus, and zinc.

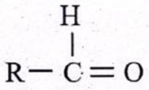
Particulate generation can be reduced by engine design and control of operating conditions, but quite often this will create other adverse results. If the combustion time is extended by combustion chamber design and timing control, particulate amounts in the exhaust can be reduced. Soot particles originally generated will have a greater time to be mixed with oxygen and combusted to CO_2. However, a longer combustion time means a high cylinder temperature and more NO_x generation. Dilution with EGR lowers NO_x emissions but increases particulates and HC emissions. Higher injection pressure gives a finer droplet size. This will reduce HC and particulate emissions but increases cylinder temperature and NO_x emissions. Engine management systems are programmed to minimize CO, HC, NO_x, and particulate emissions by controlling ignition timing, injection pressure, injection timing, and/or valve timing. Obviously, some sort of compromise is necessary. In most cases exhaust particulate amounts cannot be reduced to acceptable levels solely by engine design and control.

15.12 OTHER EMISSIONS

Apart from major emissions like unburnt hydrocarbon, carbon monoxide and NO_x, there are other emissions that come out of the exhaust. A brief account of other emissions are given in the following sections.

15.12.1 Aldehydes

A major emission problem when alcohol fuel is used is the generation of aldehydes, an eye and respiratory irritant. These have the chemical formula of: where R denotes various chemical radicals.



$$R-\overset{\overset{\displaystyle H}{|}}{C}=O$$

This is a product of incomplete combustion and would be a major problem if as much alcohol fuel were used as presently as gasoline.

15.12.2 Sulphur

Many fuels used in CI engines contain small amounts of sulphur. When exhausted in the form of SO_2 and SO_3 (called SO_x) they contribute to the acid rain problem of the world. Unleaded gasoline generally contains 150-550 ppm sulphur by weight. Some diesel fuels contain up to 5500 ppm by weight, but in the developed countries this is restricted by law to a tenth of this value or less.

At high temperatures, sulphur combines with hydrogen to form H_2S and with oxygen to form SO_2:

$$H_2 + S \rightarrow H_2S \tag{15.14}$$

$$O_2 + S \rightarrow SO_2 \tag{15.15}$$

Engine exhaust can contain up to 20 ppm of SO_2. SO_2 then combines with oxygen in the air to form SO_3

$$2\ SO_2 + O_2 \rightarrow 2\ SO_3 \tag{15.16}$$

These combine with water vapor in the atmosphere to form sulphuric acid (H_2SO_4) and sulphurous acid (H_2SO_3), which are ingredients in acid rain

$$SO_3 + H_2O \rightarrow H_2\ SO_4 \tag{15.17}$$

$$SO_2 + H_2O \rightarrow H_2\ SO_3 \tag{15.18}$$

Many countries have laws restricting the amount of sulphur allowed in fuel. These are continuously being made more stringent. During the 1990s, the developed countries reduced acceptable levels of sulphur in diesel fuel from 0.05% by weight to 0.01%.

The amount of sulphur in natural gas can range from little (sweet) to large (sour) amounts. This can be a major emissions problem when natural gas is used in a IC engine or any other combustion system.

15.12.3 Lead

Lead was a major gasoline additive from its introduction in 1920s to when it was phased out in the 1980s. The additive TEL (tetraethyl lead) was effectively used to increase gasoline octane number, which allowed higher compression ratios and more efficient engines. However, the resulting lead in the engine exhaust was a highly poisonous pollutant. During the first half of the 1900s, due to the lower number of automobiles and other engines, the atmosphere was able to absorb these emissions of lead without noticeable problems. As population and automobile density increased, the awareness of air pollution and its danger also increased. The danger of lead emissions was recognized, and a phase-out occurred during the 1970s and 1980s.

The use of lead could not be stopped immediately but had to be phased out over a number of years. First, low-lead gasoline was introduced, and then, years later no-lead gasoline. Lead was still the major additive to raise the octane number of gasoline, and alternate octane raisers had to be developed as lead was phased out. Millions of modern high-compression ratio engines could not use low-octane fuel.

Metals used in engines also had to be changed as lead in gasoline was phased out. When leaded fuel is burned, it hardens the surfaces in the combustion chamber and on the valves and valve seats. Engines designed to use leaded fuel had softer metal surfaces to start and relied on surface hardening effects that occurred in use. If these engines are used with unleaded fuel, surface hardening is not realized. Quick and serious wear problems were experienced. Catastrophic failures of valve seats or piston faces are common in a short period of time (i.e., 10,000–20,000 km in an automobile). Hence, harder metals and added surface treatments are being employed for engines designed to use unleaded fuel. It was necessary to phase out leaded gasoline over a period of time as older automobiles wore out and were taken out of operation.

Leaded gasoline contains about 0.15 gm/liter of lead in the fuel. 10 to 50% of this gets exhausted out with the other combustion products. The remaining lead gets deposited on the walls of the engine and exhaust system. The hardened combustion chamber surfaces which resulted from the burning of leaded gasoline were quite impervious to the absorption of gases such as fuel vapor. HC emissions were also, therefore, slightly reduced in these engines.

15.12.4 Phosphorus

Small amounts of phosphorus are emitted in engine exhaust. These come from impurities in the air and small amounts found in some fuel blends and lubricating oil.

15.13 EMISSION CONTROL METHODS

It is to be noted that combustion process in the four-stroke cycle occurs only for about 25 to 50 ms depending upon the operating conditions. After the combustion process ends, the exhaust gas constituents in the cylinder gas mixture that have been partially burned continue to react during the expansion stroke, during exhaust blowdown, and into the exhaust process. Over 90 to 95% of the HC remaining after combustion reacts during this time either in the cylinder, near the exhaust port, or in the upstream part of the exhaust manifold. CO and small component hydrocarbons react with oxygen to form CO_2 and H_2O and reduce undesirable emissions. The higher the exhaust temperature, the more these secondary reactions occur and the lower the engine emissions. Higher exhaust temperature can be caused by stoichiometric air-fuel combustion, high engine speed, retarded spark, and/or a low expansion ratio. Hence, in order to reduce emissions, some after-treatments are necessary with add on devices. The details are discussed in the following sections.

15.13.1 Thermal Converters

Secondary reactions occur much more readily and completely if the temperature is high. So some engines are equipped with thermal converters as a means of lowering emissions. Thermal converters are high-temperature chambers through which the exhaust gas flows. They promote oxidation of the CO and HC which remain in the exhaust.

$$\mathrm{CO} + \frac{1}{2}\,\mathrm{O_2} \rightarrow \mathrm{CO_2} \qquad (15.19)$$

For this reaction to occur at a useful rate, the temperature must be held above 700 °C. Now consider the reaction

$$C_x\,H_y + z\,O_2 \;\rightarrow\; x\,CO_2 + y\,H_2\,O \qquad (15.20)$$

where $z = x + 0.25y$.

The above reaction needs a temperature above 600 °C for at least 50 milliseconds to substantially reduce HC. It is therefore necessary for a thermal converter to be effective, it should operate at a high temperature. Further, it should also be large enough to provide adequate residence time of the exhaust gases to promote the occurrence of these secondary reactions. Most thermal converters are essentially an enlarged exhaust manifold connected to the engine immediately outside the exhaust ports. This is necessary to minimize heat losses and keep the exhaust gases from cooling to nonreacting temperatures.

However, in automobiles this creates two very serious problems for the engine compartment. In modern, low-profile, aerodynamic automobiles, space in the engine compartment is very limited, and fitting in a large, usually insulated thermal converter chamber is almost impossible. Secondly, because the converter must operate above 700 °C to be efficient, even if it is insulated the heat losses create a serious temperature problem in the engine compartment.

Some thermal converter systems include an air intake which provides additional oxygen to react with the CO and HC. This increases the complexity, cost, and size of the system. Air addition is especially necessary during rich operating conditions such as startup. Because exhaust from engines is often at a lower temperature than is needed for efficient operation of a thermal converter, it is necessary to sustain the high temperatures by the reactions within the system. Adding outside air, which is at a lower temperature, compounds this problem of maintaining the necessary operating temperature. Even though HC and CO emissions can be reduced by oxidation, NO_x emissions cannot be reduced using a thermal converter.

15.14 CATALYTIC CONVERTERS

The most effective aftertreatment for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines of medium or large size. CO and HC can be oxidized to CO_2 and H_2O in exhaust systems and thermal converters if the temperature is held at 600–700 °C. If certain catalysts are present, the temperature needed to sustain these oxidation processes is reduced to 250–300 °C, making for a much more attractive system.

A catalyst is a substance that accelerates a chemical reaction by lowering the energy needed for it to proceed. The catalyst is not consumed in the reaction and so functions indefinitely unless degraded by heat, age, contaminants, or other factors. Catalytic converters are chambers mounted in the flow system through which the exhaust gases pass through. These chambers contain catalytic material, which promotes the oxidation of the emissions contained in the exhaust flow.

Generally, catalytic converters are called three-way converters because they are used to reduce the concentration of CO, HC, and NO_x in the exhaust. Catalytic converter is usually a stainless steel container mounted somewhere along the exhaust pipe of the engine. Inside the container is a porous ceramic structure through which the exhaust gas flows. In most converters, the ceramic is a single honeycomb structure with many flow passages (Fig.15.7). Some converters use loose granular ceramic with the gas passing between the packed spheres. Volume of the ceramic structure of a converter is generally about half the displacement volume of the engine. This results in a volumetric flow rate of exhaust gas such that there are 5 to 30 changeovers of gas each second, through the converter. Catalytic converters for CI engines need larger flow passages because of the solid soot in the exhaust gases.

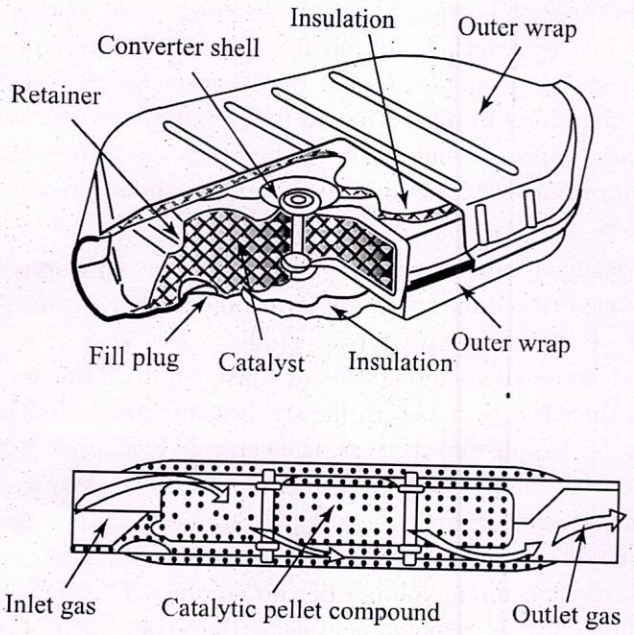
The surface of the ceramic passages contains small embedded particles of catalytic material that promote the oxidation reactions in the exhaust gas as it passes. Aluminum oxide (alumina) is the base ceramic material used for most catalytic converters. Alumina can withstand the high temperatures, it remains chemically neutral, it has very low thermal expansion, and it does not thermally degrade with age. The catalyst materials most commonly used are platinum, palladium, and rhodium.

Palladium and platinum promote the oxidation of CO and HC as in Eqs.15.19 and 15.20, with platinum especially active in the hydrocarbon reaction. Rhodium promotes the reaction of NO_x in one or more of the following reactions:

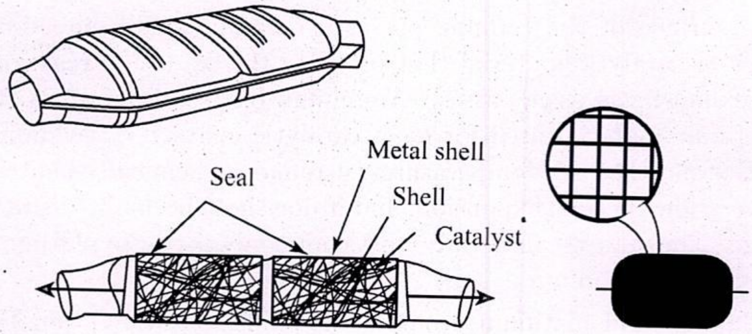
$$\mathrm{NO + CO \rightarrow \frac{1}{2}\,N_2 + CO_2} \qquad (15.21)$$

$$\mathrm{2\,NO + 5\,CO + 3\,H_2O \rightarrow 2\,NH_3 + 5\,CO_2} \qquad (15.22)$$

$$\mathrm{2\,NO + CO \rightarrow N_2O + CO_2} \qquad (15.23)$$



(a) Packed spheres



(b) Honey comb structure

Fig. 15.7 Catalytic Converters for SI Engines

$$NO + H_2 \rightarrow \frac{1}{2} N_2 + H_2O \qquad (15.24)$$

$$2\,NO + 5\,H_2 \rightarrow 2\,NH_3 + 2\,H_2\,O \qquad (15.25)$$

$$2\,NO + H_2 \rightarrow N_2\,O + H_2\,O \qquad (15.26)$$

Also often used is cerium oxide, which promotes the so-called water gas shift

$$CO + H_2\,O \rightarrow CO_2 + H_2 \qquad (15.27)$$

This reduces CO by using water vapor as an oxidant instead of O_2, which is very important when the engine is running rich.

Figure 15.8 shows that the efficiency of a catalytic converter is very much dependent on temperature. When a converter in good working order is operating at a fully warmed temperature of 400 °C or above, it will remove 98-99% of CO, 95% of NO_x, and more than 95% of HC from exhaust flow emissions.

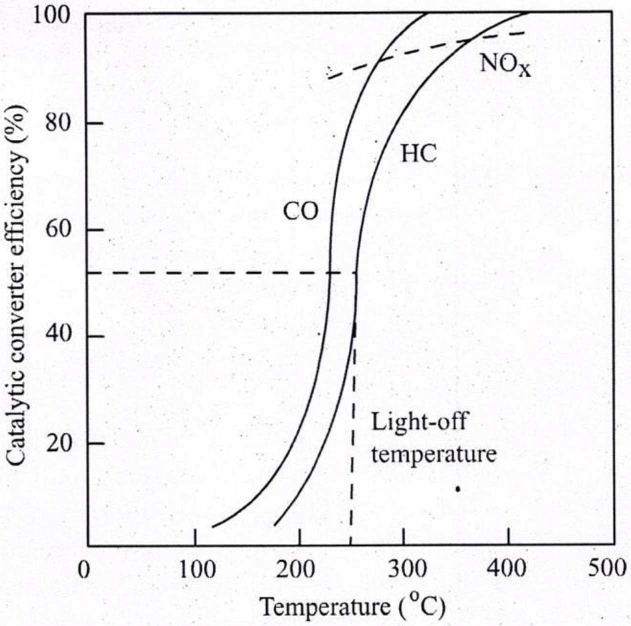


Fig. 15.8 Conversion Efficiency of Catalytic Converters as a Function of Converter Temperature

Figure 15.9 shows that it is also necessary to be operating at the proper equivalence ratio to get high converter efficiency. Effective control of HC and CO occurs with stoichiometric or lean mixtures while control of NO_x requires near stoichiometric conditions. Very poor NO_x control occurs with lean mixtures.

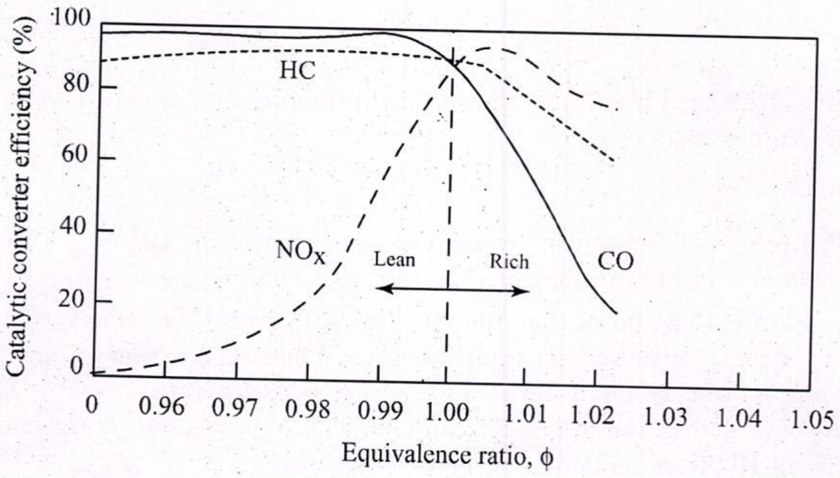


Fig. 15.9 Conversion Efficiency of Catalytic Converters as a Function of Fuel Equivalence Ratio

It is important that a catalytic converter be operated hot to be efficient, but not hotter. Engine malfunctions can cause poor efficiency and overheating of converters. A poorly tuned engine can have misfires and periods of too lean and/or too rich conditions. These cause the converter to be inefficient. A turbocharger lowers the exhaust temperature by removing energy, and this can make a catalytic converter less efficient.

It is desirable that catalytic converters have an effective life time equal to that of the automobile or at least 200,000 km. Converters lose their efficiency with age due to thermal degradation and poisoning of the active catalyst material. At high temperature the metal catalyst material can sinter and migrate together. This can cause larger active sites which are, overall, less efficient. Serious thermal degradation occurs in the temperature range of 500–900 °C. A number of different impurities contained in fuel, lubricating oil, and air find their way into the engine exhaust and poison the catalyst material. These include lead and sulphur from fuels, and zinc, phosphorus, antimony, calcium, and magnesium from oil additives.

Figure 15.10 shows how just a small amount of lead on a catalyst site can reduce HC emission reduction by a factor of two or three.

Small amounts of lead impurities are found in some fuels, and 10 to 30% of this ends up in the catalytic converter. Up until the early 1990s leaded gasoline was quite common. Note that leaded gasoline cannot be used in engines equipped with catalytic converters. Use of leaded gasoline filled two times (full tank) would completely poison a converter and make it totally useless. To reduce the chances of accidently using leaded gasoline with a catalytic converter, the fuel pump nozzle size and the diameter of the fuel tank inlet are made smaller for unleaded gasoline.

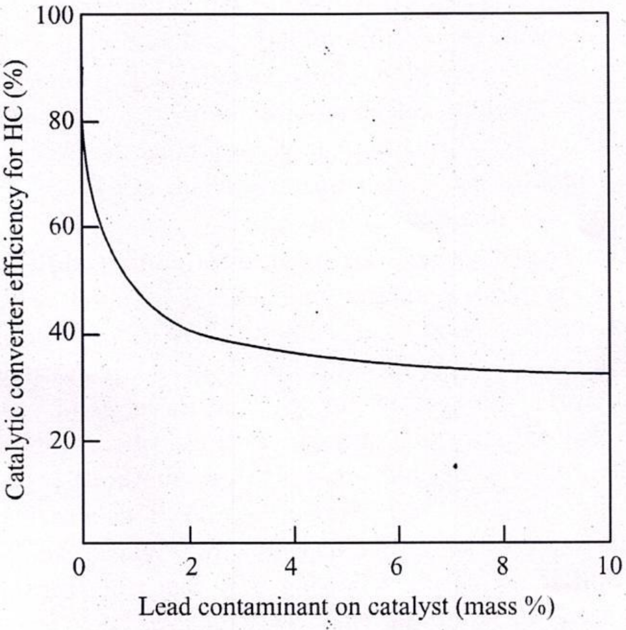


Fig. 15.10 Reduction of catalytic Converter Efficiency due to Contamination by Lead

15.14.1 Sulphur

Sulphur offers unique problems for catalytic converters. Some catalysts promote the conversion of SO_2 to SO_3, which eventually gets converted to sulphuric acid. This degrades the catalytic converter and contributes to acid rain. New catalysts are being developed that promote the oxidation of HC and CO but do not change SO_2 to SO_3. Some of these create almost no SO_3 if the temperature of the converter is kept less than 400 °C.

15.14.2 Cold Start-Ups

As can be seen from Fig.15.8 catalytic converters are not very efficient when they are cold. When an engine is started after not being operated for several hours, it takes several minutes for the converter to reach an efficient operating temperature. The temperature at which a converter becomes 50% efficient is defined as the light-off temperature, and this is in the range of about 250–300 °C.

A large percentage of automobile travel is for short distances where the catalytic converter never reaches efficient operating temperature, and therefore emissions are high. Unfortunately, most short trips occur in cities where high emissions are more harmful. Further, all engines use a rich mixture when starting. Otherwise cold start-ups pose a major problem.

It is estimated that cold start-ups are the source of 70-90% of all HC emissions. A major reduction in emissions is therefore possible if catalytic converters could be preheated, at least to light-off temperature, before engine startup. Preheating to full steady-state operating temperature would be even better. Several methods of pre-heating have been tried with varying success. Because of the time involved and amount of energy needed, most of these methods preheat only a small portion of the total converter volume. This small section is large enough to treat the low exhaust flow rate which usually occurs at startup and immediately following. By the time higher engine speeds are used, most of the catalytic converter has been heated by the hot exhaust gas, and the higher flow rates are fully treated. Methods of catalytic converter preheating include the following.

(i) by locating the converter close to the engine

(ii) by having superinsulation

(iii) by employing electric preheating

(iv) by using flame heating

(v) incorporating thermal batteries

15.15 CI ENGINES

Catalytic converters are being tried with CI engines but are not efficient at reducing NO_x due to their overall lean operation. HC and CO can be adequately reduced, although there is greater difficulty because of the cooler exhaust gases of a CI engine (because of the larger expansion ratio). This is counter balanced by the fact that less HC and CO are generated in the lean burn of the CI engine. NO_x is reduced in a CI engine by the use of EGR, which keeps the maximum temperature down. EGR and lower combustion temperatures, however, contribute to an increase in solid soot.

Platinum and palladium are two main catalyst materials used for converters on CI engines. They promote the removal of 30–80% of the gaseous HC and 40–90% of the CO in the exhaust. The catalysts have little effect on solid carbon soot but do remove 30–60% of the total particulate mass by oxidizing a large percent of the HC absorbed on the carbon particles. Diesel fuel contains sulphur impurities, and this leads to poisoning of the catalyst materials. However, this problem is getting minimized as legal levels of sulphur in diesel fuels continue to be lowered.

15.15.1 Particulate Traps

Compression ignition engine systems are equipped with particulate traps in their exhaust flow to reduce the amount of particulates released to the atmosphere. Traps are filter-like systems often made of ceramic in the form of a monolith or mat, or else made of metal wire mesh. Traps typically remove 60–90% of particulates in the exhaust flow. As traps catch the soot particles, they slowly fill up with the particulates. This restricts exhaust gas flow and raises the back pressure of the engine. Higher back pressure causes the engine to run hotter, the exhaust temperature to rise, and fuel consumption to increase. To reduce this flow restriction, particulate traps are regenerated when they begin to saturate. Regeneration consists of combusting the particulates in the excess oxygen contained in the exhaust of the lean-operating CI engine.

Carbon soot ignites at about 550–650 °C, while CI engine exhaust is 150–350 °C at normal operating conditions. As the particulate trap fills with soot and restricts flow, the exhaust temperature rises but is still not high enough to ignite the soot and regenerate the trap. In some systems, automatic flame igniters are used which start combustion in the carbon when the pressure drop across the trap reaches a predetermined value. These igniters can be electric heaters or flame nozzles that use diesel fuel. If catalyst material is installed in the traps, the temperature needed to ignite the carbon soot is reduced to the 350–450 °C range. Some such traps can automatically regenerate by self-igniting when the exhaust temperature rises from increased back pressure. Other catalyst systems use flame igniters.

Another way of lowering the ignition temperature of the carbon soot and promoting self-regeneration in traps is to use catalyst additives in the diesel fuel. These additives generally consist of copper compounds or iron compounds, with about 6 to 8 grams of additive in 1000 liters of fuel is usually normal. To keep the temperatures high enough to self-regenerate in a catalytic system, traps can be mounted as close to the engine as possible, even before the turbocharger.

On some larger stationary engines and on some construction equipment and large trucks, the particulate trap is replaced when it becomes close to filled position. The removed trap is then regenerated externally, with the carbon being burned off in a furnace. The regenerated trap can then be used again.

Various methods are used to determine when soot buildup becomes excessive and regeneration is necessary. The most common method is to measure pressure drop in the exhaust flow as it passes through the trap. When a predetermined pressure drop Δp is reached, regeneration is initiated. Pressure drop is also a function of exhaust flow rate, and this must be programmed into the regeneration controls. Another method used to sense soot buildup is to transmit radio frequency waves through the trap and determine the percent that is absorbed. Carbon soot absorbs radio waves while the ceramic structure does not. The amount of soot buildup can therefore be determined by the percent decrease in radio signal. This method does not readily detect soluble organic fraction (SOF).

Modern particulate traps are not totally satisfactory, especially for automobiles. They are costly and complex when equipped for regeneration, and long-term durability does not exist. An ideal catalytic trap would be simple, economical, and reliable; it would be self-regenerating; and it would impose a minimum increase in fuel consumption.

15.15.2 Modern Diesel Engines

Carbon soot particulate generation has been greatly reduced in modern CI engines by advanced design technology in fuel injectors and combustion chamber geometry. With greatly increased mixing efficiency and speeds, large regions of fuel- rich mixtures can be avoided when combustion starts. These are the regions where carbon soot is generated, and by reducing their volume, far less soot is generated. Increased mixing speeds are obtained by a combination of indirect injection, better combustion chamber geometry, better injector design and higher pressures, heated spray targets, and air-assisted injectors. Indirect injection into a secondary chamber that promotes high turbulence and swirl greatly speeds the air-fuel mixing process. Better nozzle design and higher injection pressures create finer fuel droplets which evaporate and mix quicker. Injection against a hot surface speeds evaporation, as do air-assisted injectors. Some modern, top-of-the-line CI automobile engines have reduced particulate generation enough that they meet stringent standards without the need for particulate traps.

15.16 REDUCING EMISSIONS BY CHEMICAL METHODS

Development work has been done on large stationary engines using cyanuric acid to reduce NO_x emissions. Cyanuric acid is a low-cost solid material that sublimes in the exhaust flow. The gas dissociates, producing isocyanide that reacts with NO_x to form N_2, H_2O, and CO_2. Operating temperature is about 500 °C. Up to 95% NO_x reduction can be achieved with no loss of engine performance. At present, this system is not practical for automobile engines because of its size, weight, and complexity.

Research is being done using zeolite molecular sieves to reduce NO_x emissions. These are materials that absorb selected molecular compounds and catalyze chemical reactions. Using both SI and CI engines, the efficiency of NO_x reduction is being determined over a range of operating variables, including air-fuel ratio, temperature, flow velocity, and zeolite structure. At present, durability is a serious limitation with this method.

Various chemical absorbers, molecular sieves, and traps are being tested to reduce HC emissions. HC is collected during engine startup time, when the catalytic converter is cold, and then later released back into the exhaust flow when the converter is hot. The converter then efficiently burns the HC to H_2O and CO_2. A 35% reduction of cold-start HC has been achieved.

H_2S emissions occur under rich operating conditions. Chemical systems are being developed that trap and store H_2S when an engine operates rich and then convert this to SO_2 when operation is lean and excess oxygen exists. The reaction equation is

$$H_2S + O_2 \rightarrow SO_2 + H_2 \qquad (15.28)$$

15.16.1 Ammonia Injection Systems

Some large marine engines and stationary engines reduce NO_x emissions with an injection system that sprays NH_3 into the exhaust flow.

In the presence of a catalyst, the following reactions occur

$$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O \qquad (15.29)$$

$$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2\ O \qquad (15.30)$$

Careful control must be adhered to, as NH3 itself is an undesirable emission.

Ammonia injection systems are not practical in automobiles or on other smaller engines. This is because of the needed NH_3 storage and fairly complex injection and control system.

15.17 EXHAUST GAS RECIRCULATION (EGR)

The most effective way of reducing NO_x emissions is to hold combustion chamber temperatures down. Although practical, this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. Those who have undergone thermodynamics course are aware that to obtain maximum engine thermal efficiency it should be operated at the highest temperature possible.

Probably the simplest and practical method of reducing maximum flame temperature is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input. The net result is a lower flame temperature. Any nonreacting gas would work as a diluent, as shown in Fig.15.11. Those gases with larger specific heats would absorb the most energy per unit mass and would therefore require the least amount; thus less CO_2 would be required than argon for the same maximum temperature. However, neither CO_2 nor argon is readily available for use in an engine. Air is available as a diluent but is not totally nonreacting. Adding air changes the air-fuel ratio and combustion characteristics. The one nonreacting gas that is available to use in an engine is exhaust gas; and this is used in all modern automobile and other medium-size and large engines.

Adding any non reacting neutral gas to the inlet air-fuel mixture reduces flame temperature and NO_x generation, Exhaust gas (EGR) is the one gas that is readily available for engine use.

Exhaust gas recycle (EGR) is done by ducting some of the exhaust flow back into the intake system, usually immediately after the throttle. The amount of flow can be as high as 30% of the total intake. EGR combines with the exhaust residual left in the cylinder from the previous cycle to effectively reduce the maximum combustion temperature. The flow rate of EGR is controlled by the Engine

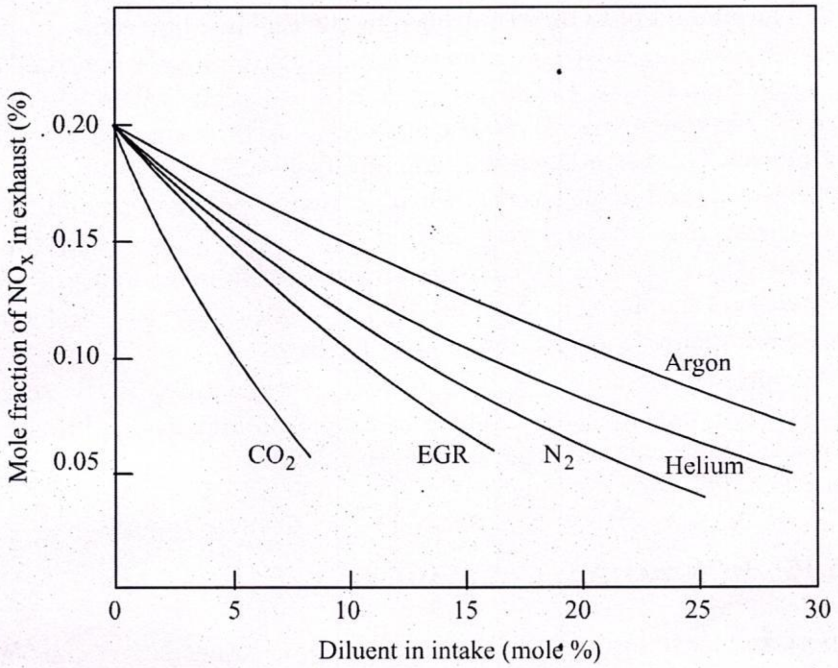


Fig. 15.11 NO$_x$ Reduction using Non-combustible Diluent Gas to Intake Mixture

Management System. EGR is defined as a mass percent of the total intake flow

$$\text{EGR} = \left(\frac{\dot{m}_{\text{EGR}}}{\dot{m}_{cyl}}\right) \times 100 \qquad (15.31)$$

where *cyl* is the total mass flow into the cylinders.

After EGR combines with the exhaust residual left from the previous cycle, the total fraction of exhaust in the cylinder during the compression stroke is

$$x_{ex} = \left(\frac{\text{EGR}}{100}\right) \times (1 - x_r) + x_r \qquad (15.32)$$

where x_r is the exhaust residual from previous cycle.

Not only does EGR reduce the maximum temperature in the combustion chamber, but it also lowers the overall combustion efficiency. Increase in EGR results in some cycle partial burns and, in the extreme, total misfires. Thus, by using EGR to reduce NO$_x$ emissions, a costly price of increased HC emissions and lower thermal efficiency must be paid.

The amount of EGR is controlled by the Engine Management System. By sensing inlet and exhaust conditions the flow is controlled, ranging from 0 upto 15–30%. Lowest NO_x emissions with relatively good fuel economy occur at about stoichiometric combustion, with as much EGR as possible without adversely affecting combustion. No EGR is used during WOT, when maximum power is desired. No EGR is used at idle and very little at low speeds. Under these conditions, there is already a maximum exhaust residual and greater combustion inefficiency. Engines with fast-burn combustion chambers can tolerate a greater amount of EGR.

A problem unique to CI engines when using EGR is the solid carbon soot in the exhaust. The soot acts as an abrasive and breaks down the lubricant. Greater wear on the piston rings and valve train results.

15.18 NON-EXHAUST EMISSIONS

Apart from exhaust emissions there are three other sources in an automobile which emit emissions. They are

(i) *Fuel tank*: The fuel tank emits fuel vapours into the atmosphere.

(ii) *Carburetor*: The carburettor also gives out fuel vapours.

(iii) *Crankcase*: It emits blow-by gases and fuel vapours into the atmosphere.

The fourth source is the tail pipe which brings out exhaust emissions. The contribution of pollutants by sources, as shown in Fig.15.12 is as follows:

(i) Evaporative losses (both from fuel tank and carburetor)

(ii) Crankcase blowby (from crankcase)

(iii) Tail pipe (from the exhaust pipe)

The percentage emissions of various pollutants are as marked in Fig.15.12. The evaporative losses are the direct losses of raw gasoline from the engine fuel system; the blowby gases are the vapours and gases leaking into the crankcase from the combustion chamber and the pollutants from the exhaust pipe are due to incomplete combustion. The following sections discuss the details of the non-exhaust emissions and their control methods.

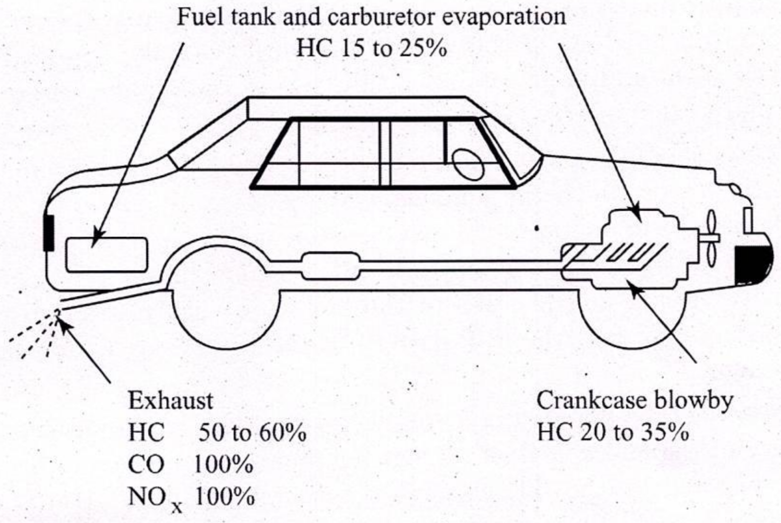


Fig. 15.12 Distribution Of Emissions By Source (Petrol Engine Powered Vehicle)

15.18.1 Evaporative Emissions

Evaporative emissions account for 15 to 25% of total hydrocarbon emission from a gasoline engine. The two main sources of evaporative emissions are the fuel tank and the carburettor.

Fuel tank losses: As the temperature inside the engine rises, the fuel tank heats up. The air inside the fuel tank expands, part of which goes out through the tank vent tube or leaves through the vent of the cap in the tank. This air is mixed with gasoline vapours.

As the temperature decreases, the tank cools. The air inside the tank contracts and there is more space inside the tank. Air enters the tank from the atmosphere and ventilates it. This process of ventilation is called *breathing*.

Some of the gasoline is lost by the process of breathing. If the temperature is high, more gasoline is lost. The mechanism of tank loss is as follows:

When a partially filled fuel tank is open to atmosphere the partial pressure of the vapour phase hydrocarbons and vapour pressure of the liquid are equal and they are in equilibrium. If the temperature of the liquid is increased, say by engine operation, the vapour pressure of the liquid will increase and it will vapourize in an attempt to restore equilibrium. As additional liquid vapourize, the total pressure of the tank increases and since the tank is vented to atmosphere the vapour will flow out of the vent. This outflow of the vapour will increase if in addition to temperature rise of the liquified gasoline the vapour temperature is also increased.

The evaporation from the tank is affected by a large number of variables of which the ambient and fuel tank temperature, the mode of vehicle operation, the amount of fuel in the tank and the volatility of the fuel are important. Other significant factors are the capacity, design and location of the fuel tank with respect to the exhaust system and the flow pattern of the heated air underneath the vehicle.

Less the tank fill, greater is the evaporation loss. An approximate picture of the effect of tank fill and temperature are given in Table 15.2, This reflects the difference in the tank vapour space. Also when a vehicle is parked in a hot location the evaporation of the gasoline in the tank accelerates, so the loss due to evaporation are high.

Table 15.2 Effect of Tank Fill on Evaporation Loss

Tank fill	Ambient temperature (°C)	Loss during operation (%)
Quarter	10	5.8
Half	15	1.1
Three-fourth	18	0.1
Full	22	0.0

The operational mode substantially affect the evaporation loss. When the tank temperature rises the loss increases. The vapour which goes out from a partially filled tank during vehicle operation called soak, is a mixture of air and hydrocarbon. After a prolonged high speed operation the HC per cent in the soak is as high as 60 per cent as compared to about 30 per cent after an overnight soak. The fuel composition also affects the tank losses. About 75 per cent of the HC loss from tank are C_4 and C_5 hydrocarbons.

Carburettor losses: The operation of an engine depends on the level of gasoline in the float chamber inside the carburettor. The engine stops running when the gasoline has been completely utilized. Heat produced by the engine causes evaporation of some quantity of gasoline from the float chamber. The evaporation of gasoline constitutes the main reason for the loss of gasoline from the carburettor.

Approximately, 10% of the total hydrocarbon emission of the engine into the atmosphere is through the fuel tank and the carburetor.

Carburettor losses result from (a) external venting of the float bowl relieving the internal pressure as the carburettor heats, and (b) 'hot soak' losses which occur after the engine has been stopped, as a result of evaporation of petrol stored in the bowl, loss being through vent pipe or through the air cleaner. Most of the loss from the carburettor occurs due to direct boiling of the fuel in the carburettor bowl during hot soak. Carburettor bowl temperature during hot soak rises by 15 to 45 ° C above the ambient. This can cause fuel boiling and the front end gasoline components, C5 and C6 hydrocarbons, vaporise. The amount of hydrocarbon emissions from the carburettor depend upon the design variables. In some designs the small passage from bowl leading to the throat after heating causes siphon action leading to HC loss.

If the pressure in the fuel line becomes greater than the pressure holding the closed needle valve, after supply will occur. One of the possible reasons may be fuel evaporation in the carburettor bowl which presses down the bowl and increases the pressure in the fuel line. If the after-supply is more than the bowl volume the losses from the carburettor will change drastically. Thus bowl volume and maximum bowl temperature both significantly affect the evaporative losses from the carburettor. The losses of gasoline from the fuel tank and the carburettor should be prevented by special devices such as those used in evaporative emission control systems.

15.18.2 Evaporation Loss Control Device (ELCD)

This device aims at controlling all evaporative emissions by capturing the vapours and recirculating them at the appropriate time. The device, as shown in Fig.15.13, consists of an absorbent chamber, the pressure balance valve and the purge control valve. The adsorbent chamber, which consists of a charcoal bed or foamed polyurethane, holds the hydrocarbon vapour before they can escape to atmosphere. The carburettor bowl and the fuel tank, main sources of HC emissions, are directly connected to the adsorbent chamber when engine is turned off, i.e. under hot soak. As already mentioned, hot soak is the condition when a warmed up car is stopped and its engine turned off. This results in some boiling in the carburettor bowl and significant amount of HC loss occurs. Thus the hot soak loss and also the running loss from the carburettor as well as the tank are arrested in the chamber and the absorbed there. Also diurnal cycle loss from the tank is taken care of. Diurnal cycle is the daily cyclic variation in the temperature which causes tank 'breathing' or forcing the gasoline out of tank.

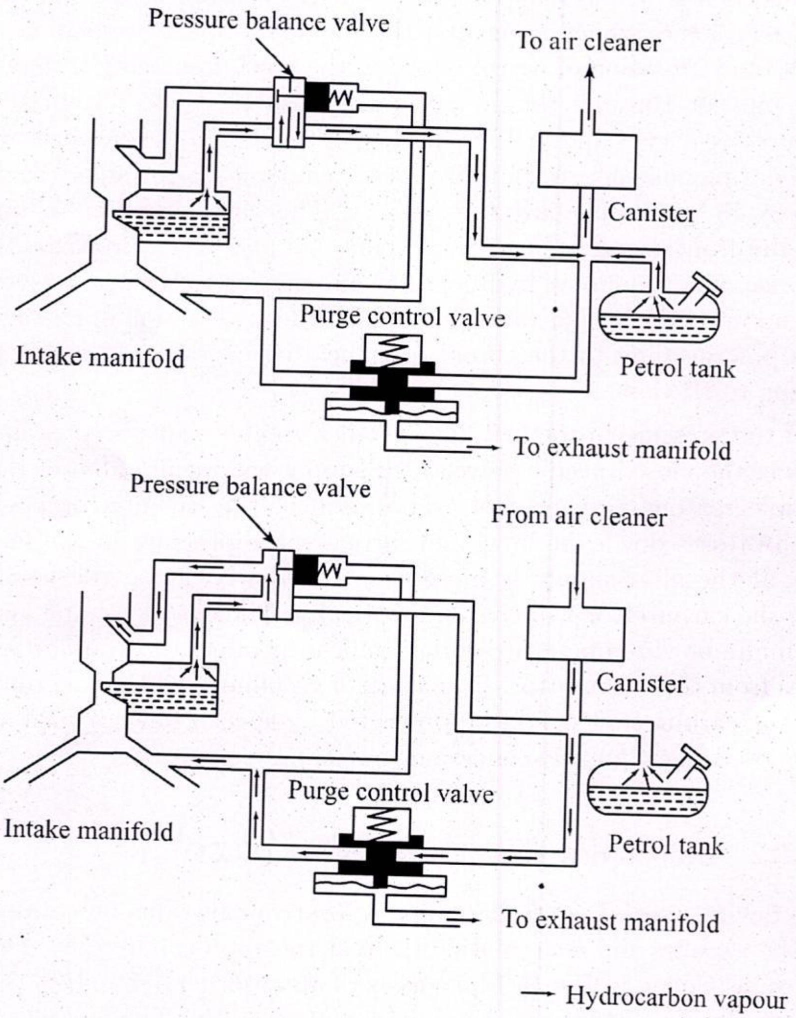


Fig. 15.13 Fuel System Evaporation Loss Control Device

The adsorbent bed when saturated is relieved of the vapours by a stripping action allowing the air from the air cleaner to draw them to the intake manifold through the purge valve. The internal seat of the pressure valve at that time is so located that there is a direct pressure communication between the internal vent and the top of the carburettor bowl, maintaining designed carburettor metering forces.

The operation of the purge control valve is taken care of by the exhaust back pressure. Under idling conditions the fuel supply is cut off so that the level of HC can be reduced.

The ELCD completely controls all types of evaporative losses. However, the tolerance of the carburettor for supplying fuel-air ratio reduces to about 3 per cent only. This requires very accurate metering control.

15.19 MODERN EVAPORATIVE EMISSION CONTROL SYSTEM

A modern evaporative emission control system is illustrated in Fig.15.14. The fuel tank is fitted to the vapour-liquid separator which is in the form of a chamber on the fuel tank. Vapour from the fuel tank goes to the top of the separator where the liquid gasoline is separated and sent back to the fuel tank through the fuel return pipe. A vent valve or a vent hole is provided for the carburettor for the flow of fuel vapours. This vent hole is connected by a tube to the canister. Fuel vapours from the float chamber flow through the vent hole and the tube to the canister. The canister adsorbs the fuel vapours and stores them. *Adsorption* refers to the process of trapping of the gasoline vapours by the activated charcoal particles filled inside the canister. Vapour laden air from both the fuel tank and the carburettor passes through the canister. Hydrocarbons (HC) are left in the canister due to the process of adsorption, and air leaves from the canister into the atmosphere. When an engine is started, the inlet manifold sucks fresh air through the canister.

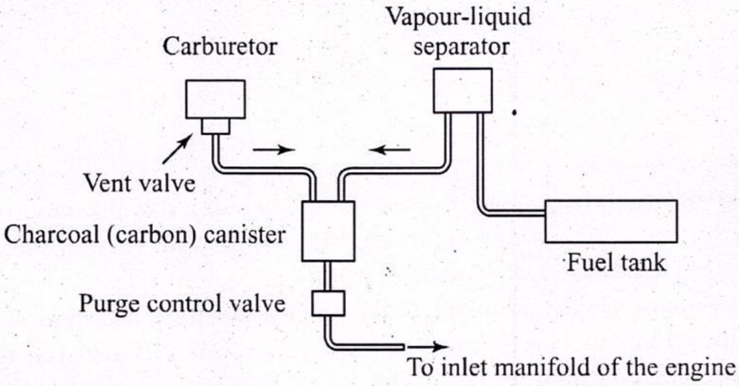


Fig. 15.14 Layout of Vapour Recovery System

The fresh air purges the gasoline vapours from the canister. 'Purging' is the process by which the gasoline vapours are removed from the charcoal particles inside the canister. The air carries the hydrocarbons (HC) through the purge control solenoid valve to the engine induction system. The purge control solenoid valve is controlled by the Electronic Control Module (ECM) of the Computer Command Control (CCC) system in modern automobiles.

15.19.1 Charcoal Canister

A charcoal canister used for trapping gasoline vapours is shown in Fig.15.15. This type of charcoal canister is used in the evaporative emission control system of a petrol engine. Fuel vapours from the float chamber of the carburetor enter into the canister though the left end passage. Fuel vapours from the fuel tank enter through the mid passage into the canister. The flow of these vapours is shown by the arrows pointing downwards. When the engine is not running, the fuel vapours flow in this manner . The fuel vapours are absorbed by the charcoal particles present in the canister. When the engine runs, air reaches the charcoal, canister due to the suction provided by the engine. This air carries away the hydrocarbons (HC) in the fuel vapours to the engine manifold. This purging action is shown at the right end of the charcoal canister by the arrows pointing upwards. As charcoal is a form of carbon, the charcoal canister is also called the carbon canister.

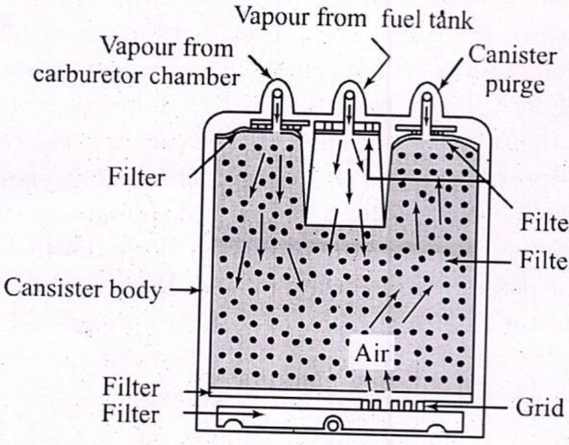


Fig. 15.15 Charcoal Canister

15.20 CRANKCASE BLOWBY

The blowby is the phenomenon of leakage past the piston and piston rings from the cylinder to the crankcase. The blowby HC emission are about 20 per cent of the total HC emission from the engine. This is increased to about 35 per cent if the rings are worn.

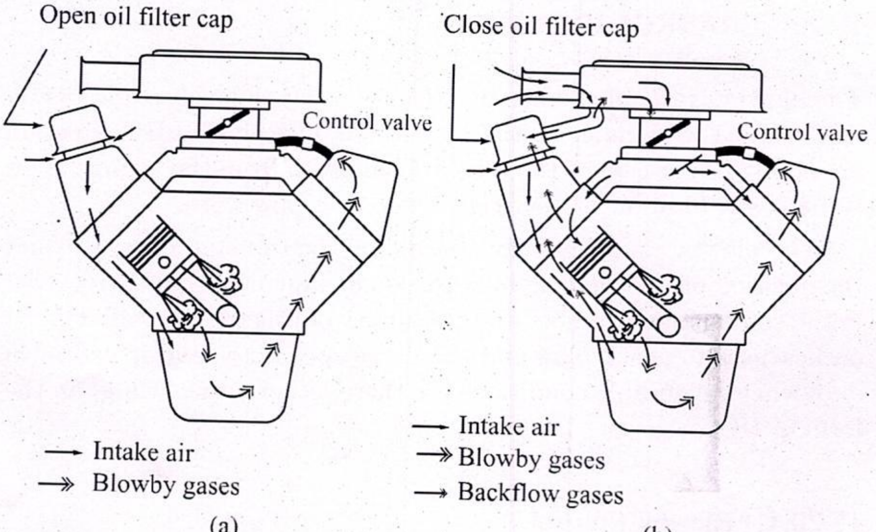
The blowby rate is greatly affected by the top land clearance and the position of the top ring because some of quenched gas is recycled in the combustion chamber and the ability of this to burn will depend on nearness to spark plug and the flame speed etc. and it will burn only when favourable conditions are there, otherwise it will go in the form of HC.

15.20.1 Blowby Control

The basic principle of all types or crankcase blowby control is recirculation of the vapours back to the intake air cleaner. There are a large number of different systems in use. Figure 15.16 shows typical closed or positive crankcase ventilation systems. In the PCV system the draft tube as shown in Fig.15.17 is eliminated and the blowby gases are rerouted back into the intake manifold or inlet of the carburettor. The blowby gases are consequently reintroduced into the combustion chamber where they are burned along with fresh incoming air and fuel. Since the blowby handling devices place the crankcase under a slight vacuum, they quickly became known as positive crankcase ventilation (PCV) systems.

15.20.2 Intake Manifold Return PCV System (Open Type)

Figure 15.16 (a) shows the intake manifold return PCV or open type system. It has a tube leading from crankcase or else the rocker arm cover through a flow control valve and into the intake manifold, usually, through an opening just below the carburettor. To provide proper ventilation of the interior of the engine, fresh air is usually drawn in through a rocker arm cover opposite that containing the PCV system. The closed PCV system Fig.15.16 (b) has a tube connected between the oil fill tube cap and the air cleaner, Both open and closed systems function in the same manner as long as the PCV valve remains unplugged. If the PCV valve plugs, using an open system, the blowby gases exhaust out of the oil fill tube cap and into the atmosphere. With PCV valve plugged it is no longer possible for fresh air crankcase ventilation to occur.



(a) (b)

Fig. 15.16 Positive Crankcase Ventilation

In closed PCV system if the PCV valve is plugged the blowby is rerouted through the tube to the air cleaner and subsequently into the air horn of the carburettor. As can be seen from Fig.15.16 (b) there is no possible escape of blowby into the atmosphere, even with 100 per cent PCV valve plugging. Again, with the PCV valve plugged, fresh air ventilation cannot take place. The closed system, however, requires the engine to digest all blowby developed regardless of the mechanical condition of the PCV system.

The PCV valve, located between the crankcase and the intake manifold, controls the flow rate of blowby gas and fresh air mixture going into the intake manifold below the carburettor [Fig.15.16 (b)]. If there is no crankcase ventilation, the blowby will be passed on to the atmosphere as per the path shown in Fig.15.17.

Figure 15.18 shows the two positions of the PCV valve. The design of the valve is such that at high speed and power, i.e. at low manifold vacuum the valve opens and allows a free flow of blowby gases to the intake system. This is consistent with the high quantity of blowby gas which has to be transferred to carburettor at high speed. The valve restricts the flow at high manifold vacuum as the corresponding blowby gas is in small quantity. The air drawn for the ventilation of blowby gas has a very small tolerance. A small amount of air will not effect any circulation and too much air will

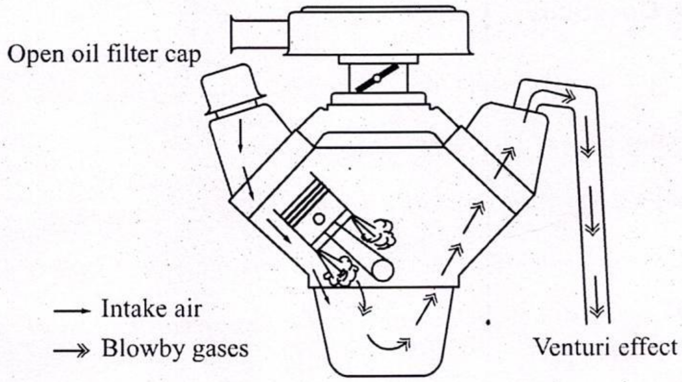
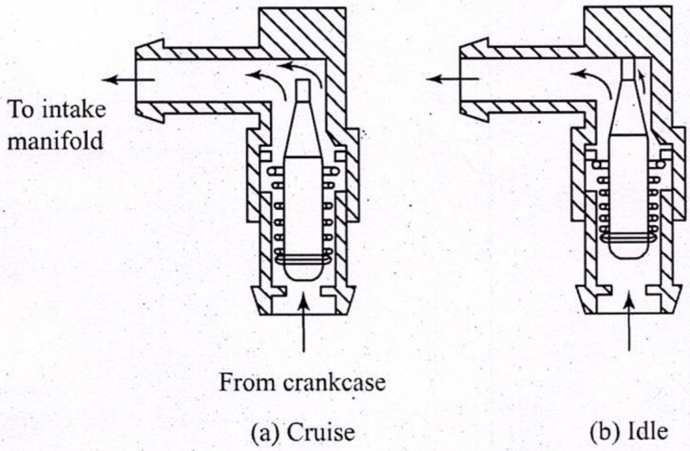


Fig. 15.17 Blowby Path without Positive Crankcase Ventilation

lift the lubricating oil. Also the carburettor has to be modified and adjusted to account for the charge coming from the crankcase in order to meter exact fuel-air ratio into the combustion chamber. The carburettor deposits and deposits on the blowby gas metering valve will significantly affect the performance of the carburettor. So high grade motor oil has to be used. In the closed ventilation system a provision is made for the blowby gases to escape to atmosphere in case of the metering valve failure.



(a) Cruise (b) Idle

Fig. 15.18 Two Positions of PCV Valve

Review Questions

15.1 *What are the problems created by exhaust emissions?*

15.2 *What causes the engine emissions?*

15.3 *Give a brief account of air pollution due to engines.*

15.4 *What are the major emissions that come out of engine exhaust?*

15.5 *Describe in detail the causes of hydrocarbon emissions from SI engines.*

15.6 *How knock emissions are caused and what are their effects on environment?*

15.7 *What are particulates? Describe in detail how particulate emissions are caused.*

15.8 *Give a brief account of other emissions from engines.*

15.9 *What is a thermal converter? How does it help to reduce emissions from engines?*

15.10 *What are catalytic converters? How are they helpful in reducing HC, CO and NO_x emissions?*

15.11 *Give a brief account of emissions from CI engines.*

15.12 *How can emissions be reduced using chemical methods?*

15.13 *What do you understand by the term EGR? Explain how EGR reduces NO_x emission.*

15.14 *Explain with a sketch the non-exhaust emission from a vehicle.*

15.15 *Explain with sketches how non-exhaust emission are controlled.*

15.16 *Explain with a neat sketch fuel system evaporation loss control device.*

15.17 *Give a layout of a vapour recovery system and explain.*

15.18 *With a neat sketch explain a charcoal canister for controlling non-exhaust emission.*

15.19 *What is crankcase blowby? How it is controlled?*

15.20 *Explain intake manifold open type PCV system.*

K.S.R.M. COLLEGE OF ENGINEERING

UGC - AUTONOMOUS
KADAPA , AP – 516 005

Certificate of Completion

This is to certify that

Mr/Ms. G. MURALIDHAR REDDY

Bearing the Roll No 199Y1A0309

has Succesfully completed certification course on

COMBUSTION AND EMISSION IN ENGINES

From 24/8/20 *to* 11/9/20 *, Organized by Department of*

MECHANICAL ENGINEERING

Coordinator

Head Of Department

V. S. S. Murty

Principal

K.S.R.M. COLLEGE OF ENGINEERING

UGC - AUTONOMOUS

KADAPA , AP – 516 005

Certificate of Completion

This is to certify that

Mr/Ms. M. KIRAN KUMAR

Bearing the Roll No 199Y1A0327

has Succesfully completed certification course on

COMBUSTION AND EMISSION IN ENGINES

From 24/8/20 *to* 11/9/20 *, Organized by Department of*

MECHANICAL ENGINEERING

Coordinator

Head Of Department

V. S. S. Murty

Principal

K.S.R.M.COLLEGE OF ENGINEERING

(UGC-AUTONOMOUS)

Kadapa,Andhra Pradesh,India–516 005

ApprovedbyAICTE,NewDelhi&AffiliatedtoJNTUA,Ananthapuramu.

Department of Mechanical Engineering

Certification Course on **Combustion and Emission in Engines**

Feedback Form

S.No	**Name of the Student**	**Roll List**	**Is the Course content meet your expectation**	**Is the lecture sequence well planned**	**Is the level of course high**	**Is the course exposed you to the new knowledge and practices**	**Rate the Knowledge of the Speaker**	**Rate the value of Course in increasing your skills**	**Any Issues**
1	AKULA SREEDHAR	199Y1A0301	Yes	Agree	Strongly Agree	Yes	4	5	Nil
2	B SRINIDHI SAI	199Y1A0302	Yes	Agree	Agree	Yes	5	5	Nil
3	BANDI SHIVA REDDY	199Y1A0303	Yes	Agree	Agree	Yes	4	5	Nil
4	CHAGANTI SUNIL KUMAR REDDY	199Y1A0304	Yes	Agree	Agree	Yes	4	5	Nil
5	CHEPPALI AMATHYA	199Y1A0305	Yes	Agree	Agree	Yes	4	5	Nil
6	CHIRUCHAPALA ABDUL SUBAHAN	199Y1A0306	Yes	Agree	Agree	Yes	5	4	Nil
7	DEVAPATLA BHARATH SIMHA REDDY	199Y1A0307	Yes	Agree	Agree	Yes	5	5	Nil
8	DUDIMANI SAI SRUJAN KUMAR	199Y1A0308	Yes	Agree	Agree	Yes	5	5	Provide PPt

9	GADIKOTA MURALIDHAR REDDY	199Y1A0309	Yes	Agree	Agree	Yes	5	5	Nil
10	GANGALA VENKATA PRATHAP	199Y1A0310	Yes	Agree	Agree	Yes	5	4	Nil
11	GANUGAPENTA BHARATH	199Y1A0311	Yes	Agree	Agree	Yes	5	5	Nil
12	GODDENDLA ASHOK KUMAR	199Y1A0312	Yes	Agree	Agree	Yes	4	5	Nil
13	GUDURU SUBHAN	199Y1A0313	Yes	Agree	Agree	Yes	5	5	Nil
14	KAPURAM VAMSINATH REDDY	199Y1A0315	Yes	Agree	Agree	Yes	4	5	Nil
15	KETHIREDDY NAVEEN KUMAR REDDY	199Y1A0316	Yes	Agree	Agree	Yes	4	5	Nil
16	KONANGI SUBBANNA	199Y1A0317	Yes	Agree	Agree	Yes	4	5	Nil
17	KONERU SAI KARTHIK	199Y1A0318	Yes	Agree	Agree	Yes	5	5	Nil
18	KOTHAPALLE VAMSIDHAR REDDY	199Y1A0319	Yes	Agree	Agree	Yes	5	5	Nil
19	KUMMARI MANJUNATH	199Y1A0320	Yes	Agree	Agree	Yes	5	4	Nil
20	KUMMETHA SAI KUMAR REDDY	199Y1A0321	Yes	Agree	Agree	Yes	5	5	Nil
21	L M VINAY KUMAR	199Y1A0322	Yes	Agree	Agree	Yes	5	5	Nil
22	MALEPATI SIVA SAI REDDY	199Y1A0324	Yes	Agree	Agree	Yes	5	5	Nil
23	MANJUNATHA DINESH KUMAR	199Y1A0325	Yes	Agree	Agree	Yes	4	5	Nil
24	MARKAPURAM MYSORA REDDY	199Y1A0326	Yes	Agree	Agree	Yes	5	5	Nil
25	MEDIMALA KIRAN KUMAR	199Y1A0327	Yes	Agree	Agree	Yes	4	5	Nil
26	MOGHAL JUNAID BAIG	199Y1A0328	Yes	Agree	Agree	Yes	4	5	Nil
27	MOLAKALA SREEKANTH REDDY	199Y1A0329	Yes	Agree	Agree	Yes	4	5	Nil
28	MOYILLA CHARAN REDDY	199Y1A0330	Yes	Agree	Agree	Yes	5	4	Nil
29	NADIMINTI NAVANEETH KUMAR	199Y1A0331	Yes	Agree	Agree	Yes	5	5	Nil
30	NAGULAGARI VENKATA SANDEEP KUMAR REDDY	199Y1A0332	Yes	Agree	Agree	Yes	5	5	Nil
31	PAGIDIPALEM VAMSI ACHARI	199Y1A0333	Yes	Agree	Agree	Yes	5	5	Nil
32	PALLETI VAMSIDHAR REDDY	199Y1A0334	Yes	Agree	Agree	Yes	5	5	Nil
33	PASUPALA RAVI KUMAR	199Y1A0335	Yes	Agree	Agree	Yes	5	5	Nil
34	PATHAN KHALEELULLA KHAN	199Y1A0336	Yes	Agree	Agree	Yes	4	5	Nil
35	PULAKONDAM BHEEMAIAH	199Y1A0337	Yes	Agree	Agree	Yes	5	5	Nil
36	REDDAM VEERA TEJASWAR	199Y1A0338	Yes	Agree	Agree	Yes	4	5	Nil

	REDDY									
37	S K RAJESH	199Y1A0339	Yes	Agree	Agree	Yes	4	4	Nil
38	SAGIRAJU DILLI VARMA	199Y1A0340	Yes	Agree	Agree	Yes	4	5	Nil
39	SHAIK ABDUL RASHEED	199Y1A0341	Yes	Agree	Agree	Yes	5	5	Nil
40	SHAIK GHOUSE BASHA	199Y1A0343	Yes	Agree	Agree	Yes	5	5	Nil
41	SHAIK KURNOOL DADA KHALANDAR	199Y1A0344	Yes	Agree	Agree	Yes	5	5	Nil
42	SHAIK MAHAMMED MANSOOR	199Y1A0345	Yes	Agree	Agree	Yes	5	5	Nil
43	SHAIK MOHAMMED GHOUSE	199Y1A0346	Yes	Agree	Agree	Yes	5	5	Nil
44	SHAIK MOHAMMED SAJID	199Y1A0347	Yes	Agree	Agree	Yes	5	5	Nil
45	SHAIK MOHAMMED SHOAIB AKTHAR	199Y1A0348	Yes	Agree	Agree	Yes	4	5	Nil
46	SHAIK NAYEEMUR RAHMAN	199Y1A0349	Yes	Agree	Agree	Yes	5	4	Nil
47	SHAIK ZABEEULLA	199Y1A0350	Yes	Agree	Agree	Yes	4	5	Nil
48	SUDA ABHILASH KUMAR REDDY	199Y1A0352	Yes	Agree	Agree	Yes	4	5	Nil
49	SUNKESULA BABA SAB	199Y1A0353	Yes	Agree	Agree	Yes	4	5	Nil
50	SYED ASLAM	199Y1A0354	Yes	Agree	Agree	Yes	5	5	Nil
51	TAMMINENI SURENDRA NAIDU	199Y1A0355	Yes	Agree	Agree	Yes	5	5	Nil
52	VANGALA BHARGAVA KUMAR REDDY	199Y1A0356	Yes	Agree	Agree	Yes	5	5	Nil
53	VENKATAGIRI BHARGAV	199Y1A0357	Yes	Agree	Agree	Yes	5	5	Nil
54	VUTUKURU HITESH REDDY	199Y1A0358	Yes	Agree	Agree	Yes	5	5	Nil
55	YANDAPALLI SAI KUMAR REDDY	199Y1A0359	Yes	Agree	Agree	Yes	5	5	Nil
56	YARRAPUREDDY HARSHAVARDHAN REDDY	199Y1A0360	Yes	Agree	Agree	Yes	5	5	Nil

Coordinator

HOD

Professor & head
Department of Mechnical Engineering
K.S.R.M. College of Engineering
KADAPA - 516 003.