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Control Exhaust Emissions of Four-Stroke Copper Coated Spark Ignition with Copper Coated Combustion Chamber with Methanol Blended Gasoline with Improved Design of A Catalytic Converter

Ch. Indira Priyadarsini[1], M.V.S. Murali Krishna[2], P.Ushasri[3]

[1]Assistant Professor, [2] Professor and [3]Professor
[1,2]Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology,
Gandipet, Hyderabad 500 075, Andhra Pradesh, India,
3 Mechanical Engineering Department, College of Engineering, Osmania University,
Hyderabad 500 007, Andhra Pradesh, India
[1]ch_priya@yahoo.com, [2]maddalivs@gmail.com, [3]emailushasri@gmailcom

Abstract: *Investigations were carried out on control of carbon mono oxide emissions (CO) and un–burnt hydro carbons (UBHC) from a four–stroke, single–cylinder, spark ignition (SI) engine, with methanol blended gasoline (methanol 20% by volume) having copper coated combustion chamber [CCE, copper-(thickness, 300 μ) coated on piston crown, inner portion of cylinder head] provided with improved design of catalytic converter with sponge iron as catalyst and compared with conventional SI engine (CE) with pure gasoline operation. CO and UBHC emissions were determined at full load operation of the engine. A microprocessor–based analyzer was used for the measurement of exhaust emissions. Engine with copper coated combustion chamber with methanol blended gasoline considerably reduced pollutants in comparison with CE with pure gasoline operation. Catalytic converter with improved design significantly reduced pollutants with methanol blended gasoline on both configurations of the combustion chamber. Air injection in to the catalytic converter further reduced pollutants.*

Keywords: *Composition of fuel; Combustion chamber design; Pollutants and catalytic converter*

NOMENCLATURE

BMEP=Brake mean effective pressure, bar
BP=Brake power of the engine, kW
D=Bore of the engine, 70mm
K=Number of cylinders, 01
L=Stroke of the engine, 66mm
N=Speed of the engine, 3000 rpm
T=Torque applied on engine, N–m

1. INTRODUCTION

Increasing evidence of anthropogenic induced global worming calls for more effective policies to regulate levels of green house gases emitted to the atmosphere. The transport sector is one of the prominent sectors contributing the most to annual carbon emissions due to large dependency on fossil fuels that are non-renewable and becoming increasingly scarce, significant uncertainties regarding supply and high prices prevailing affecting the global economy.

Alcohols (ethyl alcohol and methyl alcohol) are important substitutes for gasoline fuel as their properties are comparable and in particular their octane numbers are more than 100. However, methanol is preferred to ethanol, as its octane number, which determines the quality of combustion in SI engine is higher than that of ethanol, in addition to its value of C/H, which determines the pollution levels is less when compared to ethanol and gasoline. The modification of the engine is not necessary if alcohols are blended with gasoline in small quantities. Investigations were carried out on conventional spark ignition engine with alcohol (methanol and ethanol) blended with gasoline [1–3]. It was reported that carbon monoxide (CO) and un-burnt hydrocarbons (UBHC) emissions decreased by 20% with alcohol when compared with pure gasoline operation on conventional engine. The use of a catalytic surface to enhance chemical reaction rates is a well established and common practice. Copper is a good conductor of heat, it enhances the combustion process by increased rate of pre-flame reactions and combustion flame stabilization. Copper coating of thickness 300 microns was provided on piston crown and inside portion of cylinder head, which improved engine performance and reduced pollutants of CO and UBHC [4–6].

Catalytic converter is one of the effective methods to control pollutants in SI engine. CO and UBHC, major exhaust pollutants formed due to incomplete combustion of fuel and quenching of the fuel-air mixture in the crevices of piston. Inhaling of these pollutants causes asthma, bronchitis, emphysema, slowing down of

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WINGS TO YOUR THOUGHTS…..

reflexes, vomiting sensation, dizziness, drowsiness and severe headache. Such pollutants also cause detrimental effects on animal and plant life, besides environmental disorders [7]. Driving methodology, road layout, traffic density, traffic condition, age and maintenance of the vehicle were some of the reasons for the formation of pollutants [8]. Hence control of these pollutants from SI engine is necessary and an urgent task.

Investigations were carried out on conventional spark ignition engine to control CO and UBHC emissions with expensive catalysts like tungsten, molybdenum and platinum. It was reported from their investigations that these catalysts reduced exhaust emissions by 30%. [9]. Investigations were also carried out with catalytic converter with less expensive catalysts like sponge iron and manganese ore on methanol blended gasoline and methanol blended gasoline on four stroke copper coated spark ignition engine [10-12]. It was reported that CO emissions decreased by 40% and UBHC emissions by 30% when compared with conventional engine with pure gasoline operation. Reduction of pollutants was reported with varied the parameters of catalytic converter such as void ratio (defined as ratio of volume of the catalyst to volume of catalytic chamber), mass of the catalyst, air flow rate, temperature of injected air.

Little literature was reported on comparative studies on reduction of pollutants with methanol blended gasoline on copper coated spark ignition engine with various designs of catalytic converter. An attempt was made here in this direction. Results were compared with data of other researchers.

2. MATERIAL AND METHOD

2.1. Fabrication of Copper Coated Combustion Chamber.

In catalytic coated engine, piston crown and inner surface of cylinder head were coated with copper by flame spray gun. The surface of the components to be coated were cleaned and subjected to sand blasting. The material to be coated, which is either in the form of wire, rod or fine powder, was fed to a melting zone. The molten metal was further heated to a very high temperature leading to plasma stage. The hot plasma is accelerated along with carrier gas in the form of a jet towards the substrate. When the plasma impinges on the surface to be coated, the coating material flattens and sticks to the surface. It forms a hard surface when it is cooled and coalesced. The plasma coating consists of a spray gun, feed hopper, carrier gas supply unit and power supply unit. The spray gun is used to coat the material of the surface. The coating was applied in layers until the desired thickness was obtained. A bond coating of nickel- cobalt- chromium of thickness 100 microns was sprayed over which copper (89.5%), aluminium (9.5%) and iron (1%) alloy of thickness 300 microns was coated with METCO (A trade name) flame spray gun. The coating has very high bond strength and does not wear off even after 50 h of operation [5].

2.2. Four Stroke Copper Coated Spark Ignition Engine

Fig.1 shows the schematic diagram of experimental set-up used for investigations**.** It is a four- stroke, variable speed (2200–3000 rpm), variable compression ratio (3:1–9:1), single–cylinder, water–cooled, SI engine (brake power 2.2 kW, at the speed 3000 rpm) was coupled to an eddy current dynamometer for measuring its brake power. Dynamometer was loaded by a loading rheostat. The accuracy of engine load is ±0.2kW. The bore of the engine was 70 mm while the stroke was 66 mm. Compression ratio of engine was varied with change of clearance volume by adjustment of cylinder head, threaded to cylinder of the engine. Brake power at different percentages of load was calculated by knowing the values of the output signals (voltmeter reading and ammeter reading) of dynamometer and speed of the engine. The accuracies obtained with measurement of output signals of dynamometer were within the limits. The speed of the engine was measured with digital tachometer with accuracy ±1%. Percentage error obtained with measurement of fuel flow rate assuming laminar film in the burette was within the limit.

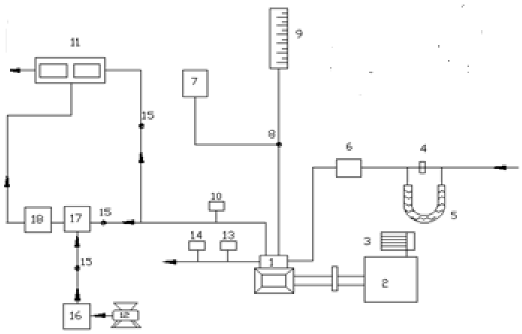

Figure 1: Schematic Diagram of experimental set–up for four–stroke SI engine

1. Engine 2.Eddy current dynamometer, 3. Loading arrangement 4. Orifice flow meter 5. U-tube water monometer 6. Air box, 7. Fuel tank 8. Three-way valve, 9. Burette 10. Exhaust gas temperature indicator 11 CO analyzer 12. Air compressor 13. Outlet jacket water temperature indicator 14. Outlet jacket water flow meter 15. Directional valve 16. Rotometer 17. Air chamber 18. Catalyst chamber

Air-consumption of the engine was obtained with an aid of air box, orifice flow meter and U-tube water manometer assembly. By means of orifice flow meter and U-tube water manometer, discharge of air was calculated, from which mass flow rate of air was calculated. Percentage error obtained with measurement of difference of water levels in U–tube water manometer assuming laminar film in the manometer was within the limit. Air box with diaphragm was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. Coolant water jacket inlet temperature, outlet jacket temperature and exhaust gas temperature were measured by employing iron and iron–constantan thermocouples connected to

Vol. 2, Issue IV, April 2014
ISSN 2320-6802

INTERNATIONAL JOURNAL FOR ADVANCE RESEARCH IN ENGINEERING AND TECHNOLOGY

WINGS TO YOUR THOUGHTS…..

analogue temperature indicators. The accuracies of analogue temperature indicators are ±1%.

2.3. Measurement of Exhaust Emissions:

CO/ UBHC emissions in engine exhaust of different versions of the combustion chamber of two stroke/four-stroke engine were measured with Netel Chromatograph analyzer at full load operation of the engine. The accuracy of measurement of emission is ±1% at full load operation.

2.4. Catalytic Converter:

A catalytic converter (Fig.2) was fitted to exhaust pipe of engine. Using mild steel, hollow cylinders were made and chemically cleaned with a solution of 10% sodium hydroxide and then with 5% nitric acid and finally dried. For the preparation of catalytically active coating, aluminium oxide was used as the oxidizing catalyst. Kaolinite is clay mineral with the composition of $Al_2SiO_5(OH)_4$, high temperature RTV silicone, bentonite clay and gel solutions consisting of tetra ethyl ortho silane and ethanol were used as the binders. The finely powdered catalyst and chosen binder were intimately mixed and slurry was made by mixing with a suitable solvent. The hollow cylinders mentioned above were dip coated by dipping in the above slurry solution and then dried. In order to improve the adhesion of coating, an under coat of slurry of above mentioned binders in a suitable solvent was first applied on the cylinders, dried and then the catalytic coating was applied over the under coat. After drying, the adhesion of the catalytic coating was tested by manual abrasion of the coatings. Aluminium oxide of thickness 500 microns was coated on inside portion of catalytic converter. Holes of size 25 mm were provided on circumference of intermediate cylinder and inner cylinder. However, aluminum coating was not provided and holes of size 20 mm were provided on cylinders in previous studies [11]. Holes were made larger in order to ensure proper contact of exhaust gases with catalysts of sponge iron/manganese ore which were less expensive and easily available with low initial cost. Discharge of the engine was calculated from which diameter of the opening through which exhaust gases enter into the catalytic chamber was determined assuming the velocity of exhaust gases (3-4 m/s). The length of the chamber was determined calculating the pressure drop. [13]. Provision was also made to inject a definite quantity of air (60 l/m) into catalytic converter. Air quantity drawn from compressor and injected into converter was kept constant so that backpressure does not increase. If necessary, provision was also made to heat injected air by means of heater (Part No.21). Experiments were carried out under different operating conditions of catalytic converter like set–A, without catalytic converter and without air injection; set–B, with catalytic converter and without air injection; and set–C, with catalytic converter and with air injection by operating direction valve (Part No.18).

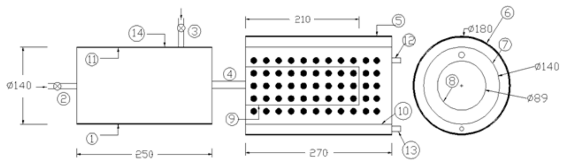

Figure 2: Details of catalytic converter.
(All dimensions are in mm)

1.Air chamber, 2. Inlet for air chamber from the engine, 3. Inlet for air chamber from the compressor, 4. Outlet for air chamber, 5. Catalytic chamber, 6. Outer cylinder, 7. Intermediate-cylinder, 8. Inner-cylinder, 9.Inner sheet, 10.Intermediate sheet, 11. Outer sheet, 12. Outlet for exhaust gases, 13. Provision to deposit the catalyst, and, 14. Insulation.

2.5 Manufacturing of Methanol

Ethanol is produced from organic materials such as grains, fruit, wood and even municipal solid wastes and waste or specifically grown biomass. The municipal solid wastes can be converted to alcohol. The wastes are first shredded and then passed under a magnet to remove ferrous materials. The iron free wastes are then gasified with oxygen. The product synthesis gas is cleaned by water scrubbing and other means to remove any particulates, entrained oils, H_2 S and CO_2. CO-shift conversion for H_2 / CO / CO_2 ratio adjustment, alcohol synthesis, and alcohol purification are accomplished. Ethanol is renewable in nature. They have oxygen in their molecular composition. They have low C/H value. It has a low stochiometric air fuel ratio. Its properties are suitable as blended fuel in spark ignition engine. The properties of test fuels are shown in Table.1 [14]. However, the excess vapor pressure as noticed from Table.1 with alcohol blends can lead to vapor problems (drivability problems), difficulties with hot starts, stalling, hesitation, and poor acceleration. It is possible to add high vapor pressure liquids or gases such as butane either generally or preferably during cold start situations. Either gasoline or LPG could be injected at cold starts to accomplish the same effect.

Table-1

Properties of test fuels [14]

Property	**Test Fuel**		**Test Method**
	Gasoline	**M-20**	
Low Calorific Value (MJ/kg)	44.133	38.233	ASTM D340
Reid vapor pressure (kPa)	35.00	66.58	ASTM D323
Research Octane Number	84.8	94.4	ASTM D2699
Density at 15.5ºC (kg/l)	0.7678	0.7707	ASTM D1298
Latent Heat of Evaporation (kJ/kg) at 15.5ºC	600	700	

2.6 Operating Conditions

Test fuels used in the experimentation were pure gasoline and methanol blended gasoline (methanol 20% by volume blended with gasoline). Different combustion chambers used in the investigations were conventional combustion chamber and copper coated combustion chamber. Different operating conditions of catalytic converter were Set–A (without catalytic converter and without air injection), Set–B (with catalyst and without air injection) and Set–C (with catalyst and with air injection). Void ratio was maintained as 0.7 for sponge iron in order to obtain minimum pollution levels [14]. Air flow rate was maintained as 60 l/m, for minimum pollution levels [11]. Mass of the sponge iron was kept as 2.0. The engine was started and allowed to warm up for a period of 20–30 min. Before running the engine with a new fuel blend, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. All the blends were tested under same speed.

2.7 Definitions of Used Values

BP= (1)

BP= $\frac{BM}{}$ (2)

3. RESULTS AND DISCUSSION

Fig.3 indicates the bar charts showing the variation of carbon monoxide (CO) emissions with different versions of the combustion chamber with test fuels at full load operation with compression ratio of 9:1 and speed of 3000 rpm. Methanol blended gasoline decreased CO emissions at full load operation when compared with pure gasoline operation on different versions of the combustion chamber, as fuel-cracking reactions were eliminated with ethanol. The combustion of gasoline operation was predominantly one of oxidation of products of destructive decomposition. In this case, there were greater chances of fuel cracking and forming carbon particles. On the other hand, the combustion of alcohol was predominantly a process of hydroxylation and the chances of fuel cracking were negligible. Methanol does not contain carbon-carbon bonds and therefore cannot form any un–oxidized carbon particles. The combustion of methanol produces more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.25 against 0.5 of gasoline.

Methanol has oxygen in its structure and hence its blends have lower stoichiometric air requirements compared to gasoline. Therefore more oxygen that is available for combustion with methanol blended gasoline, which leads to reduction of CO emissions. Methanol dissociates in the combustion chamber of the engine forming hydrogen, which helps the fuel-air mixture to burn quickly and thus increases combustion velocity, which brings about complete combustion of carbon present in the fuel to CO_2 and also CO to CO_2 thus makes leaner mixture more combustible, causing reduction of CO emissions.

Engine with copper coated combustion chamber reduced CO emissions in comparison with CE. Copper or its alloys acts as catalyst in combustion chamber, whereby facilitates effective combustion of fuel leading to formation of CO_2 instead of CO. Similar trends are observed with Ref–4 with pure gasoline operation on CCE. From Table-2, it was observed that CO emissions decreased with alcohol blended gasoline, when compared with pure gasoline operation on both versions of the combustion chamber. Methanol does not contain carbon–carbon bonds and therefore cannot form any un-oxidized carbon particles. Ethanol has oxygen in its structure and hence their blends have lower stoichiometric air requirements compared to pure gasoline. Therefore more oxygen is available during combustion, which leads to reduction of CO emissions.

Copper coated combustion chamber reduced CO emissions in comparison with conventional engine with test fuels. Copper acts as catalyst in combustion chamber, whereby facilitates effective combustion of fuel leading to formation of CO_2 instead of CO. Similar trends were observed with Reference with pure gasoline operation on copper coated combustion chamber. [4]. From Table–2, it was observed that CO emissions deceased considerably with catalytic operation in set–B with alcohol blended gasoline and further decrease in CO was pronounced with air injection. The effective combustion of the alcohol blended gasoline itself decreased CO emissions in both configurations of the combustion chamber. It was observed from Table.2, CO emissions decreased considerably when compared with data of other researcher [6]. This was due to improved design of catalytic converter with aluminum coating.

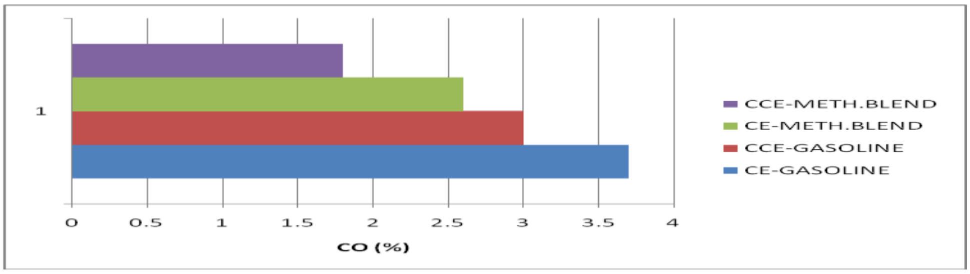

Figure 3: Bar charts showing the variation of carbon monoxide (CO) emissions with different versions of the combustion chamber with test fuels at full load operation with a compression ratio of 9:1 and speed of 3000 rpm.

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WINGS TO YOUR THOUGHTS.....

Table-2

Comparative data of 'CO' emissions (%) with different test fuels with different configurations of the combustion chamber at different operating conditions of catalytic converter with other researcher

Researcher	Set	Conventional Engine (CE)		Engine with copper coated combustion chamber	
		Pure Gasoline	Methanol blended gasoline	Pure Gasoline	Methanol blended gasoline
Indira Priyadarsini [6]	Set-A	3.7	2.6	3.0	1.8
	Set-B	2.2	1.3	1.8	1.1
	Set-C	1.5	0.8	1.2	0.5
Authors	Set-A	3.7	2.6	3.0	1.8
	Set-B	1.9	1.1	1.5	0.9
	Set-C	1.2	0.6	0.9	0.4

Hence reduction of CO emissions was due to the combined effect of catalytic action of aluminum coating and catalyst. A reduction of 15% was observed with Set–B operation, while a reduction of 20% was noted with Set–C operation with test fuels with improved design when compared with data of other researcher.

UBHC are due to accumulation of fuel in the crevices of piston, gap between the piston and liner while starting of the engine at no load and increase of rich mixture due to reduction in volumetric efficiency at full load conditions due to reduction in volumetric efficiency. The mechanism of the formation of UBHC emissions is different from CO emissions. UBHC emissions are formed due to quenching effect, while CO emissions are formed due to incomplete combustion of the fuel. UBHC emissions were lower with methanol blended gasoline operation when compared with gasoline operation on both versions of the combustion chamber as noticed from Fig.4. This was due to more availability of oxygen with combustion of methanol blended gasoline as theoretical air-fuel ratios are less when compared with gasoline operation. Engine with copper coated combustion chamber reduced UBHC emissions. Effectively in comparison with conventional engine with test fuels due to improved combustion as copper is a good conductor of heat as it promotes combustion.

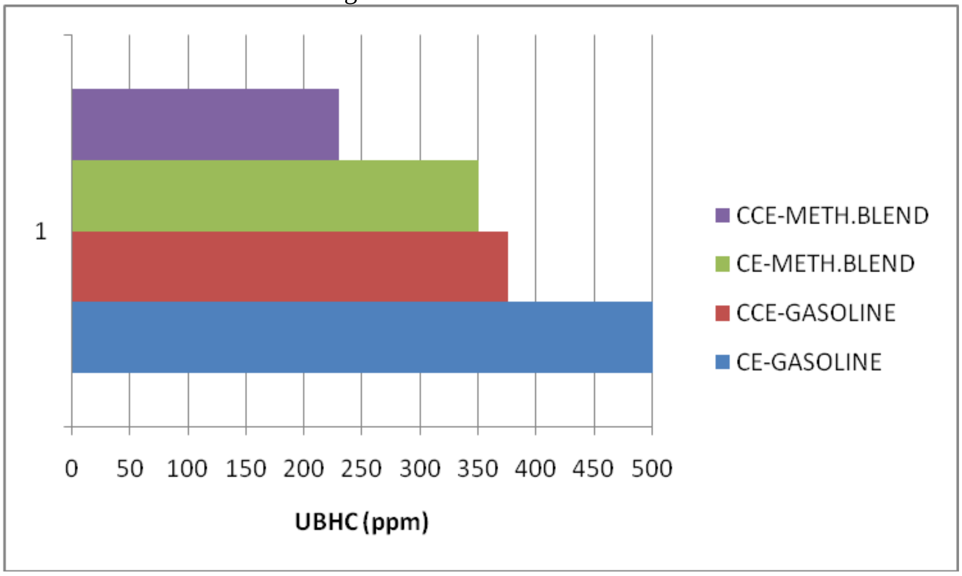

Figure 4: Bar charts showing the variation of un burnt hydro carbons (UBHC) emissions with different versions of the combustion chamber with test fuels at full load operation with a compression ratio of 9:1 and speed of 3000 rpm.

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WINGS TO YOUR THOUGHTS…..

Researcher	Set	Conventional Engine (CE)		Engine with copper coated combustion chamber	
		Pure Gasoline	Methanol blended gasoline	Pure Gasoline	Methanol blended gasoline
Indira Priyadarsini [6]	Set-A	500	350	375	230
	Set-B	300	165	205	130
	Set-C	200	120	105	80
Authors	Set-A	500	320	375	205
	Set-B	255	140	175	110
	Set-C	160	95	85	65

Table.3
Comparative data of 'UBHC' emissions (ppm) with different test fuels with different configurations of the combustion chamber at different operating conditions of the catalytic converter with other researcher

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It was observed from Table.3, UBHC emissions decreased considerably when compared with data of other researcher [6]. This was due to improved design of catalytic converter with aluminum coating. UBHC emissions decreased with combined catalytic reaction of catalyst and aluminum coating. A reduction of 15% was observed with Set–B operation, while a reduction of 20% was noted with Set–C operation with test fuels with improved design when compared with data of other researcher.

4. SUMMARY

Methanol blended gasoline decreased CO and UBHC emissions by 30% when compared with gasoline operation on both versions of the combustion chamber. Emissions of CO and UBHC decreased by 20% with copper coated combustion chamber, when compared with conventional engine with test fuels. Set–B operation decreased these emissions by 50%, while Set–C operation decreased these emissions by 65% with test fuels when compared to Set–A operation. Catalytic converter with improved design reduced pollutants further by 15% with set-B operation and 20% with set–C operation when compared with existing design.

4.1Research Findings

Studies on exhaust emissions from four stroke copper coated spark ignition engine with methanol blended gasoline operation were reported with improved design of catalytic converter with sponge iron as catalyst and results were compared with gasoline operation.

4.2 Future Scope of Studies

Spark plug timings can be varied to reduce the pollutants further and increase the performance of the engine. Nano materials can be tried on design of catalytic converter to further reduce pollutants. The major pollutants emitted from alcohol run SI engine are aldehydes which can be controlled by employing a catalytic converter.

ACKNOWLEDGEMENTS
Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for facilities provided. The financial assistance from Andhra Pradesh Council of Science and Technology (APCOST), Hyderabad is greatly acknowledged.

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