Cold Start Emission Reduction Techniques of an IC Engine: A Review

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Abstract:

Air pollution generated from mobile sources is a problem of general interest. Due to incomplete combustion in the engine, there are a number of incomplete combustion products CO, HC, NOx, particulate matters etc. These pollutants have negative impact on air quality, environment and human health that leads in stringent norms of pollutant emission. Nearly 60-80% of engine emissions occur in the engine cold start during first 300s. To reducing emissions during cold start of an IC engine many techniques has been invented. Among them use of the latent heat storage system is one of the best methods to reduce emissions from IC engine. There are many researchers designed, analyzed & tested latent thermal energy storage system (LTESS) to reduce emissions during cold start of an IC engine.

This review paper discusses these techniques to control emissions during cold start period using latent thermal energy storage system. Using latent thermal energy storage system we can maintain the temperature of engine or catalytic converter which directly affects on the emissions during cold start period.

Keywords: Phase change material (PCM), IC engine, Catalytic converter, cold start period, light off temperature, emissions.

Introduction:

Now a day's motor vehicles are the major source of air pollution in the world. Automobile vehicles consume petroleum fuels and produces the emissions like carbon monoxides (CO), unburn hydrocarbons (HC) and oxides of nitrogen (NOx). As government stringent the norms in each country like EUROIV (European Union) and BSIV (Bharat Stage, India), it is essential to reduce the emissions from the vehicles. Nearly 60-80% of engine emissions occurs in the engine cold start during first 300s in the case of New European D.C. and the US FTP 75 cycles[2]. Over long years we are use catalytic converter as an emission controlled device in the vehicles. But its performance mainly depends on its temperature[2]. The conversion efficiency of catalytic converter increase as its temperature increases. When conversion efficiency of catalytic converter is equal to 50%, that temperature is called as "light off temperature". The light off temperature of catalytic converter mainly depends upon pollutant composition and active catalyst material. For the base metal catalyst it is around 350^0C[1].

The catalytic converter besides the housing has three main components:

- Catalyst: Pt, Pd & Rh.
- Substrate or Support: Ceramic honeycomb or metallic honeycomb.
- Intermediate coat or washcoat: Mixture of Si or Alumina.[8]

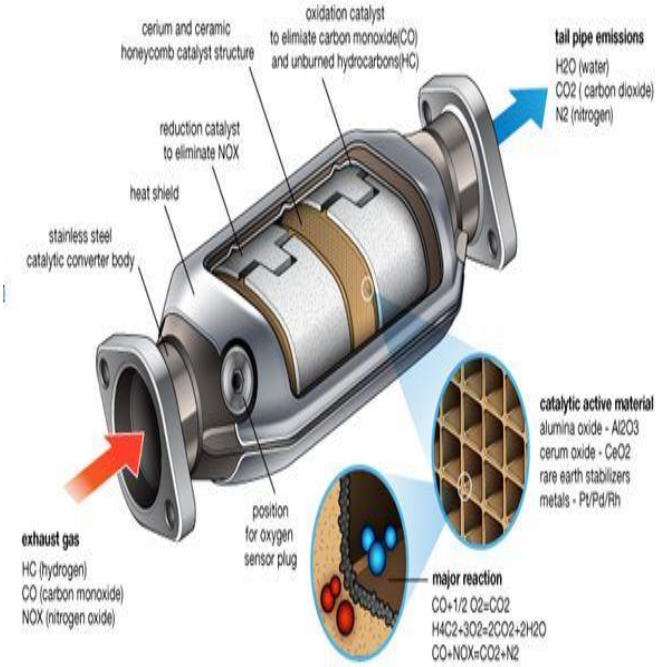

Figure 1 Construction of Catalytic Converter

During cold start of an IC engine, the temperature of an exhaust gas is less and catalytic converter at room temperature. So its conversion efficiency is nearly zero and goes on increasing as temperature increases[1].

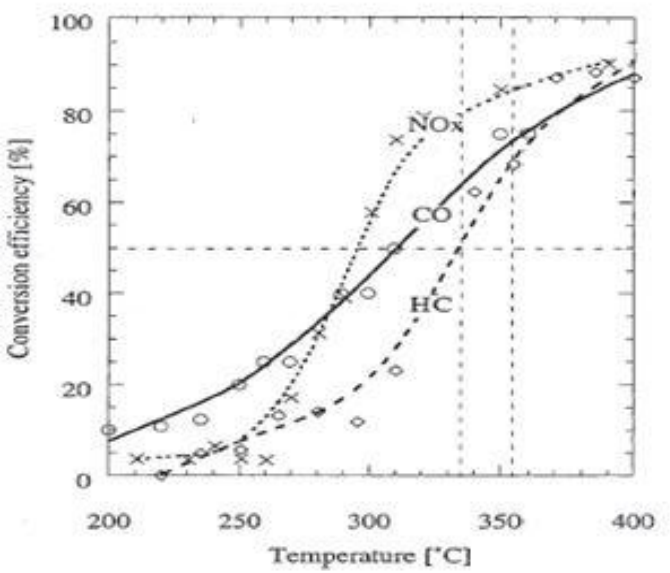

Figure 2 Conversion Efficiency vs Temperature Graph

As we see in the fig__ the conversion efficiency of the catalytic converter mainly depends on the temperature of the catalytic converter or its substrate. During the cold start, temperature of catalytic converter should be high enough, so it can convert emission gases into CO_2, H_2O and N_2. Many techniques are available to obtain less emission & obtain fast light off temperature of catalytic converter during cold start of an IC engine using heat storage system to store & maintain temperature of catalytic converter, heating with electrical power, heating with an external combustion chamber, installing an auxiliary small-capacity catalytic converter, employing an adsorber between two catalysts with or without a secondary air source.

Literature review:

Sr. No	Year	Author	Work Done	Remarks
1.	1999	E. Korin et. al.	Reducing cold start emission from an IC engine using eutectic mixture of LiCl/KCl phase change material with catalytic converter.	Catalytic Converter temperature maintained above "light off" temperature for 4hrs.
2.	2008	M. Gumus	Designed & tested experimental sample of thermal heat storage (Na_2SO_4 $10H_2O$) system for pre-heating of an IC engine to reduce cold start emission.	64% & 15% emission reduction in CO (carbon monoxide) & HC(hydrocarbons). Also 17.4^{0}C average temperature increase of an IC engine.
3.	1994	Steven Burch et. al.	Reduction of cold start emission by maintaining catalytic converter temperature using Al eutectic alloy phase change material. Used vacuum insulation to increase heat retention time.	Vacuum insulation with Phase Change Material maintains Catalytic converter temperature above 350^{0}C temperature for 10hrs.
4.	2013	K.K.Bokde & A.V. Waghmare	Use of latent heat storage system (LHSS) for improving cold start performance of Catalytic Converter.	23% of %CO & 21% of HCppm reduction in cold start emission has been achieved.
5.	2014	Andrew Roberts et. al.	Review on the problem, cause & potential solution on internal combustion engine cold start efficiency.	Study the different techniques to reduce cold start increase engine emissions and improve engine performance.
6.	1997	P.M.Golben et.al.	Design, fabricated & tested the novel hydride cold start heater to instantly increase the temperature of catalytic converter during cold start of an IC engine.	Using the novel hydride temperature of catalytic converter is increases from room temperature to above light off temperature in 6-8 sec. It reduces nearly 65% of non methane hydrocarbons during US Federal Test Procedure(FTP).
7.	2000	L.L. Vasiliev et. al.	Used heat storage system(HSS) for pre heating of an IC engine of the bus. NaOH H_2O phase change material having 64^{0}C melting temperature has been used to store 65KJ heat energy.	As engine is turned off stored heat in the heat storage system(HSS) is rejected in 10min. & preheat the engine upto 30^{0}C with storage period was 36hrs.
8.	1997	G.C. Koltsakis & A.M. Stamatelos	Discuss review on the exhaust gas (emission) treatment using the catalytic converter.	
9.	2013	Nichol	Detailed review	Gives various PCM

		as Janko wski & P.McC luskey	on the PCM used for vehicle component thermal buffering.	based applications in vehicle.

Techniques to reduction of emission during engine cold start:

As we know an emission from IC engine during the cold start is high, because the temperature of an IC engine is low. Because of that air fuel mixture in the cylinder is not burn completely causing more unburn HC(hydrocarbons) in exhaust gas. To avoid this extra emission many ways has been developed, like maintaining temperature of IC engine, use fast light off catalytic converter, change in the design parameters of an IC engine, fuel additives etc. Also there are many techniques available for maintaining temperature of the catalytic converter as use heater to increase temperature of catalytic converter, use of the pre catalytic converter for fast light off, use of latent heat storage system to maintain temperature of catalytic converter etc. A. Roberts et.al. gives a brief review on the problem, causes & potential solutions to the cold start efficiency of IC engine[4].

In 1994 S.D.Burch et. al. design, fabricated & tested the catalytic converter with layer of the phase change material on the catalytic converter[3]. With use of 2.2kg of Al eutectic alloy temperature of catalytic converter maintained above its light off temperature for 10hrs. Also use of vacuum insulation reduces loss of heat to the surrounding. By use of 3.8kg phase change material (PCM) latent thermal energy storage system has been designed by E. Korin et. al.[1] Eutectic mixture of LiCl/KCl PCM was used to maintain temperature of catalytic converter above 335^0C (highest light off temperature) for 4hrs. In fig. 3 the cross section of catalyst & PCM assembly is shown. As we see the catalyst has cut into four quarter parts & PCM has placed in-between them. It gives more interface area which helps to increase the heat transfer during charging & discharging cycle. Fig. 4 shows temperature vs. time graph of catalytic converter after engine was shut off.

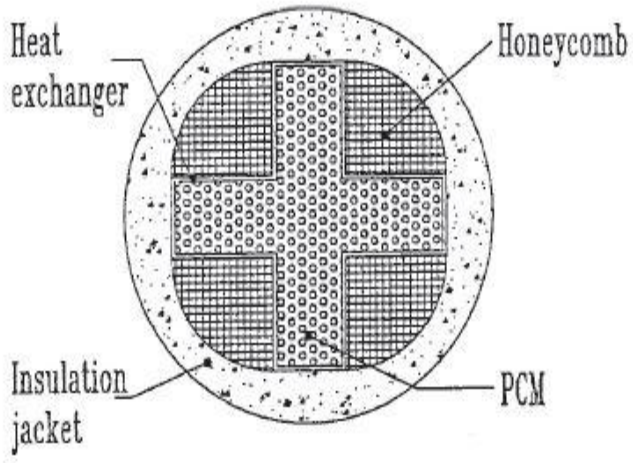

Figure 3 Cross section of PCM embedded catalytic converter

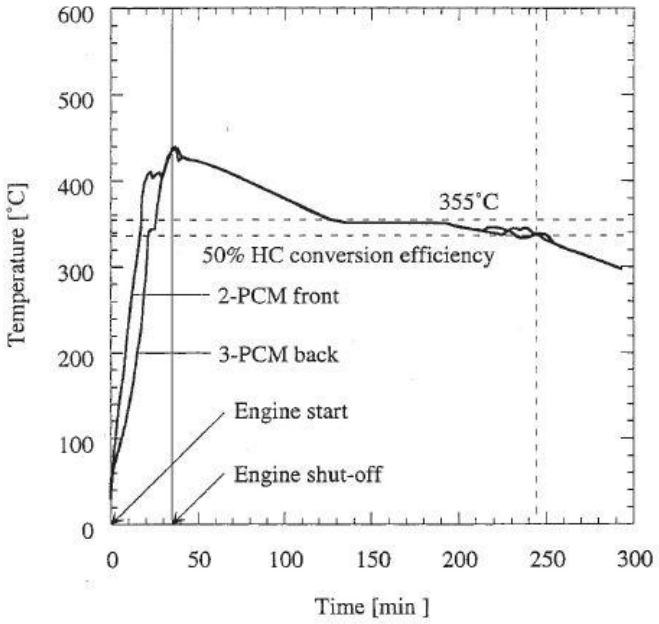

Figure 4 Temperature vs time graph

K.K.Bodake & A.V. Waghmare designed, fabricated & integrated latent heat storage system to maintain temperature of catalytic converter above surrounding temperature[5]. Paraffin wax as PCM was used to store the heat during vehicle in normal running condition. They able to obtain 23% & 21% reduction of %CO & HCppm in exhaust gas respectively.

M. Gumus design thermal energy storage system (TESS) to maintain temperature of an IC engine nearly at 19^0C. The heat loss from an engine cylinder block & cylinder block cover has stored in TESS[2]. The working fluid was water to transfer heat from engine to TESS. Because of pre heating of an engine, reduction of 64% & 15% in CO & HC achieved respectively. Fig. 5 shows %Vol. concentration of CO emission & temperature with respect to time. HC emission in ppm & temperature with respect to time is showed in fig. 6.

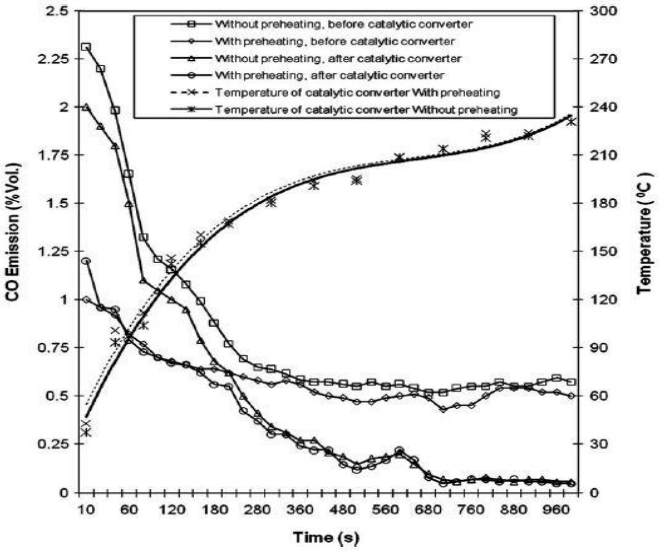

Figure 5 CO emissions (%vol) vs time graph

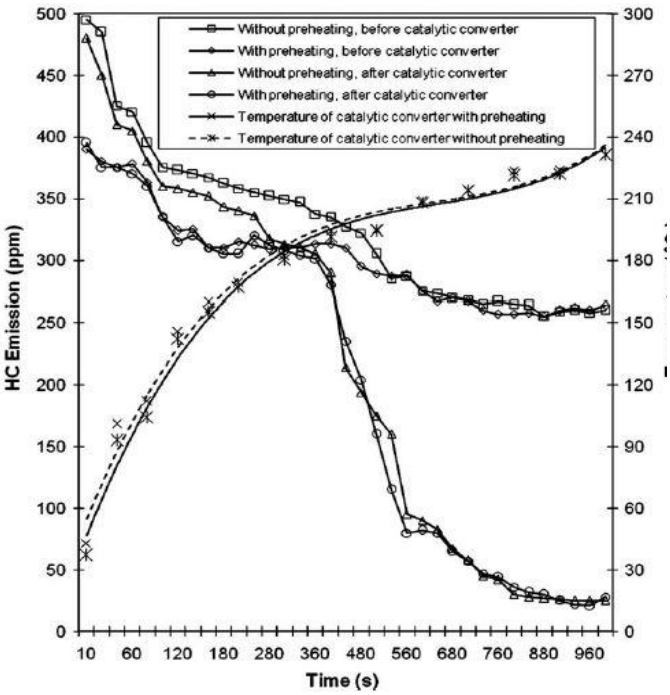

Figure 6 HC emission (ppm) vs time graph

L.L. Vasiliev et. al. used latent heat storage module to pre heat IC engine[7]. NaOH H_2O (phase change temperature=64^0C)PCM has used to store 14MJ heat energy. This latent heat storage module heats an engine up to 30^0C in 10 min. during discharge cycle with 36 hrs. heat storage period. Fig 7 shows the temperature of an engine at various points with respect to time during heat storage module discharge cycle.

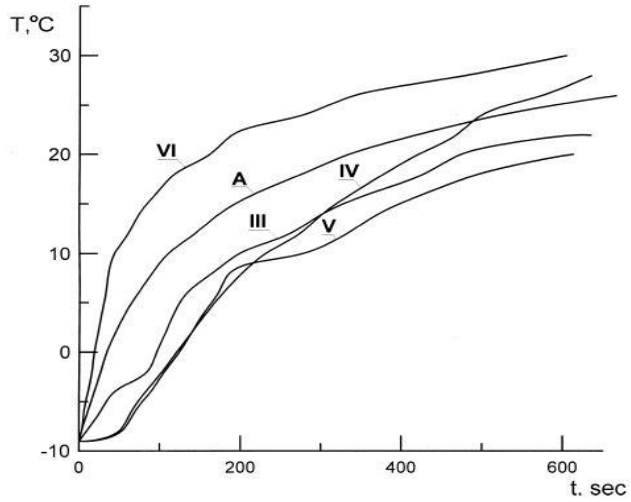

Figure 7 Temperature Of An Engine Vs Time Graph

P.M. Golben et. al. [6] design fabricated & tested novel hydride cold start heater to increase temperature of an exhaust gases. It increases temperature of catalytic converter above light off temperature within 6-8 sec. It helps to reduce emission nearly by 65% during US Federal Test Procedure (FTP). Fig. 8 shows temperature of air downstream with respect to time.

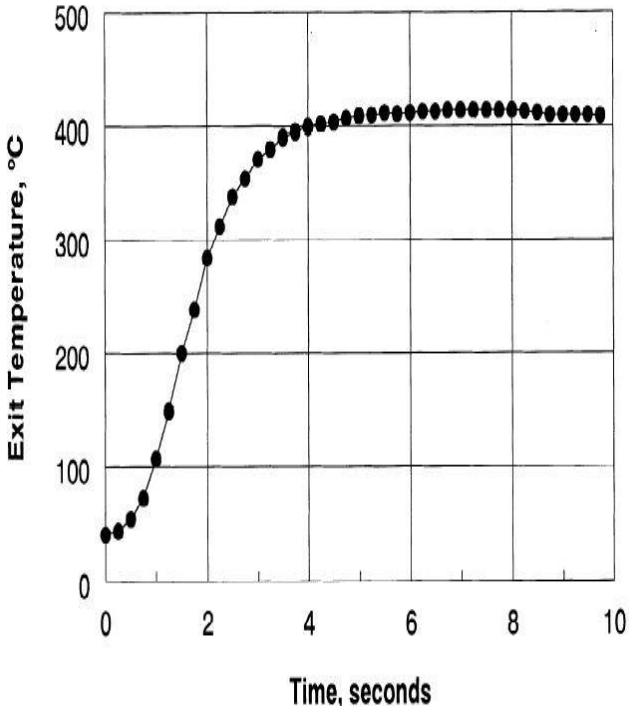

Figure 8 Exit Temperature vs time graph

Conclusion:

Under the normal operating conditions, catalytic converters appear to be the most effective means of reducing emissions from internal combustion (IC) engines. Catalytic converter work more efficiently when its temperature is above the 'light off" temperature. During the cold start of an engine catalytic converter conversion efficiency is nearly zero or very less. About 80% of total emissions are emitted during the cold start period. There are many techniques available to reduce emissions during cold start period of an IC engine. But some methods required external energy source. So use of the latent heat storage system is one of the best methods to reduce emissions from IC engine. There are many researchers designed, analyzed & tested latent thermal energy storage system (LTESS) to reduce emissions during cold start of an IC engine.

Without disturb to an engine we can reduces emission of cold start period by maintaining the temperature of catalytic converter. Using PCM as latent heat storage, we can store more heat than sensible heat storage. It is very efficient to design latent heat thermal storage system to control & maintain temperature of catalytic converter during engine off condition. It will helps to reduce emissions during next cold start period.

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