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Research Article

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Reduction of cold start emissions in automotivecatalytic converter using thermal energy storage system

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ABSTRACT

Catalytic converters are used to convert harmful exhaust gases like CO, NO_x andunburnt hydrocarbons released by internal combustion engine of automobiles into less harmful gases like CO2, H2O and N2. During the start-up of engine run, catalytic converters suffer cold start problems as the catalyst does not remain active in cold conditions. This results in emission of unconverted harmful gases into the atmosphere. This work attempts to eliminate cold start problems using a heat storage system to keep the catalytic converter hot even under engine off conditions. A eutectic alloy of Mg-Zn-Al is used as the Phase Change Material (PCM) to store the heat around the catalyst. This alloy has high latent heat of fusion, high specific heat, suitable melting point and high thermal stability. Mg-Zn-Al eutectic alloy changes its state between liquid and solid on application and removal of heat. Thus this phase change material acts as a heat storage mechanism in the catalytic converter. Catalytic converter design also involves Rockwool insulation in order to aid longer heat storage. This thermal energy storage system as a combination of PCM and insulation, keeps the catalytic converter hot for several hours even after the engine is shut off.

Keywords: Mg-Zn-Al eutectic alloy, Rockwool insulation, Thermalenergy storage (TES)

INTRODUCTION

Over the years, catalytic converters are proved to be the essential component of automobiles for converting the harmful exhaust gases coming out of the internal combustion engine into less harmful gases. Harmful gases that are present in the exhaust of the internal combustion engine are typically unburnt hydrocarbons, carbon monoxide, nitrogen oxides, etc. Catalytic converters use oxidizing and reducing catalysts to convert the harmful gases. While most of the catalytic converters rely upon the noble metals for the catalytic activity, other kinds of catalysts, including transition metal oxides can also be used to carry out the conversion in catalytic converters.

Along with the catalyst, several other components can also be incorporated to improve the performance of the catalytic converter. Components incorporated can aid the performance of catalytic converter either by storing the heat in the catalytic converter or by improving the oxygen storage capacity in the catalytic converter, or by any other means.

Cold start emission has been one of the main problems in the catalytic converter. Every time the engine is started after being shut down for a long period, the catalytic converter remains in cold condition for the initial period of engine run, making the catalyst in the converter to render ineffective for the conversion. During this period, engine emits high amount ofpollutantsmainly the unburnt hydrocarbons which pass through the catalytic converter without being converted because of the inactivity of the catalyst at low temperatures.

In this paper, Thermal Energy Storage (TES) system is used to store the heat in the catalytic converter and thereby reduce the cold start emission problems in catalytic converter.

The TES system includes PCM and thermal insulation. PCMs are the materials which undergo phase change and hence stores the heat both in terms of latent heat and sensible heat. When PCM is heated beyond its melting point, it stores an extra amount of heat in terms of latent heat. So when it is cooling down, it has to give out latent heat as well along with sensible heat, hence it cools slower. PCMs which undergo phase transition between solid and liquid are of interest in catalytic converter as it can store more amount of heat and keep the catalytic converter hot for longer time. PCM used in this paper is Mg-Zn-Al eutectic alloy. When the alloy is formed by mixing the components of alloy in a proportion in Table 1. The characteristics of Mg-Zn-Al eutectic alloywhich it shows the lowest melting temperature over all of the mixing ratios for the involved components species, such an alloy is known as eutectic alloy. Mg-Zn-Al eutectic alloy is more suitable for this operation because of its physical properties. E. Risuenoet al[1] studied the physical characteristics of Mg-Zn-Al eutectic alloy, which is described in Table 1. It has high latent heat of fusion, high specific heat capacity and high thermal stability. It has a melting point of 340^0C which is more suitable as it keeps the catalyst active for the catalytic conversion. Thermal insulation is used to prevent the heat loss from the PCM. In this work, Rockwool insulation is used along with Mg-Zn-Al eutectic alloy to aid in storing the heat. By using the TES system in

the catalytic converter it is possible to store the heat during the period of engine run and keep the catalytic converter hot during the engine-off period and hence reducing the cold start emission problems in catalytic converter.

Table 1. The characteristics of Mg-Zn-Aleutectic alloy

	Melting Point (K)	Latent heat of fusion ($1o^3$ J/Kg)	Specific heat capacity (J/Kg/K)		Thermal Conductivity (W/mK)			Density (Kg/m^3)
Temperature			298	573	373	573	673	298
$Mg_{70}Zn_{24.9}Al_{5.1}$	613	157	690	830	47	59	38	2820

EXPERIMENTAL SECTION

The eutectic alloy was prepared for a particular composition by using a vacuum furnace. The obtained alloy was then placed in the prepared apparatus to carry out the test.

Preparation of Mg-Zn-Al eutectic alloy:
250g of Mg-Zn-Al eutectic alloy was prepared as shown in Figure 2 by mixing the elements Mg, Zn, and Al in the proportion of 70, 24.9, and 5.1 respectively. The elements were taken in a steel vessel and mixed properly. It was kept in the vacuum furnace shown in Figure 1, and the temperature inside the furnace was raised to 450^oC and kept for 10 hours. Then, the furnace was allowed to cool in the vacuum conditions. The heating and cooling cycle was carried for two moretimes.

(a) **(b)**

Figure 1: (a) Vacuum furnace, (b) Mg-Zn-Al eutectic alloy

Apparatus used for the testing of the PCM

Two concentric tubes of diameter 32mm and 44mm, both having the length of 14cm were taken and were welded by keeping the smaller tube in the larger tube and the annulus was produced between the tubes. 250g. of $Mg_{7}0Zn_{24}.{_9}Al_{5.1}$ alloy was filled in the annular region and both sides of the annulus were closed. This assembly of tubes and ceramic material is heated to 600^0C in the muffle furnace and kept at 600^0C for one hour and removed from the furnace. Rockwool insulation of 20mm thickness is provided around the larger tube. Honeycomb like ceramic cordierite (which is widely used as the substrate on which catalyst is coated) were made into the small cylinders and kept inside the smaller tube. Temperature of ceramic that is kept inside the tube is measured using IR thermometer gun at periodic time intervals.

(a) (b)

Figure 2: a) Two set of concentric tubes with ceramic cordierite substrate inside, (b) Rockwool insulation

RESULTS AND DISCUSSION

When the TES system is incorporated in the catalytic converter, during the period of engine run the temperature of catalytic converter increases. As the temperature of Mg-Zn-Al eutectic alloy reaches 340^0C, further heat supply is used for the phase change from solid to liquid. And hence whenever the catalytic converter is heated to more than 340^0C, additional amount of heat which is equivalent to latent heat of fusion of the eutectic alloy is stored in the catalytic converter. Experiments shown that as the cylindrical ceramic substrates were placed in the heatedtubes, the temperature of the ceramic was raised from the room temperature to around 250^0C and the temperature reduced slowly thereafter. Temperature of the ceramic remained more than 200^0C for around three and half hours.

Experiments proved the working of Mg-Zn-Al eutectic alloy. However the conditions will be different in the actual catalytic converter. In the actual catalytic converter the substrate material (like ceramic cordierite) is heated along with the rest of the catalytic converter assembly. Hence, the actual catalytic converter remains at higher temperature for longer period of time. Figure 4 shows the CATIA model of catalytic converter

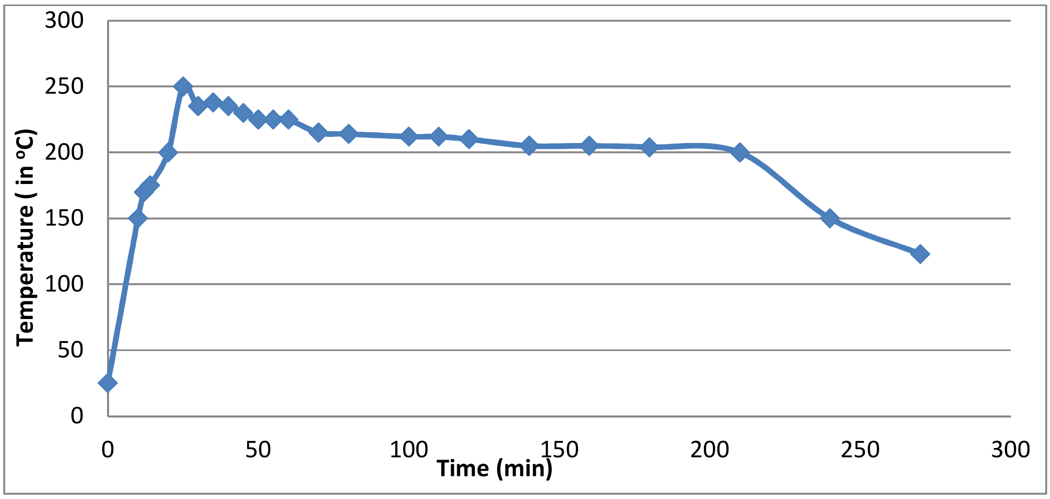

Figure 3: Temperature v/s time curve for the ceramic cordierite substrate kept inside the tube

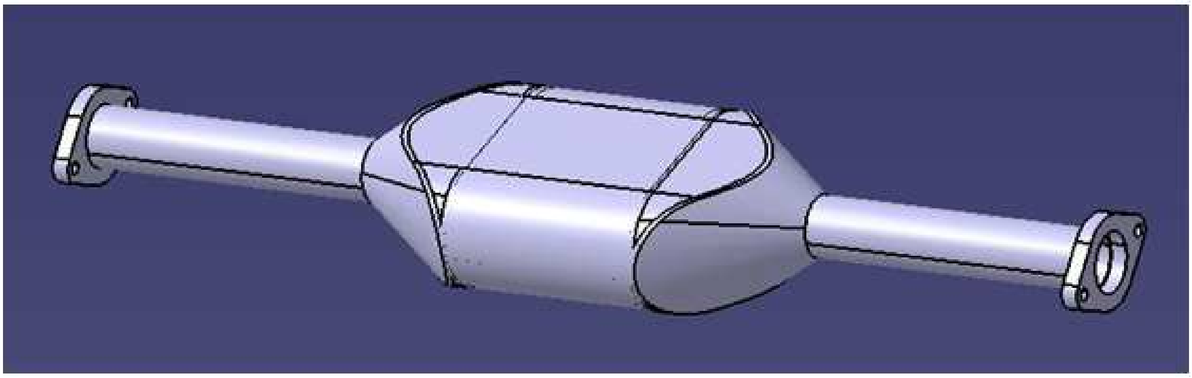

Figure 4: Model of the proposed catalytic converter

CONCLUSION

Over the years, catalytic converters are improving in every possible aspect of operation for the better conversion of harmful exhaust gases from the automobiles. The TES system is one of the possible means of improving the performance of catalytic converter by storing the heat and in turn aiding the performance of the catalyst. The characteristics of Mg-Zn-Al eutectic alloy are best suitable for catalytic converter operation and Rockwool insulation also play a vital role in improving the performance of the catalytic converter.

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