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Experimental Investigation on SI Engine Emissions via EGR and Catalytic Converter with Air Injection Mechanism

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ABSTRACT

Exhaust emissions emitted from spark ignition engines cause air pollution, human health hazards and ecological imbalance. Hence, effective curtail of these is an essential task. For this, an experimental evaluation was carried out on emissions and performance characteristics of the four-stroke three-cylinder Maruthi engine at varied brake power. Three different techniques, initially the exhaust gas recirculation (EGR) system was coupled to the test engine and varied from 0 to 10% for estimation of optimal value. Secondly, the provision of the catalytic converter with the copper as a catalyst and finally by the air injection mechanism of 60 l/m into the catalytic converter is executed and evaluated for optimum emission reduction. Also, the combined effect of these techniques on the characteristics was analysed. From the results, it was found that up to an EGR rate of 5%, an enhancement of 2% in brake thermal efficiency and a reduction of 9.5% in brake specific fuel consumption, 21% in carbon monoxide (CO), 19% in un-burnt hydrocarbon (UHC) and 29% in NOx emissions and a further increase in the EGR rate causes performance deterioration. The NOx emissions decreased by 44% at 7% of EGR. The catalytic converter setup alone decreased CO and UHC by 40% and by application of air injection it was 60%. The CO& UHC emissions decreased by 54% &52% respectively at 7% EGR rate combined with the catalytic converter and air injection mechanism.

Keywords: *SI Engine; EGR; Catalytic Converter; Air Injection.*

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Introduction

For an individual transport, the spark ignition (SI) engine is preferred to the compression ignition (CI) engine as it is relatively low for the same horsepower and configuration. It is also lighter and cheaper in construction than CI engine due to low compression ratio. The start of the SI engine is comparatively easy because of the homogeneous burning of fuel and also thus achieving very high speeds in a short interval of time [1]. The robustness in appearance and generation of lower speeds due to the heterogeneous burning of fuel are quite visible with CI engines. Through the experimental works [2] it is understood that the total elimination of carbon monoxide (CO) emissions in the gaseous exhaust were not possible under any condition/case. The skimpy resident period available for complete combustion of fuel and insufficient air in the air-fuel ratio were responsible factors for this. Also, with the engine functioning at higher mixture ratios than 16:1, CO emissions can be reduced to negligible quantity. The CO emissions are high when the engine is idling and reaches a maximum value during deceleration. Hence, control of CO emissions is crucial. The complete elimination of CO emissions from the exhaust is not possible but its control achieved by modifications in engine design and treatment of exhaust gases by after-treatment methods and using alternative fuel compositions. One established technique for CO reduction is the provision of the Catalytic converter in the engine setup.

Marco Nuti [3] found that in engine exhaust emissions the prime outcome of improper fuel combustion was unburnt hydro carbons. The low surface temperature of the combustion chamber and improper mixture ratio are known to be the causes for this. The flame of combustion dies before it reaches the layer of air-fuel mixture next to the metal surface because this layer is chilled by the cool metal. The result is that these layers do not burn. These layers are then swept out during the exhaust stroke resulting in the UHC in the exhaust gas. The reduction of cool metal surface i.e., a surface-volume ratio (S/V) reduces the HC emissions. The second reason of incomplete combustion is imperfect fuel-air mixture ratio. The ratio in a cylinder may vary, say, from 13:1 (rich) to 14.5: 1 (comparatively lean). An imperfect air-fuel ratio means imperfect combustion. Designs of the combustion chamber, mixture (air and fuel) ratio, engine running speed at corresponding load are chief influencing parameters on exhaust HC emissions pattern. The significance of improper burning of the mixture in the chamber is because of straight interaction with mixture via walls which often quench and inhibit the flame spreading, finally leads to HC increment in emissions. The Un-burnt hydrocarbons (UHC) and Carbon monoxide are found to be key emissions in the exhaust of gasoline engine and upon a long time, exposure and inhalation are responsible for several health hazards of human beings and other life on the earth along with the environmental damage [4-9].

Several influential parameters such as traffic density, engine driving condition, driving methodology and road layout are responsible for the increase in the amount of engine exhaust emissions. One effective method for reducing the emissions is the catalytic converter provision for gasoline engine [10–13]. The EGR technique adopted in S.I. Engine significantly reduced NOx emissions and specific fuel consumption with an improvement in thermal efficiency [14].

Materials and Method

The test engine coupled with the hydraulic dynamometer for load application as represented by a block diagram in Figure 1. The engine operated at a fixed compression ratio of 9:1. The engine configuration, three cylinders each with 60 mm stroke and 70 mm bore, four-stroke working cycle, water as a coolant and brake power of 7.5 kW at the speed of 3000 rpm. The fuel and air consumption during the operation are measured via burette and air-box method respectively. During the experimentation, at varied EGR rates and brake power, the performance parameters of brake thermal efficiency, brake specific fuel consumption were evaluated. Also, the gaseous emissions of CO, UHC and NOx were measured by the analyser of Netel Chromatograph type. The operating principle and specifications of CO/UHC/NOx analyser are shown in Table.1.

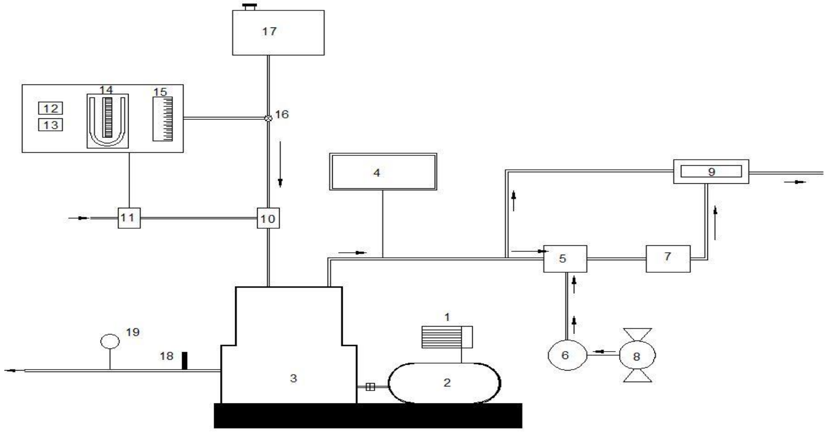

Figure1: Block diagram of engine test rig

1. Loading arrangement 2.Hydraulic dynamometer 3.Test engine 4.Exhaust gas recirculation system 5.Air chamber 6. Rota meter 7.Catalyst chamber 8.Air compressor 9.CO analyzer 10.Carburetor 11.Air box 12.Speed indicator 13.Temperature indicator 14.U-tube water monometer 15.Burette 16.Three-way valve 17.Fuel tank 18.Outlet water temperature sensor 19. Outlet water flow meter

Table 1: Specifications of the CO /UHC/NOx Analyzers (Netel India)

Pollutant	Measuring Principle	Range	Least Count
CO	NDIR	1–10%	0.1% of Full Scale (FS)
UHC	NDIR	1–1000 ppm	1 ppm
NOx	Chemiluminiscence	1-5000 ppm	0.1%

Catalytic Converter

Initially, a catalytic converter with provision for desired air injection 60 l/m was produced and coupled to the exhaust side of test case gasoline engine as shown in figure 2. During the operation to curb the development of back pressure, injection of constant air quantity into converter from compressor was done. The whole experimental process was divided & taken under three sets such as devoid of the catalytic converter and air injection as set-A, using the catalytic converter and devoid of air injection as set-B and mutual use of air injection and catalytic converter. Trail run was done to verify the accuracy of the system and it was found to be 0.1%.

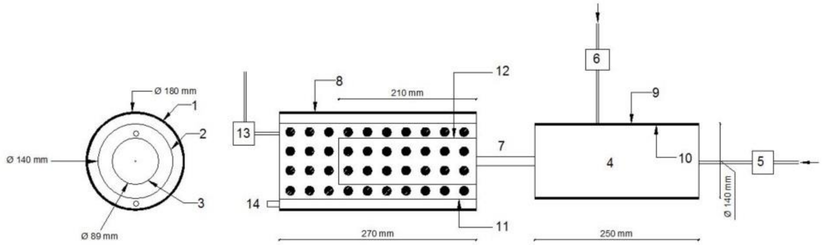

Figure 2: Particulars of Catalytic converter

Design of Heat Exchanger

A double pipe heat exchanger (DPHX) is designed for cooling the exhaust gas from the engine. The heat exchanger was designed with following input data: the mass flow of exhaust gas, the mass flow of air, the inlet temperature of the hot fluid (i.e., exhaust gas), the inlet temperature of the cold fluid, the diameter of the tube, the specific heat of exhaust gas and air. Assessment of coefficients of heat transfer was done via standard equations of heat transfer. The desired surface area for heat transfer and the pipe length of two pass tube was determined. Recirculation of desired quantity of exhaust gases to intake manifold of the engine was done via control value as shown in figure 3. During the process just beneath the throttle valve, the intercourse of the fresh and recirculated gases happened. At low load, the influence of EGR as a diluent for reducing peak temperatures was evident.

The residual gas fraction is influenced by load and valve timing (especially the extent of valve overlap) and, to a lesser degree, by the air-fuel ratio and compression ratio. Since the burned gases dilute the unburned mixture, the absolute temperature reached after combustion varies inversely with the burned gas mass fraction. The details of heat exchanger were presented in table 2.

The optimum quantity of EGR in a particular combustion chamber was normally determined by the combustion characteristics, the speed and the load and the equivalence ratio. Especially in a typical gasoline engine under part throttle condition an EGR of 15 to 30 % are known to be the feasible quantity of EGR. Also, slow-burning engines will tolerate less EGR. The falling influence of EGR on burn rate gives rise to fluctuations in combustion and thereby increment in hydrocarbons in emissions.

Table 2: Specifications of the heat exchanger

Parameter	Specification
Type	Double pipe
Inner tube diameter	25.4 mm
Length of Heat exchanger	1000 mm
Outer tube diameter	50.8 mm
Number of passages	2

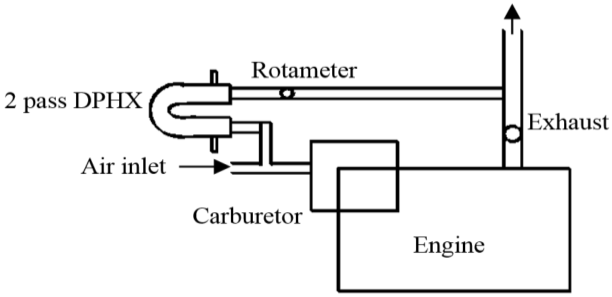

Figure 3: Schematic diagram of engine with the provision of heat exchanger

Results and Discussion

Performance Parameters

Figure 4 demonstrates the variation of Brake thermal efficiency (BTE) with the percentage of the load at the various percentage of EGR. Brake thermal efficiency augmented up to 80% of full load and beyond it reduced at various percentages of EGR. The increase of fuel conversion efficiency and mechanical efficiency might have augmented BTE up to 80% of the full load. Reduction of fuel conversion efficiency and mechanical efficiency might have reduced BTE beyond 80% of the full load. BTE augmented by 2% at 5% EGR at all loads in comparison with 0% EGR. The increase of the mass flow rate of oxygen might have augmented BTE with 5% EGR. However, BTE reduced beyond 5% EGR. Reduction of the density of fresh charge with hot exhaust gases might have lowered BTE.

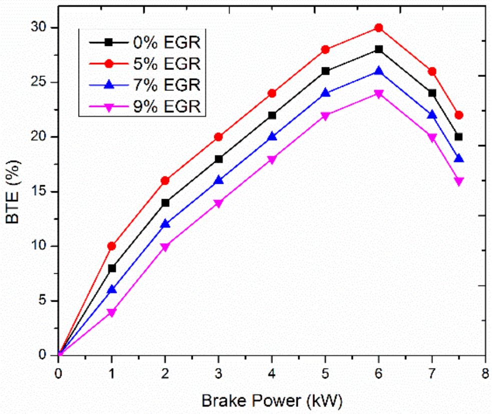

Figure 4: Variation of Brake thermal efficiency (BTE) with brake power at various percentage of EGR

Figure 5 demonstrates histograms showing brake specific fuel consumption (BSFC) at various % of EGR. At 5% EGR, BSFC was observed to be inferior in comparison with other percentages of EGR. Efficient conversion of heat into work might have reduced BSFC at 5% EGR. BSFC diminished by 9.5% with 5% EGR in comparison with 0% EGR, which confirmed that brake thermal efficiency augmented with 5% EGR. BSFC diminished due to the decrease of pumping load, reduced heat loss to the walls because the burned gas temperature is decreased significantly; and a reduction in the degree of dissociation in the high-temperature burned gases which allow more of the fuel's chemical energy to be converted to sensible energy near TDC.

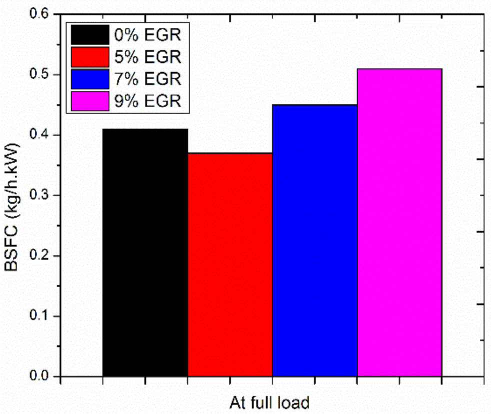

Figure 5: Histograms showing variation of brake specific fuel consumption (BSFC) at different percentages of EGR

Emissions characteristics with EGR

Figure 6 demonstrates the variation of un-burnt hydrocarbons (UHC) with brake power at different percentages of EGR. UHC emissions were found to be higher at no load and decreased at 80% of full load and beyond that load; they increased up to full load at various percentages of EGR. The increase of fuel consumption and accumulation of some amount of fuel in the crevices volume of piston leads to increasing of UHC emissions.

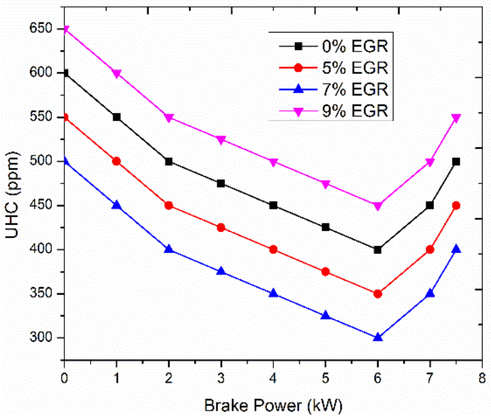

Figure 6: Variation of Un-burnt hydrocarbons (UHC) with brake power at various percentages of EGR

At no load, with the supply of rich mixture during starting, leads to increasing of UHC emissions. At full load, incomplete combustion caused high UHC emissions. At 80% of the full load, UHC emissions were observed to be lower, due to improved combustion. UHC emissions decreased at all loads, with an increase of EGR up to 7% EGR. This might be due to the additional supply of EGR at a faster rate leading to increasing of oxidation reactions & thus reducing UHC emissions. However, at 9% EGR, replacement of fresh oxygen with EGR increased UHC emissions at all loads. At 7%, EGR, UHC emissions reduced by 19% in comparison with 0% EGR. The increase of oxidation reaction with hot exhaust gases might have lowered the UHC emissions.

Figure 7 demonstrates the variation of carbon monoxide (CO) emissions with brake power at different percentages of EGR. The CO emissions followed similar trends of UHC emissions at all loads. CO emissions increased with the increase of brake power at different percentages of EGR. This might be due to the increase in fuel consumption. Like UHC emissions, CO emissions were observed to be higher at both no load and full load. At no load, the supply of rich mixture for starting the engine might have increased the CO emissions. At full load, incomplete combustion reactions of rich mixtures might have increased CO emissions. At 80% of full load, CO emissions found to be lower with improved combustion, where thermal efficiency was found to be higher.

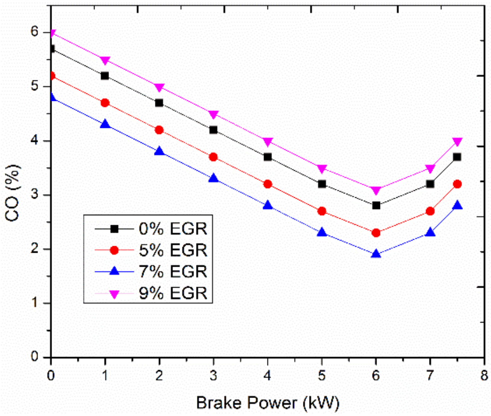

Figure 7: Variation of Carbon monoxide (CO) with brake power at various percentage of EGR

However, CO emissions at all loads, reduced with an increase of EGR up to 7% and beyond they were increased in comparison with 0% EGR. This might be due to the increase of additional air supply at a faster rate up to 7% EGR, thus improving combustion reactions & reducing CO emissions, Beyond 7% EGR, replacement of fresh oxygen with the hot exhaust gases might have increased rich mixture and thus causing a higher amount of CO emissions. The CO emissions at full load were reduced by 21% with 7% EGR in comparison with 0% EGR.

Figure 8 shows variation of nitrogen oxide levels with brake power of the engine at various percentages of EGR. The Nitrogen oxide levels increased with the brake power of the engine at various percentages of EGR due to an increase of combustion temperatures with the load. However, NOx emissions decreased with an increase of EGR at various load as observed from the Figure. Reduction of supply of fresh air might have reduced combustion temperatures leading to reduce NOx emissions with EGR. However, optimum EGR ratio was found to be at 7%. When EGR ratio was increased more than optimum, air-fuel ratios might have approached to stoichiometric air-fuel ratios leads to increase in combustion temperatures.

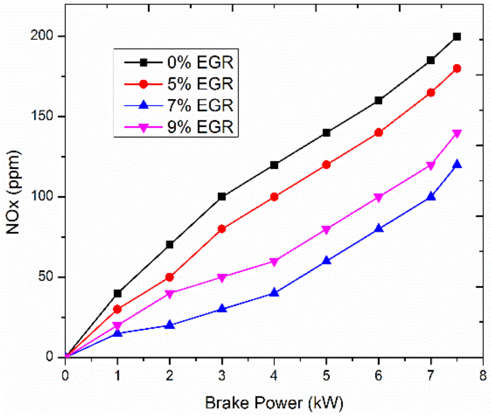

Figure 8: Variation of nitrogen oxide levels (NOx) with brake power at various percentage of EGR

Outcomes of EGR and Catalytic Converter- Comparison

As mentioned earlier, Set-A condition of the catalytic converter denotes devoid of catalyst- Set-B condition of catalytic converter represents the use of catalytic converter with copper as the catalyst and devoid of air injection, while the Set-C condition of catalytic converter represents the mutual use of the catalyst and air injection. Figure 9 presents histograms showing the variation of UHC emissions with different operating conditions of the catalytic converter. In the same Figure, 7% EGR where UHC emissions were found to be lower was also shown for comparison purpose. The Set-C condition of the catalytic converter showed lower UHC emissions when compared to other conditions of the catalytic converter and also with 7%

EGR. The increase of oxidation reaction of air with improved combustion might have lowered the UHC emissions.

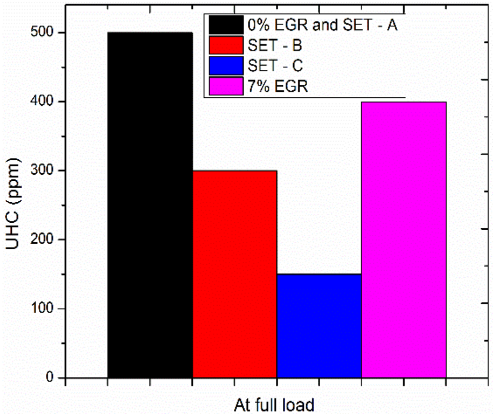

Figure 9: Histograms showing the variation of UHC emissions at full load with different operating conditions of the catalytic converter and 7% EGR

Figure 10 demonstrates histograms showing the variation of CO emissions with different operating conditions of the catalytic converter. The reaction of air with improved combustion might have lowered the CO emissions. In the same Figure, 7% EGR where CO emissions were found to be lower was also shown for comparison purpose. The Set-C condition of the catalytic converter showed lower CO emissions when compared to other conditions of the catalytic converter and also with 7% EGR.

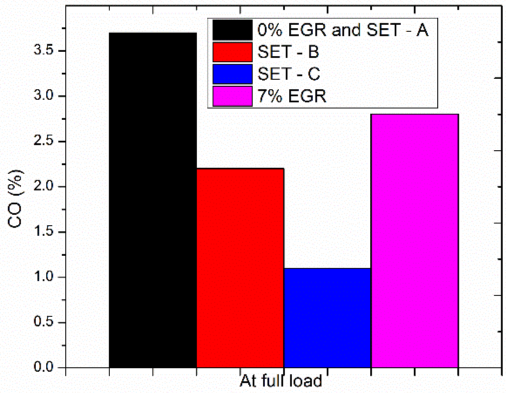

Figure 10: Histograms showing the variation of CO emissions at full load with different operating conditions of the catalytic converter and 7% EGR.

Figure 11 presents histograms showing the variation of nitrogen oxide levels with different operating conditions of the catalytic converter. The reaction of air with improved combustion might have lowered the NOx levels. Set-B operating condition (with copper as a catalyst) might have increased oxidation reaction increasing the temperatures leading to increasing of NOx emissions. Set-C condition (with catalyst and air injection) might have further improved the rate of oxidation reactions causing an increase of NOx levels. However, 7% EGR reduced NOx levels considerably with reduction of supply of fresh air at the inlet manifold of the engine.

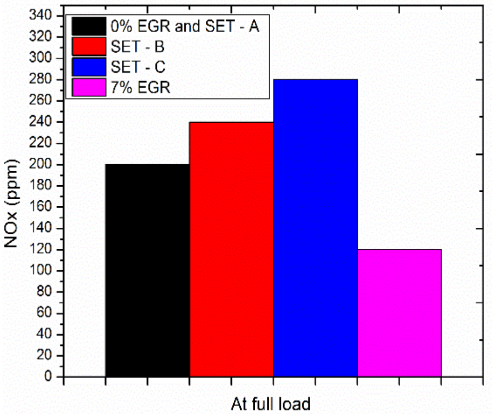

Figure 11 Histograms showing the variation of nitrogen oxide levels at full load with different operating conditions of the catalytic converter and 7% EGR

Exhaust Emissions with Catalytic Converter and EGR rate of 7%

Table 3, shows comparative data of exhaust emissions with EGR (7%) along with different operating conditions of the catalytic converter. Drastic reduction of pollutants of CO and UHC emissions were observed with catalytic converter along with 7% EGR in comparison with conditions of without catalytic converter. Reduction efficiency of 40% was observed for the Set-B condition in comparison with Set–A condition for the catalytic converter as well as EGR. However, Set–C condition showed a comparable reduction of pollutants with the use of catalytic converter and EGR. Reduction efficiency of 60% was observed for Set–C condition in comparison with Set–A condition for the catalytic converter as well as EGR. The reduction of CO in emissions by 54% with 7% EGR along with the provision of the catalytic converter. The UHC emissions decreased by 52% with 7% EGR and with the provision of the catalytic converter.

Table.3 Data of Exhaust Emissions with Catalytic Converter with 7% EGR

Pollutant	Set	Gasoline	
		Catalytic Converter	Along with 7% EGR
CO Emissions (%)	Set-A	3.7	2.8
	Set-B	2.2	1.7
	Set-C	1.1	1.2
UHC Emissions (ppm)	Set-A	500	400
	Set-B	300	240
	Set-C	150	160
Nitrogen Oxide levels (ppm)	Set-A	200	120
	Set-B	240	140
	Set-C	280	160

Conclusions

The brake thermal efficiency was significantly augmented up to 5% EGR. The provision of the catalytic converter with copper as a catalyst reduced 40% of CO and UHC in emissions. The CO and UHC emissions reduced by 60% with a combination of catalytic converter and air injection. The NOx emissions decreased by 44% at 7% of EGR.

On the whole, the combined effect of 7% EGR and catalytic converter with air injection mechanism found to be an optimal configuration for effective control of CO, UHC and NOx emissions.

Nomenclature

SI	-	Spark Ignition
CI	-	Compression Ignition
TDC	-	Top Dead Centre
EGR	-	Exhaust Gas Recirculation
BTE	-	Brake Thermal Efficiency
BSFC	-	Brake Specific Fuel Consumption
UHC	-	Unburnt Hydro Carbons
CO	-	Carbon monoxide
NOx	-	Nitrogen Oxides
DPHX	-	Double Pipe Heat exchanger
NDIR	-	Non Dispersive Infrared detector

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