

# Enrichment of CNG in Gasoline Blends- A Technical Review

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**Abstract**— Pollution from the petroleum oil increases day by day in terms of CO<sub>2</sub>, CO, NO<sub>x</sub>, PM and many other gases and particles. Price difference and economy leads people toward the use of alternative fuels. To overcome this problem Tri-fuel is the best suitable fuel for the IC engine because of its clean emission characteristics. The present study focused on non-petroleum renewable and non-polluting fuels to be used for I.C engines. The tri-fuel is assortment of petrol, butanol blend and CNG gas. It is found that power produced by the Tri-fuelled engine is more and lower NO<sub>x</sub> emissions compare to Gasoline engine because of the high volumetric efficiency, high compression ratio.

**Key words:** CNG Gas, I.C Engines, Gasoline Blend

## I. INTRODUCTION

The use of fossil fuel is increasing drastically due to its consumption in all consumer activities. The high utility of fossil fuel depleted its existence, degraded the environment and led to reduction in underground carbon resources. Hence the search for alternative fuels is paying attention for making, sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced now a days. The worldwide reduction of underground carbon resources can be substituted by the bio-fuels. The SI and CI engines are the major contributors of the GHG. The main researchers around the world are finding the alternate fuel that should have the least impact on the environmental degradation. Rudolf Diesel patented an engine design for used dual fuel system. The present fuel system involves the adaptation of Rudolf with diesel as a single fuel. The emission of NO<sub>x</sub> is unavoidable in fuel combustion systems. An attempt has been made to develop a tri fuel system without additives in conventional C.I engines to achieve biofuel and to reduce emission of Pollutants.

## II. FORMULATION OF NOVEL BIO BASED TRI FUEL FOR I.C. ENGINES

D.Kumaran, M.Rajendran, P.A.Jeeva, S.Karthikeyan[1] studied on non-petroleum renewable and non-polluting fuels to be used for I.C engines. The tri-fuel is assortment of diesel, turpentine blend and acetylene gas. The acetylene gas is produced from the lime stone (CaCO<sub>3</sub>) and the turpentine oil obtained from the pine tree. The performance of a tri-fuel has been analyzed experimentally in a single cylinder direct injection and compression ignition engine with diesel and turpentine blend as primary fuel and acetylene inducted as secondary gaseous fuel i.e., diesel and the turpentine blend (40% turpentine(40T) and 60% diesel) . The results showed that the blend and the acetylene gas flow rate of 3 liters per minute (through a gas flow meter) offered higher brake thermal efficiency between 1% and 3% than that of diesel baseline operation. Tri-fuel concept(acetylene aspiration in let manifold up to 3 lpm and mixing of turpentine with diesel fuel up to 40%) for brake thermal efficiency increased

by 1-3 % from the standard fuel. It exhibited lower exhaust gas temperature compared with diesel operation. An appreciable reduction in HC,CO and cylinder pressure and rate of pressure raise, when gas is inducted.CO<sub>2</sub> emissions was observed in Tri fuel concept with increased engine performance without much worsening its emission.

## III. TECHNICAL FEASIBILITY STUDY OF BUTANOL GASOLINE BLENDS

Suraj Bhan Singh, Atul Dhar, Avinash Kumar Agarwal[2] considered butanol as the most promising alternative fuel candidate because of its favorable chemical and physical properties, which are quite similar to gasoline. Butanol is completely miscible with gasoline in any proportion and forms a stable blend. It is not hygroscopic in nature therefore does not absorb moisture from the atmosphere similar to ethanol and methanol, which makes it a superior alternate fuel. Experiments are conducted on 5, 10, 20, 50 and 75% butanol gasoline blends for evaluating their engine performance, emissions and combustion characteristics in a medium duty transportation spark ignition (SI) engine. The engine was suitably instrumented for the experiments. Engine performance was evaluated by finding performance parameters such as brake specific fuel consumption (BSFC), power output and torque, thermal efficiency and exhaust gas temperature of butanol gasoline blends vis-a-vis baseline gasoline. Regulated emissions were compared for butanol gasoline blends vis-a-vis baseline gasoline and an attempt was made to find the reason for these variations. Combustion characteristics of butanol gasoline blends were evaluated for parameters such as in cylinder pressure history, heat release rate, rate of pressure rise, mass burn fractions and combustion duration. Overall, butanol gasoline blends showed performance, emissions and combustion characteristics similar to gasoline. In this study, engine performance, emissions and combustion characteristics of butanol gasoline blends vis-a-vis baseline gasoline were experimentally evaluated in a medium duty SI engine without any hardware modifications at various engine speeds and loads. Butanol gasoline blends have slightly higher BSFC than gasoline because of its slightly lower calorific value than gasoline. Combustion characteristics of 5, 10 and 20% butanol gasoline blends are similar to gasoline. Heat release for gasoline begins relatively earlier than butanol gasoline blends. The combustion becomes faster for richer mixtures. Combustion duration of butanol gasoline blends is marginally higher than gasoline. BTE of the butanol gasoline blends is lower in comparison to gasoline for all speeds and this difference was statistically significant for lower engine speeds. EGT of butanol gasoline blends is slightly lower than gasoline. This difference was not statistically significant. Butanol gasoline blends produced lower BSNO, BSCO emissions and smoke. BSHC emissions for butanol5 and butanol10 are similar to gasoline at higher engine speeds. BSHC emissions for butanol50 and

butanol75 are found to be lower compared to gasoline at all engine speeds. Overall, due to very small difference in engine performance, emissions and combustion characteristics, butanol blends can be used as a partial replacement of gasoline, without any significant hardware modification or sacrifice in engine performance in the existing transportation SI engines.

Ashraf Elfasakhany[3] studied exhaust emissions and engine performance for neat gasoline and gasoline/n-butanol blends in a wide range of working speeds (2600–3400 r/min) without any tuning or modification on the gasoline engine systems. The experiment has the ability of evaluating performance and emission characteristics, such as break power, torque, in-cylinder pressure, volumetric efficiency, exhaust gas temperature and concentrations of CO<sub>2</sub>, CO and UHC. Results of the engine test indicated that using n-butanol–gasoline blended fuels slightly decrease the output torque, power, volumetric efficiency, exhaust gas temperature and in-cylinder pressure of the engine as a result of the leaning effect caused by the n-butanol addition; CO, CO<sub>2</sub> and UHC emissions decrease dramatically for blended fuels compared to neat gasoline because of the improved combustion since n-butanol has extra oxygen, which allows partial reduction of the CO and UHC through formation of CO<sub>2</sub>. It was also noted that the exhaust emissions depend on the engine speed rather than the n-butanol contents. The experimental research investigates the effect of using different n-butanol blends on CO, CO<sub>2</sub> and UHC emissions, in-cylinder pressure, exhaust gas temperature, volumetric efficiency, brake power and torque of SI engine. The test engine was a single cylinder fueled with 0, 3, 7 and 10 vol.% n-butanol–gasoline blends where this is the first time of studying 3 and 7 vol.% n-butanol blends. Current study, in addition, motivated the trends of CO and UHC emissions of blended fuel; however, such trends were inconclusive and puzzling in the early studies. The n-butanol addition to gasoline fuel can significantly improve blends combustion due to its partially oxidized nature and a leaning effect caused by its lower stoichiometric air–fuel ratio. The engine performance and emissions depend on both engine speed and rates of n-butanol in the blended fuels. The higher the rate of n-butanol in the mixture, the lower the emissions and engine performance. The performance of 10 vol.% n-butanol is lower than gasoline by about 5.6%, 2.5%, 6.6%, 8.3% and 3.5% for the exhaust gases temperature, engine torque, brake power, in-cylinder pressure and volumetric efficiency, respectively. The engine performance of blends is lower than gasoline due to the combustion characteristics of n-butanol (higher latent heat and lower calorific value than gasoline). The lower saturation pressure of n-butanol compared to gasoline leads to a lower volumetric efficiency for blended fuels. The engine performance of blends could be improved by modifying ignition time and increasing compression ratio since n-butanol has more resistance to detonation than gasoline. The n-butanol addition (even with low rate, e.g., 3 vol.%) to gasoline fuel can significantly alter the emissions trends. Both CO and UHC for blended fuels increase with increasing engine speed until reaching the maximum level at moderate speed and then decrease with increasing speed. However, gasoline emissions (CO and UHC) decrease continually with engine speed. Pollutant

emissions of SI engine using blends are significantly influenced by engine speeds. At low speed, emissions of gasoline are greater than blends by about 43%, 32% and 26% for CO<sub>2</sub>, CO and UHC, respectively; however, at moderate speed, the emissions of gasoline are higher by about 40%, 6% and 11%, respectively; at high speed, CO<sub>2</sub> of neat gasoline is higher than blends by about 27%, while CO and UHC become in the same order of magnitude for gasoline and blended fuels. No major emissions differences between n-butanol blends at rate less than 10 vol.%. This study strongly supports using low blend rates of n-butanol (<10 vol.%) in SI engines. Such low rates can be mixed with gasoline without any modifications on engine systems. The low rates, in addition, can improve emissions significantly with small drawbacks on engine performance; however, high rates of n-butanol, in comparison, will make a drop in engine performance without significant reduction in emissions.

Simona Silvia Merola\*, Cinzia Tornatore, Luca Marchitto[4] studied the effect on the spark-ignition combustion process of n-butanol blended in volume with pure gasoline. Fuel blend of alcohol and conventional hydrocarbon fuels for a spark-ignition engine can increase the fuel octane rating and the power for a given engine displacement and compression ratio. In this work, the influence of butanol addition to gasoline in a port fuel injection, spark-ignition engine was investigated. The experiments were realized in a single-cylinder ported fuel injection spark-ignition (SI) engine with an external boosting device. The optically accessible engine was equipped with the head of a commercial SI turbocharged engine with the same geometrical specifications (bore, stroke and compression ratio) as the research engine. The effect on the spark ignition combustion process of 20% and 40% of n-butanol blended in volume with pure gasoline was investigated through cycle-resolved visualization. The engine worked at low speed, medium boosting and wide-open throttle. Fuel injections both in closed-valve and open-valve conditions were considered. Comparisons between the parameters related to the flame luminosity and the pressure signals were performed. Butanol blends allowed working in more advanced spark timing without knocking occurrence. The duration of injection for butanol blends was increased to obtain a stoichiometric mixture. In open-valve injection condition, the fuel deposits on intake manifold and piston surfaces decreased, allowing a reduction in fuel consumption. BU40 granted the performance levels of gasoline and, in open-valve injection, allowed to minimize the abnormal combustion effects including the emission of ultrafine carbonaceous particles at the exhaust. In-cylinder investigations were correlated to engine out emissions. The effect on the spark-ignition combustion process of n-butanol blended in volume with pure gasoline was investigated through cycle-resolved visualization applied in a single-cylinder PFI SI engine working at low speed, medium boosting and wide-open throttle. Two injection timings were fixed in order to inject the fuel at closed intake valve and open intake valve, respectively. The spark timing was changed to identify the maximum brake torque and the knocking limit. Blends of butanol up to 40% allowed working in more advanced spark timing without negative effects on performance. To work with a stoichiometric

mixture for both fuels, the duration of injection was slightly increased for the blend. DOI in CV resulted longer than in OV for both fuels because, in CV injection, part of the injected spray is deposited on the intake manifold surfaces, forming a layer of liquid film. If these fuel layers are not well atomized, they enter the cylinder as drops and ligaments. During the normal combustion process, only part of the fuel deposits was completely burned. Thus, more fuel should be injected to reach the selected air-fuel ratio measured at the exhaust. When the normal flame front reached the fuel deposits, abnormal combustion was incepted. This was characterized by intense diffusion-controlled flames. Their contribution to the combustion pressure was negligible. The different levels of intensity were related to different carbonaceous structures and soot precursor concentrations. CV condition was characterized by higher fuel deposition amount and thus more intense diffusion-controlled flames than OV. Gasoline in CV condition showed the highest luminosity and BU40 in OV condition, the lowest one. This demonstrated that BU40\_OV allowed the reduction of emission of ultrafine carbonaceous particles at the exhaust and the optimization of fuel consumption at fixed performance. Moreover, medium-low percentage of butanol in the gasoline allowed the reduction of NO<sub>x</sub> and unburned hydrocarbon emission. Finally, even if an increase in the injected fuel amount should be considered to obtain the same air-fuel ratio for butanol-gasoline blend, if compared to pure gasoline, the better efficiency of fuel deposit burning allowed the reduction of that amount.

#### IV. PERFORMANCE AND EVALUATION OF ALTERNATIVE FUELS IN SI ENGINE

Abhishek Paul, Probir Kumar Bose, Raj Sekhar Panua , Rahul Banerjee[5] studied with one such approach in which the potential of diesel ethanol blending and subsequent CNG (compressed natural gas) enrichment have been investigated. The study starts with a miscibility test of ethanol in diesel, which paves the way for an experimental comparison between performance and emission characteristics of Diesel Ethanol blends, Diesel CNG combinations and Diesel Ethanol blends with CNG enrichment. The results indicates that diesel ethanol blend D95E5 (95% diesel 5% ethanol) with low CNG enrichment produces a better performance-emission characteristics as compared to base diesel operation as well as diesel ethanol blend operation. Results also portrayed ethanol's potential in reducing NO<sub>x</sub> emission, BSEC and smoke opacity .This study provides a comprehensive assessment on CNG enrichment of diesel and different diesel ethanol blends in terms of their performance and emission aspects. It also provides a suggestive analysis of ethanol's limited miscibility in diesel, which restricts its use in higher percentage of volume of diesel. The tested blends consisted of 5% and 10% by volume of ethanol. On the other hand, CNG was port injected for 5 different injection durations which depended on the RPM of the engine. Furthermore, the trade -off study provides a clear picture of blend usability along with CNG enrichment at different load conditions. Ethanol cannot be mixed in diesel in excess of 10% (V/V) at normal room temperature. Anything above 10% results in distinct phase separation problem. Diesel ethanol blends

with 5% and 10% ethanol showed stability over a wide period. Hence, they were perfect for engine testing. The study showed that diesel ethanol blend, D95E5 produced better performance characteristics than diesel CNG combination when both diesel ethanol and diesel CNG combinations are compared with diesel. As an alternative to conventional diesel, D95E5 and D90E10 showed higher brake thermal efficiency (21.53% and 19.5% respectively) than any Diesel CNG combination. The present study also provides a definitive approach toward determining the best fuel combination for the tested set of fuel combinations, which will offer the best performance with minimal amount of emissions at a particular load condition. This Experimentation thus revealed the potential of CNG enrichment of diesel and diesel ethanol blends as an efficient instrument to overcome the inherent paradox of simultaneously reducing emissions and without much penalization of performance characteristics in conventional diesel engine.

M. M.Gosal,L.M.Das,M.K.Gajendr Babu[6] experimentally studied using hydrogen as a substitute fuel in stationary motor cycle engine. Mixing a small percentage of hydrogen and CNG and supplying it to the engine very clearly shows that hydrogen gas could be easily substituted up to 30% in CNG in S I engine. A better or comparable performance was obtained with about 20 to 30° by volume wise substitution of hydrogen fuel under all load conditions. Brake thermal efficiency increases by 20% and brake specific energy consumption values decrease by 14% with increasing hydrogen.HC and CO emissions values decrease by 30% and 80% respectively. Marginal increase in exhaust temperature level was observed. An increase in the level of NO<sub>x</sub> emissions values by 13% takes place with addition of hydrogen to CNG. CNG replacement reduces as hydrogen substitution rate is increased.Exhaust gas temperatures are higher in the hydrogen enriched mode of operation due to faster combustion and high temperature reached in the cylinder. Hydrogen enrichment of natural gas enhances combustion characteristics of the engine. The tests show that the optimum concentration of hydrogen in the fuel mixture for producing a power gain appears to be about 20-30% by volume over the range of conditions considered. Higher hydrogen contents undermine the knock resistance characteristics of natural gas, lower power output of the engine and increase of the fuel cost.

Munde Gopal G., Dr. Dalu Rajendra S[7] Based on the reviewed paper for the performance and emissions of compressed natural gas , it is concluded that the compressed natural gas represents a good alternative fuel for SI engine and therefore must be taken into consideration in the future for transport purpose. The engine thermal efficiency and exhaust gas temperature produced by the CNG burning is always higher as compared with that of the petrol/diesel.CNG produces less 8-16% of brake torque, brake power and BMEP compared to gasoline fuel due to reduced volumetric efficiency and lower flame speed of CNG.On average the reduction of CO, CO<sub>2</sub> and HC emission are 20-98%, 8-20% and 40-87% respectively by CNG.Higher NO<sub>x</sub> emission is the main emission concern for CNG as automotive fuel that can be reduced by increasing fuel density and blending small quantities.

## V. EXHAUST EMISSION CHARACTERISTICS USING TRI-FUEL

Alpaslan Atman, Erol İleri [8] evaluated the effect of using n-butanol in vegetable oil–diesel fuel blends on engine performance and exhaust emissions of a direct injection diesel engine operating at full load (100% throttle conditions) with different engine speeds without any engine modification. Neat canola-hazelnut-cottonseed oil (CHC) and neat sunflower–corn–soybean oil (SCS) blends were prepared as equal vol.% by splash blending method. Diesel fuel (70 vol.%) and n-butanol (10 vol.%) are added into CHC and SCS blends. In this study, engine performance and exhaust emissions of turbocharged direct injection diesel engine were evaluated at full load and various engine speeds by using two different diesel fuel-vegetable oil-n-butanol ternary blends. Micro emulsification of vegetable oil-diesel fuel with n-butanol can be a promising technique for using neat vegetable oils efficiently in diesel engines without any modifications in the diesel engine, and the viscosity and density of the ternary blends can be reduced to close to those of diesel. The cold flow properties of vegetable oil can be significantly improved by blending vegetable oils with n-butanol and diesel fuel blend. The presence of n-butanol and vegetable oils in ternary blends has increasing effect on BSFC. Addition of n-butanol to diesel fuel-vegetable oil blends leads to increase NO, NO<sub>2</sub> and CO formations, while decrease CO<sub>2</sub> and HC emissions.

Gvidonas Labeckas, Stasys Slavinskas [9] presented the bench testing results of a four stroke, four cylinder, direct injection, unmodified, diesel engine operating on pure rapeseed oil (RO) and its 2.5 vol%, 5 vol%, 7.5 vol% and 10 vol% blends with ethanol (ERO), petrol (PRO) and both improving agents applied in equal proportions as 50:50 vol% (EPRO). Total NO<sub>x</sub> emissions behaviour determined for the engine fuelled with various ethanol, petrol and rapeseed oil blends depends on load, speed and the mass percentage of fuel bound oxygen. In spite of a lower fuel oxygen content, blends PRO10 (9.72%) and EPRO5 (11.13%) produce the biggest, 1954 and 2078 ppm, amounts of the NO<sub>x</sub> emission at 2000 min<sup>1</sup> speed against those, 1731 and 1411 ppm, generated by oxygenated ERO5 (12%) and ERO10 (13.2%) blends. This comparison indicates that in the case of using oxygenated rapeseed oil as a basic fuel the cylinder gas temperature plays a very important role in the production of nitric oxide emissions. The emissions of NO<sub>2</sub> increase with load from nearly 2–3 ppm to maximum 85 ppm (ERO7.5), 46 ppm (PRO2.5) and 28 ppm (EPRO2.5) at rated power suspending at up to 6.5, 3.5 and 2.1 times higher levels comparing with those emitted from pure RO (13 ppm). The NO<sub>2</sub>/NO<sub>x</sub> emissions have a tendency to increase with speed and the percentage of ethanol and petrol added into rapeseed oil and reach maximum 18.5 (ERO7.5), 27.4 (EPRO2.5–5) and 30% (PRO10) for light load and minimum 0.7 (ERO2.5), 0.84 (RO) and 1.0% (PRO5 and EPRO7.5) for heavy loading conditions at rated 2200 min<sup>1</sup> speed. Carbon monoxide, CO, emission and smoke opacity from a fully loaded engine run at 1800 min<sup>1</sup> speed on blend PRO10 compile 754 ppm and 26.5% that is by 47.8% and 7% lower than those generated from the mostly oxygenated blend ERO10. When a fully loaded engine is run on blend EPRO7.5 at a low 1400 min<sup>1</sup>

speed, the CO emission and visible smoke are lower by 28.6% and 67.5% and at a rated 2200 min<sup>1</sup> speed CO increases by 16.1% and smoke diminishes by 17.6% relatively to the data obtained using pure RO. Emissions of unburned hydrocarbons, HC, remain at a considerably low level ranging from 8 ppm (ERO7.5) for light to 16 ppm (EPRO7.5) for heavy loads at 2200 min<sup>1</sup> speed and they do not undergo significant changes neither with engine load, speed nor the percentage of improving agent applied. Nevertheless the HC emissions from the tested blends ERO sustain at slightly lower level than those measured from adequate percentage PRO and EPRO blends under the same loading conditions. Emissions of carbon dioxide, CO<sub>2</sub>, increase together with load, speed and fuel consumption in mass. In spite of a higher fuel consumption, the CO<sub>2</sub> emissions from a fully loaded engine run at 2200 min<sup>1</sup> speed on oxygenated blends ERO2.5–7.5 are slightly lower, 6.9–6.3 vol%, comparing with those emanating from blends PRO2.5–7.5, 6.7–7.6 vol%, pure RO, 7.8 vol%, and three agent blends EPRO2.5–7.5, 8.1–7.9 vol%. Temperature of the exhausts of a fully loaded engine operating at rated 2200 min<sup>1</sup> speed and constant air-to-fuel equivalence ratio  $k = 1.6$  increases from 500 C to 525 C and 530 C.

Samuel Rodman Oprešnik, Tine Seljak, Francišek Bizjan, Tomaz Kutrašnik [10] examined the influence of compressed natural gas, liquefied petroleum gas and gasoline fuel on the exhaust emissions and the fuel consumption of a spark-ignition engine powered passenger car. The vehicle was driven according to the urban driving cycle and extra urban driving cycle speed profiles with the warmed-up engine. Cause and effect based analysis reveals potential for using different fuels to reduce vehicle emission and deficiencies associated with particular fuels. The highest tank to wheel efficiency and the lowest CO<sub>2</sub> emission are observed with the natural gas fuelled vehicle that also featured the highest total hydrocarbon emissions and high NO<sub>x</sub> emissions because of fast three way catalytic converter aging due the use of the compressed natural gas. Retrofitted liquefied petroleum gas fuel supply systems feature the greatest air–fuel ratio variations that result in the lowest TTW efficiency and in the highest NO<sub>x</sub> emissions of the liquefied gas fuelled vehicle. Our findings indicate that fuel efficiency is the highest across the range of alternative fuels we examined when CNG is the fuel. In contrast, when gasoline is used there is lower TtW efficiency mainly because of the smaller spark advance. Retrofitted LPG fuel supply systems have the largest air/fuel ratio variations resulting in the lowest TtW efficiency and the highest NO<sub>x</sub> emissions per km.

## VI. CONCLUDING REMARKS

This study provides a comprehensive assessment on CNG enrichment of petrol and its blends in terms of their performance and emission aspects. The review shows that the CNG using in IC engines reduces the emissions, which is the most important criterion for the current environmental norms. There is a limited number of research works available related to the usage of multi-fuels in SI engine. In this regard this research work aims to study the 4 emissions, efficiency and fuel consumption in the SI engine with gasoline blends and CNG. The vital findings of this study are summarized as follows,

- 1) The engine performance and emissions depend on both engine speed and rates of n-butanol in the blended fuels.
- 2) No major emissions differences between butanol blends at rates less than 10 vol. %.
- 3) Natural Gas has considerably higher octane Number than petrol and has very low Cetane Number when compared with diesel fuel. Hence it is more suitable for SI engine rather than CI engine.
- 4) By using CNG n-butanol in dual fuel engine thermal efficiency 18-22% is increases, Emission and BSFC is decreases. but Volumetric efficiency 12-18% decrease and hence power output also decrease nearly 14-20 %.
- 5) Lean burn is an effective way to improve fuel efficiency and reduce NOx emissions. Lean burn limits are dependent on combustion chamber geometry, ignition timings, ignition energy and turbulence.
- 6) The n-butanol addition to gasoline fuel can significantly improve blends combustion due to its partially oxidized nature and a leaning effect caused by its lower stoichiometric air-fuel ratio.
- 7) Ethanol cannot be mixed in petrol in excess of 10% (V/V) at normal room temperature. Anything above 10% results in distinct phase separation problem. Petrol ethanol blends with 5% and 10% ethanol showed stability over a wide period. Hence, they were perfect for engine testing.
- 8) CNG found best alternative for the current IC engines.
- 9) Butanol gasoline blends produced lower BSNO, BSCO emissions and smoke.
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