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Effect of Fuel Injection Timing and Elevated Intake Air Temperature on the Combustion and Emission Characteristics of Dual Fuel operated Diesel Engine

K. Senthil Kumar, R. Thundil Karuppa Raj *

School of Mechanical and Building Sciences, VIT University, Vellore - 632 014, India

Abstract

Environmental concerns and rapid depletion of fossil fuels have caused interests in the study of alternative fuels for internal combustion (IC) engines. For internal combustion engines, ethanol fuel is receiving more attention because they are biodegradable, oxygenated and renewable fuels. This paper presents the experimental investigation to study the effect of fuel injection timing and intake air temperature using pure ethanol blended biodiesel fuel (B5E15), on the combustion and emission characteristics of a single cylinder, four-stroke, air cooled, direct injection diesel engine. The tests were carried out using B5E15 fuel under constant speed (1500 rpm) and load (2 kW) with different injection timing (12, 15, 18, 21 and 24^o CA bTDC) and different intake air temperatures (40^{o}C and 60^{o}C) at 1.1 bar intake manifold pressure. The combustion and emission characteristics such as in-cylinder pressure, temperature, heat release, NO_x, UHC, CO and smoke are presented and discussed. The experimental results reveal that advancing the injection timing results in increase in-cylinder pressure, temperature, heat release rate and NO_x emissions. In addition, the CO and HC emissions exhibit a decreasing trend according to an increase in the intake air temperature and advance in the injection timing. The preheated intake air favours premixed combustion, resulting in increased peak cylinder pressure and heat release rates.

Keywords: Start Of Injection; preheated air; ethanol; cotton seed oil; heat release rate; emissions.

Nomenclature

AIT	Air Intake Temperature
bTDC	before Top dead Centre
B5E15	Biodiesel 5%, Ethanol 15%, neat Diesel 80% (by volume)
CAD	Crank Angle in Degree
CO	Carbon Monoxide
CSME	Cotton Seed Methyl Ester
FSN	Filter Smoke Number
HRR	Heat Release Rate
NO_x	Oxides of Nitrogen
SOI	Start Of Injection
UHC	Unburnt Hydro Carbon

1. Introduction

Depletion of fossil fuels and environmental pollution consideration urged researchers to focus their interest on the renewable fuels such as Alcohols, hydrogen, and biodiesel [1–5]. Alcohol fuels are receiving more attention worldwide

* Corresponding author. Tel.: +919790524873.
E-mail address: thundilr@gmail.com

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as the replacement of fossil fuels. Alcohols production and transportation is much more cheaper, simple and eco-friendly. Alcohol can be used directly in an engine or it can be blended with gasoline/ diesel fuels.

Ethanol is one of the alternate fuels for diesel engines. The use of ethanol as a supplementary compression ignition (CI) engine fuel may reduce environmental pollution, reduce fossil fuel requirements, strengthen agricultural economy, create job opportunities, and thus contribute in conserving a major commercial energy source.

Ethanol fuel has higher latent heat of vaporization than diesel fuel and hence it haul out more heat for phase change. It may lead to produce cooling effect on the combustion and it reduces the peak combustion temperature and leads to reduction in nitrogen oxides emissions. Ethanol fuel has low viscosity than diesel fuel and it makes easier to fuel atomization but at the same time it is necessary to add lubricant additives to improve its lubrication. Because of its lower cetane number and higher auto ignition temperature ignition delay of ethanol fuel is more compared to neat diesel. [6, 7].

Ethanol can be used in diesel engines as pure or blended with conventional diesel fuel without any major modifications on the engine. The important difficulty encountered for making ethanol-diesel blend is phase separation. However the diesel and ethanol phase separation can be prevented by adding small quantity of biodiesel while the potential of the ethanol in reducing NOx emissions and compensate the cetane number is an added advantage. [8, 9].

Many research works [10–17] have reported that fuel injection timing, injection pressure, intake charge pressure & temperature, split injection, exhaust gas recirculation and fuel blend quantity are some of the most important variables for controlling the performance and exhaust emissions of a diesel engine.

Jayashankara *et al.* [18] studied the controlling strategy of the combustion phasing in computer simulation with chemical-kinetics for advancing and retarding the injection timing for an automotive engine and found that advanced injection timing results in increase in-cylinder pressure, temperature, heat release rate, cumulative heat release and NOx emissions and retarded injection timing results in reverse trend.

Bhale et al. [19] explored the performance and emissions characteristics on esterified Mahua oil blended with ethanol. In their analysis, they found reduction in NOx and CO emissions using 20% blended fuel but with an increase in HC emission.

Nadir Yilmaz [20] compared the emissions at two elevated intake air temperature and results indicate that high heat of vaporization of alcohol fuels affect emissions significantly. Intake air preheat was proved to be one of the effective solutions to reduce CO and HC emissions. Reduction of alcohol concentration in biodiesel–alcohol blends also showed similar effects to preheating intake air temperature.

However, there is lack of detailed data on combustion and emission characteristics of ethanol blended with biodiesel produced from cotton seed oil and elevated temperature of intake air. Thus, the aim of this study is to investigate and compare the effect of start of injection and intake air temperature on combustion and emissions of a diesel engine operating on ethanol–biodiesel blend, using biodiesel produced from cotton seed oil.

2. Experimental setup and procedure

The experimental tests have been performed in the Automotive Research Centre, School of Mechanical and Building Sciences, VIT University, Vellore, Tamil Nadu, India.

Ethanol blended diesel fuel can reduce the pollutant emissions but it may require some modification in the engine. The fuel injection timing and elevated intake air temperature have significant influence on the exhaust emissions and combustion parameters in CI engines. Therefore, the effects of injection timing and intake temperature using ethanol blended biodiesel fuel on the engine emissions and combustion parameters were experimentally investigated on a single cylinder, four stroke and air cooled CI engine has bore of 78 mm, stroke of 68 mm and a total displacement of 325 cm^3. The compression ratio of the engine is 18:1. The engine was coupled to an eddy current dynamometer to control engine speed and load.

An electric heater was located at the engine intake system to preheat and maintain the required intake air temperature. A portable reciprocating air compressor is employed for maintaining constant air mass flow rate and intake air pressure of 1.1 bar in the air intake system. The pressure and mass flow rate at engine inlet was measured by boost pressure sensor and Hot Film Mass flow (HFM) sensor (BOSCH) respectively. Engine oil temperature, intake air temperature and exhaust gas temperature were measured using K type thermocouples. A schematic depiction of the experimental arrangement is shown in Fig. 1.

The euro-diesel was blended with ethanol (purity of 99.9%) 15% and CSME 5% by volume to obtain B5E15 blend. To ensure the homogeneity the blend was prepared just before starting the experiment. A stirrer was also mounted inside the fuel tank in order to prevent phase separation of blend. The fuel properties are shown in Table 1. Exhaust emissions like NOx, CO, UHC are detected and analyzed with a 5 gas analyzer and the smoke emissions are measured using the AVL smoke tester with a filter paper method.

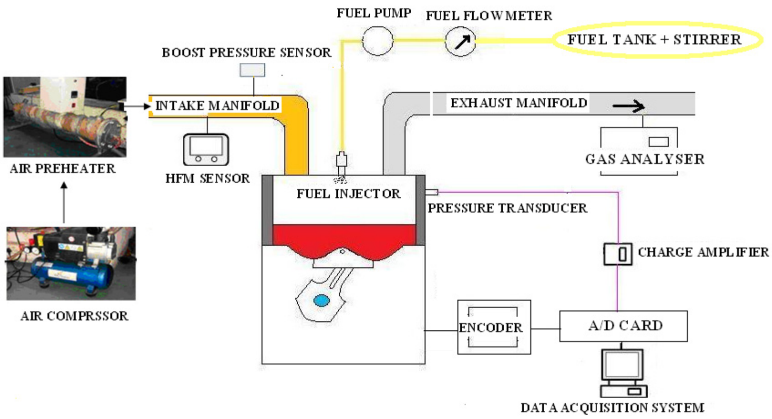


Fig 1. The experimental setup

A piezoelectric combustion pressure sensor (Kistler, 601A) and a data acquisition board are installed to measure the in-cylinder pressure. A crank angle encoder (Kistler, 2613B1) is fixed on the crankshaft which is used to clock pressure data acquisition. The net heat release rate, $dQ_n/d\theta$, is calculated using the formula given in ref. [21],

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta} \qquad (1)$$

Here γ is the ratio of specific heats, C_p/C_v. An appropriate range for γ for diesel heat release analysis is 1.3 - 1.35. The wall heat transfer and blow by losses are not considered to find the heat released due to combustion of fuel inside cylinder. This helps to eliminate additional approximation in the analysis of heat release.

Table.1 Fuel Properties

Fuel Property	Diesel	Ethanol	Cotton Seed Oil
Density (kg/m^3) at 15^{o}C	837.8	799.4	890
Viscosity (mm^2/s) at 40^{o}C	2.649	1.1	3.7
Calorific Value kJ/kg	44,893	28,180	39,564
Cetane Index	54	8	56
Flash Point(^{o}C)	50	12	148

First, the engine is started with B5E15 blend at 1.1 bar and 40^{o}C of air intake conditions. The original injection timing of the test engine is 18^{o}CA bTDC and 200 bar injection pressure. Once the engine was started, operating conditions were maintained at 2 kW and 1500 rpm and readings were recorded.

For the same load and speed conditions, the injection timing was adjusted by adjusting the timing shim thickness in the FIP (Fuel Injection Pump) circuit. The engine was operated at advanced injection timing of 21^o and 24^o CA bTDC and retarded to 15^o and 12^o CA bTDC. The intake air temperature was varied in the range of 40^{o}C and 60^{o}C using an air pre-heater and portable compressor to study the combustion and emission parameters influenced by SOI. All experiments were carried out at a constant oil temperature of 80^{o}C.

3. Results and discussions

3.1 Combustion characteristics

The experimental work is carried out to study the effect of fuel injection timing on the performance of the engine operating at 1500 rpm at 2 kW running conditions using B5E15 blended diesel fuel. The in-cylinder pressure, temperature and heat release rate are obtained for the start of injection (SOI) of 12^o, 15^o, 18^o, 21^o and 24^o CA bTDC.

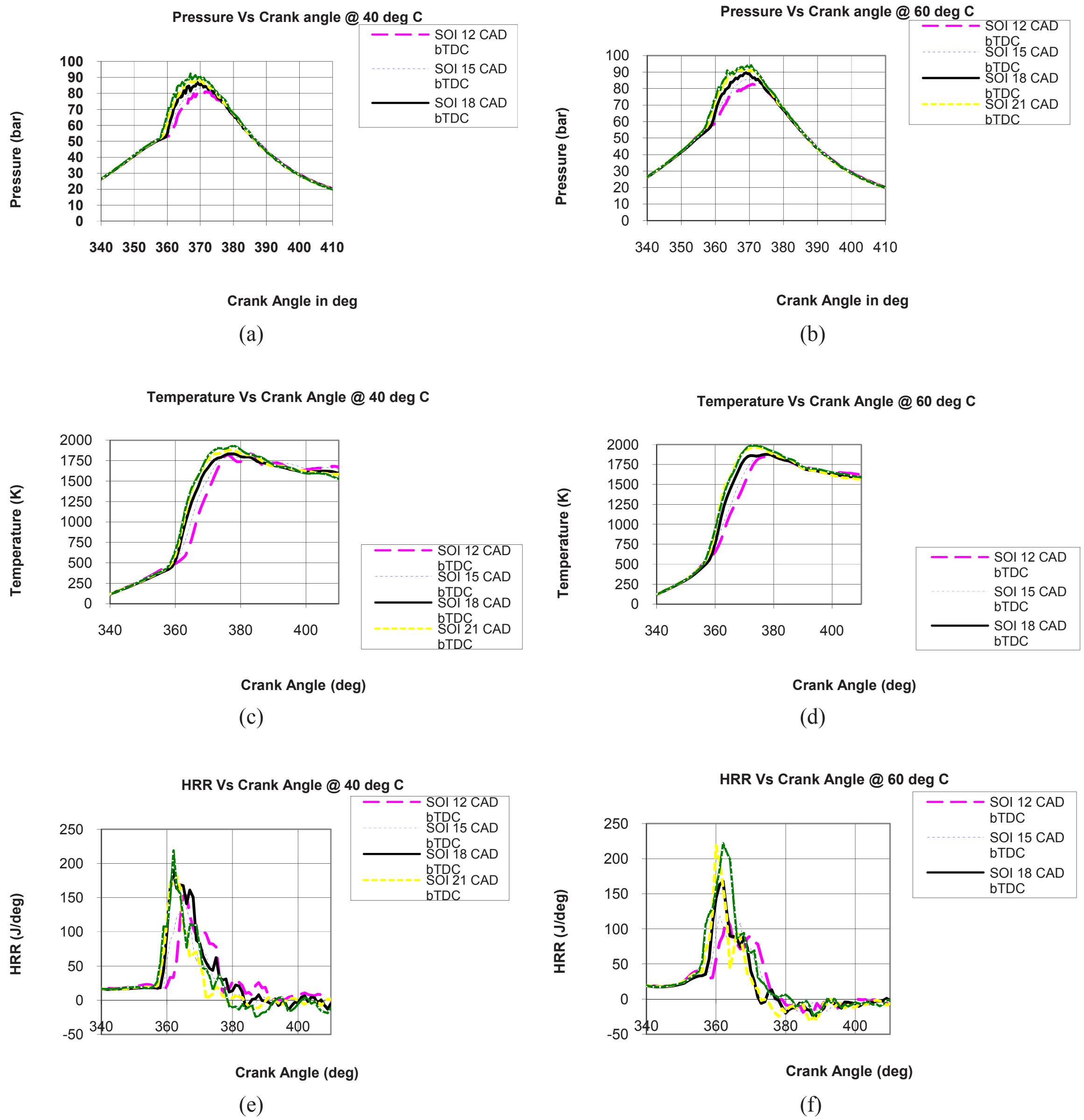
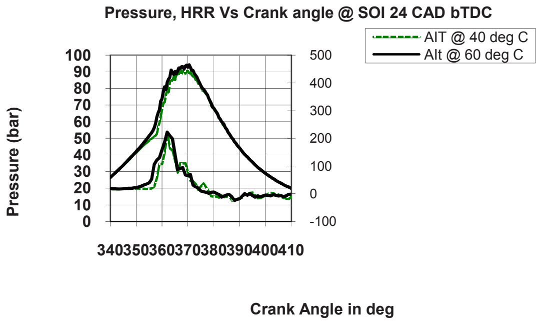
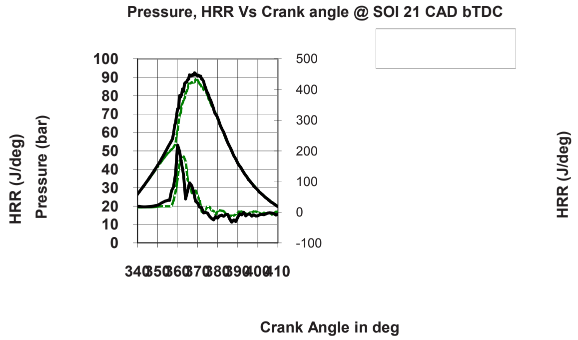


Fig.2 (a) In-cylinder pressure at 40^{o}C of air intake temperature, (b) In-cylinder pressure at 60^{o}C of air intake temperature, (c) Combustion temperature at 40^{o}C of air intake temperature, (d) Combustion temperature at 60^{o}C of air intake temperature, (e) HRR at 40^{o}C of air intake temperature, (f) HRR at 60^{o}C of air intake temperature.

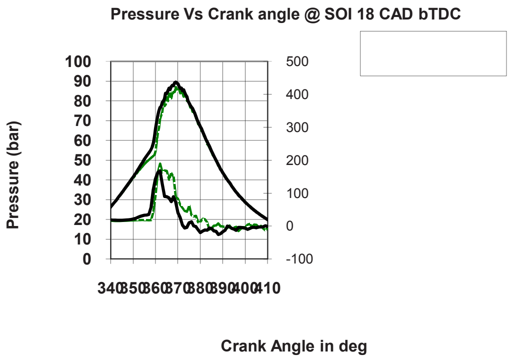
Figure (2) show the combustion parameter such as in-cylinder pressure, temperature and heat release rate with respect to crank angle. The advanced injection timing shows maximum cumulative heat release, higher peak pressure and high temperature and retarded injection timing shows lower peak heat release rate, lower peak pressure and low temperature with reference to the 18^o CA bTDC.



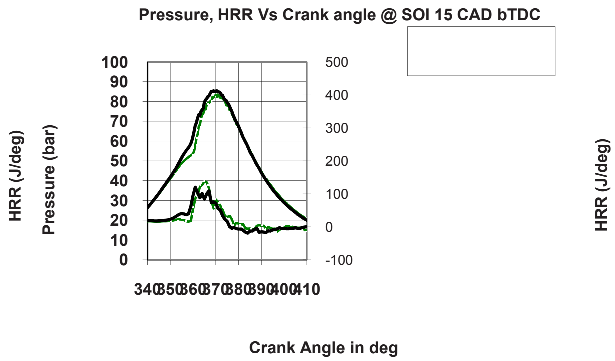
(a)



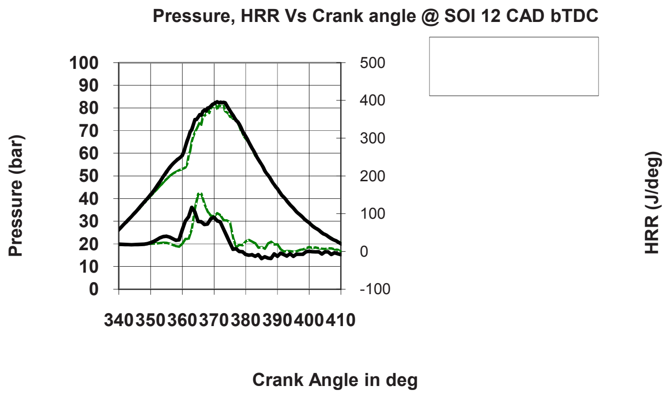
(b)



(c)



(d)



(e)

Fig.3 (a), (b), (c), (d), (e) In-cylinder pressure and heat release rate at different SOI and AIT

When advancing the injection timing, in-cylinder pressure and temperature is not sufficient to ignite the fuel as a result a large amount of evaporated fuel is accumulated during the ignition delay period. This longer ignition delay may leads to rapid burning rate in premixed mode causing shorter combustion duration and results in sudden rise in in-cylinder pressure and temperature.

But, in the case of retarded injection timing, in-cylinder pressure and temperature is sufficient to ignite the fuel and a relatively small amount of evaporated fuel is accumulated during the ignition delay period. This shorter ignition delay leads to slow burning rate in premixed mode rather than diffusion mode resulting in slow rise in pressure and temperature and longer combustion duration.

The influence of charge temperature on HRR and in-cylinder pressure is shown in Fig. 3. The start of combustion was advanced and the heat release rate was increased when the charge temperature was raised. The HRR and pressure raise is more at premixed combustion at advanced injection time with higher charge temperature but, in the case of retarded injection timing with increased charge temperature from 40°C to 60°C HRR and pressure raise is less at premixed phase and diffusion mode combustion duration is more.

3.2. Emission characteristics

NO_x emission is one of the most stringent emissions from diesel engines. The oxides of nitrogen in the exhaust emissions contain nitric oxide (NO) and nitrogen dioxides (NO_2). The formation of NO_x is highly influenced by combustion heat release rate and oxygen concentration.

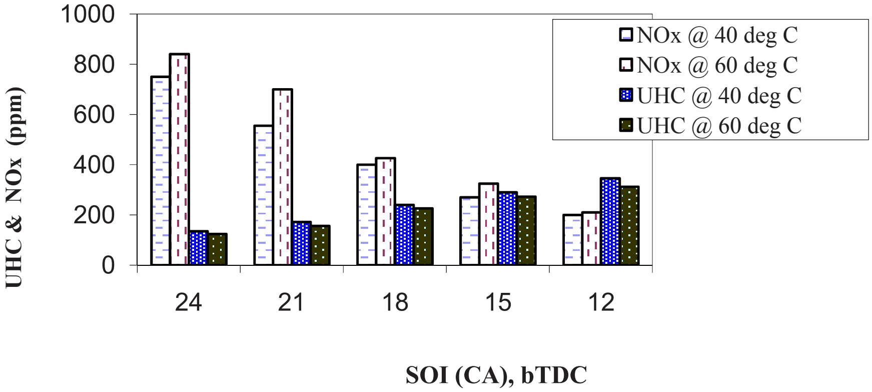


Fig.4 Variations of NOx and UHC emissions

The NO_x and UHC emissions obtained for different SOI & air intake temperatures are summarized in Fig. 4. The advanced injection timing shows higher NO_x and lower UHC emissions with increased intake air temperature through out the predicted range. It is found that the higher NO_x and reduction in UHC emission is due to high temperature caused by pre-mixed burning and high rate of oxidation of UHC at advanced injection time.

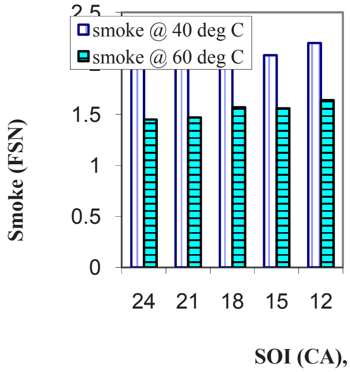


Fig.5 Variations of smoke emissions

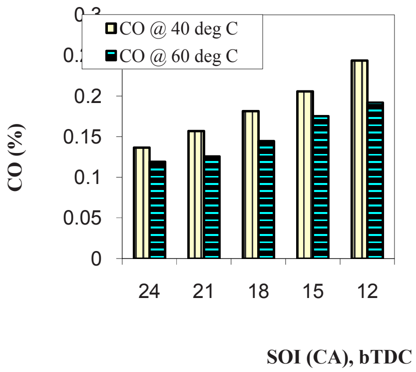


Fig.6 Variations of CO emissions

Retarded SOI with increased intake air temperature causes reduction in peak HRR at premixed combustion and low NO_x emissions. The reason perhaps is that the cooling effect of ethanol is the dominant factor on formation of NO emission at retarded SOI and oxygen content in the ethanol and biodiesel caused to reduction in UHC emissions.

Smoke and carbon monoxide formation occurs due to air / oxygen deficiency at the combustion chamber. Smoke and CO emissions were presented in Fig. (5, 6) for different injection timings and air intake temperatures. The results showed that the smoke and CO level was decreased at advanced injection timing with higher intake temperature for the same air flow rate. The presence of oxygen in ethanol and biodiesel satisfy positive chemical control over soot formation. The earlier SOI and intake air temperature leads to higher combustion temperature and more time for oxidation of CO and soot particles at expansion stroke.

4. Conclusions

- The premixed combustion dominates as the intake temperature rises at advanced SOI and results in more HRR. The diffusion stage of combustion dominates at retarded SOI with increased temperature from 40^{o}C to 60^{o}C.
- Advanced start of injection results in earlier start of combustion relative to the TDC. Because of this, the cylinder charge, being compressed as the piston moves to the TDC, had relatively increase in-cylinder pressure, temperature, heat release rate and thus, lowered the UHC emissions and increased NOx emissions and retarded injection timing results in reverse trend.
- In case of advanced injection timing and higher elevated air temperature, the soot and CO emissions show decreasing trend because of improving reaction between fuel and oxygen. At retarded injection timing soot and CO emissions show the reverse trend.
- When increasing the air intake temperature with ethanol blended biodiesel fuel mixture produced higher in-cylinder peak temperature. Increased charge temperature compensates the higher latent heat of evaporation of the ethanol fuel which causes for reduced ignition delay. This effect increased NOx emissions and reduced UHC. As a consequence of better vaporization and in-cylinder combustion, it can be concluded that intake air preheat could potentially reduce CO and smoke emissions.

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