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Parametric optimization for performance combustion and emissions characteristics of an IC engine powered by M. Elangi methyl ester blends using Taguchi Technique

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Abstract: Experimental investigation was carried on the CI engine using Diesel, Mimusops Elangi methyl ester (MEME) and its blends. The performance, combustion and emission characteristics were carried out on the direct Injection diesel (DI) engine with two input parameters like fuel and load for nine response parameters like Brake thermal efficiency (BTH), brake specific fuel consumption (BSFC), combustion characteristics' like Heat release rate (HRR), pressure and exhaust emissions like Hydro carbons (HC), Carbon monoxide (CO), Nitrogen oxides (NOX), Smoke, exhaust gas temperature (EGT), and Carbon dioxide (CO_2). In order to find out the optimal response the set of experiments were conducted using the design of experiments suggested by Taguchi for reducing time and cost. Then Grey Relational analysis was applied to the experimental data to find out the optimal combination of the load and fuel by converting the multi response problem into the single response problem with the help of Grey Relational Grade. Signal to noise ratio is calculated for the Gray Relational Grade (GRG) and optimal combination is found. It is found that the experimental results almost coincided with validation results. The optimal combination was found to be 75% of load and MEME of 20% + 80% Diesel fuel.

Keywords: IDI engine; M.Elangi methyl ester blends; Taguchi; Grey relational analysis;

I. INTRODUCTION

Now a days usage of biodiesel in diesel engine has increased rapidly. In this study we are validating to what extent the usage of biodiesel is useful in running the diesel engine. But running engine with different fuels with different targets is difficult and a lot of experimentation is needed. To reduce that effort we have used Taguchi design for design of a set of experiments, but Taguchi evaluation on multi response is not more effective when we are calculating responses with different objectives. So, this study used grey relational analysis for optimization and found the optimal combination of the load and fuel. Ghaly et al. [1] reported that the research on the production of biodiesel has increased significantly in recent years because of the need for an alternative fuel which is endowed with biodegradability, low toxicity and renewability. Theansuwan et al [2] concluded that the biodiesel produced by transesterification showed similar properties to the standard diesel. Agarwal et al. [3] investigated that the process of transesterification is found to be an effective method of reducing viscosity of vegetable oil. Maulik A Modi, et al. [4] conducted an experiment to study palm seed oil blended with diesel used in a single cylinder diesel engine. Palm Seed oil is obtained from the seeds of the palm tree. In this study, the effects of parameters i.e. load, compression ratio and injection pressure are taken as variable for optimization. As the experiment required simultaneously optimization of three parameters with three levels, they studied Taguchi method optimization in this experiment. The results of the Taguchi experiment identify that 16 compression ratio, injection pressure 180 bars and engine load 10kg are optimum parameter setting for highest brake thermal efficiency

Sivaramakrishnan et al. [5] based on the results of their study said that the design of experiments was highly helpful to design the experiment and the statistical analysis helped to identify the signifi- cant parameters which are the most influencing on the performance emission characteristics. This experimental design considerably reduced the time required by minimizing the number of experiments to be performed and provided statistically proven models for all response. It is clear from this research that CO and HC emissions have been reduced when biodiesel is fuelled instead of diesel and also better BTHE with lesser BSFC with lower CO, HC and NOx values. Desirability approach of the RSM was found to be the simplest and effi- cient optimization technique. A high desirability was obtained at the optimum engine parameters of CR, fuel blend, and power, where the values of the BTHE, BSFC, CO, HC, and NOx were found to be 3.65%, 0.2718 kg/kW h, 0.109%, 158 and 938 ppm, respectively.Krunal B Patel, et al. [6] wascarried out an experiment to study pyrolysis oil blended with diesel used in single cylinder diesel engine. Pyrolysis oil is obtained from the tire waste by pyrolysis process. Blending of pyrolysis in maximum possible proportion helps to reduce the consumption of diesel fuel.T. VenkateswaraRao et al.[7] conducted experimental investigation on performance and emission characteristics of diesel engine fuelled with methyl esters of pongamia (PME), Jatropha (JME) and Neem (NME) oil and its blends with diesel. During investigation, they observed that engine performance and emissions with B20 (20% PME and 80% diesel) were closer to diesel. Hussain et al. [8] said that the Grey relational analysis based on an orthogonal array of the Taguchi method was a way of optimizing the process parameters in engine process. The optimum operating condition was obtained producing maximum performance of the engine. Sivaramakrishnan et al. [9] in their study used Taguchi's approach analysis for optimizing the performance of Karanja biodiesel on diesel engine. The various input parameters have been optimized using SNR. Based on this study, it can be concluded that BTHE, BSFC and Emissions of diesel engine depend upon biodiesel blend, compression ratio, nozzle pressure and injection timing. The results of this study revealed that almost identical combinations of engine parameters give optimum multiple performances for engine. It was found that a diesel engine fuelled with biodiesel has a better performance than fuelled with diesel. G. Antony Miraculas et al[10] they reported that the performance and emission characteristic of Calophyllum inophyllum oil-based methyl ester and its diesel blends are analyzed at various compression ratios. Comprehensive optimization by considering the performance parameter along with emission characteristic is rather involved and is done carefully with designed set of experiments and analyzed statistically using design expert software. Higher compression ratio (CR) induces high cylinder temperature which enhances vaporization and thereby better performance only to a certain extent, that is, up to a CR of 19. The designed empirical statistical model for optimum performance with lower emission is found to be B30 (30% biofuel) at a CR of 19, which is then tested and validated.Obed M. Ali [11] has reported the properties of B30 blended palm biodiesel-diesel fuel were measured and analyzed statistically with the addition of 2%, 4%, 6% and 8% (by volume) diethyl ether additive. The engine tests were conducted at increasing engine speeds from 1500 rpm to 3500 rpm and under constant load. Optimization of independent variables was performed using the desirability approach of the response surface methodology (RSM) with the goal of minimizing emissions and maximizing performance parameters. The experiments were designed using a statistical tool known as design of experiments (DoE) based on RSM. The aim of this study was to investigate the feasibility of using blended M.Elangi biodiesel-diesel fuel with various blending ratio like B10(MEME10+90D),B20(MEME20+80D),B30(MEME30+70D),B40 (MEME40+60D) and B100 (MEME100). The blended fuel properties were characterized according to the American society for testing and materials blended fuel standard ASTM D7467. The engine performance and exhaust emissions with blended fuel and mineral diesel as a baseline fuel were investigated and discussed. Taguchi method has been used for reducing time and cost. Then Grey Relational analysis was applied to the experimental data to find out the optimal combination of the load and fuel by converting the multi response problem into the single response problem with the help of Grey Relational Grade.

II.EXPERIMENTAL SETUP AND METHODOLOGY

The engine used is a single cylinder, four stroke, DI, air cooled, computerized Kirloskar make diesel engine. Figure 1 shows line diagram and the experimental setup.

Figure 1. Experimental setup

An eddy current dynamometer is attached to the engine for loading. Various sensors for measurement of cylinder pressure, fuel line pressure, exhaust gas temperature, fuel consumption, air consumption, crank angle and speed, etc. are attached to the engine at appropriate position. Signals from sensors are amplified, conditioned and used for evaluating various engine performance and combustion characteristics. A powder coated panel box with two fuel tanks, a fuel measuring burette, an air box with a mercury manometer, a dynamometer controller with display unit, etc. is attached to the engine.

In this present study the number of factors are 2 namely load and fuel and the number of levels are 5 i.e., B10(MEME10+90D),B20(MEME20+80D), B30(MEME30+70D), B40(MEME40+60D) and B100 (MEME100) Table 1 shows the levelsand factors.

A. General Regression Analysis: GRG versus LOAD, BTH, SFC, PRESSURE, HRR, ...

1) Regression Equation

FUEL

B10 GRG = 20.7216 + 0.00702151 LOAD + 0.00348982 BTH + 0.423391 SFC - 0.611225 PRESSURE + 0.00120718 HRR - 0.0795637 HC - 5.50627 CO- 0.0015255 NOX - 0.0134048 SMOKE - 0.00108342 EGT + 0.0386283 CO2 - 5.06918e-005 LOAD*LOAD + 0.000177181 BTH*BTH + 0.0247877 SFC*SFC + 0.00479146 PRESSURE*PRESSURE + 1.20731e-005 HRR*HRR + 0.00285161 HC*HC + 27.8198 CO*CO + 8.67542e-007 NOX*NOX + 0.000460399 SMOKE*SMOKE

B20 GRG = 20.6643 + 0.00702151 LOAD + 0.00348982 BTH + 0.423391 SFC - 0.611225 PRESSURE + 0.00120718 HRR - 0.0795637 HC - 5.50627 CO - 0.0015255 NOX - 0.0134048 SMOKE - 0.00108342 EGT + 0.0386283 CO2 - 5.06918e-005 LOAD*LOAD + 0.000177181 BTH*BTH + 0.0247877 SFC*SFC + 0.00479146 PRESSURE*PRESSURE + 1.20731e-005 HRR*HRR + 0.00285161 HC*HC + 27.8198 CO*CO + 8.67542e-007 NOX*NOX + 0.000460399 SMOKE*SMOKE

B30 GRG = 20.7425 + 0.00702151 LOAD + 0.00348982 BTH + 0.423391 SFC -0.611225 PRESSURE + 0.00120718 HRR - 0.0795637 HC - 5.50627 CO- 0.0015255 NOX - 0.0134048 SMOKE - 0.00108342 EGT + 0.0386283CO2 - 5.06918e-005 LOAD*LOAD + 0.000177181 BTH*BTH + 0.0247877 SFC*SFC + 0.00479146 PRESSURE*PRESSURE + 1.20731e-005 HRR*HRR + 0.00285161 HC*HC + 27.8198 CO*CO + 8.67542e-007 NOX*NOX + 0.000460399 SMOKE*SMOKE

B40 GRG = 20.7236 + 0.00702151 LOAD + 0.00348982 BTH + 0.423391 SFC - 0.611225 PRESSURE + 0.00120718 HRR - 0.0795637 HC - 5.50627 CO- 0.0015255 NOX - 0.0134048 SMOKE - 0.00108342 EGT + 0.0386283 CO2 - 5.06918e-005 LOAD*LOAD + 0.000177181 BTH*BTH + 0.0247877 SFC*SFC + 0.00479146 PRESSURE*PRESSURE + 1.20731e-005 HRR*HRR + 0.00285161 HC*HC + 27.8198 CO*CO + 8.67542e-007 NOX*NOX + 0.000460399 SMOKE*SMOKE

B100 GRG = 20.729 + 0.00702151 LOAD + 0.00348982 BTH + 0.423391 SFC - 0.611225 PRESSURE + 0.00120718 HRR - 0.0795637 HC - 5.50627 CO- 0.0015255 NOX - 0.0134048 SMOKE - 0.00108342 EGT + 0.0386283 CO2 - 5.06918e-005 LOAD*LOAD + 0.000177181 BTH*BTH + 0.0247877 SFC*SFC + 0.00479146 PRESSURE*PRESSURE + 1.20731e-005 HRR*HRR + 0.00285161 HC*HC + 27.8198 CO*CO + 8.67542e-007 NOX*NOX +0.000460399 SMOKE*SMOKE

Table 1 Setting levels for design parameters.

Factor	LEVELS				
	1	2	3	4	5
Load (%)	0	25	50	75	100
Fuel	B10+90D	B20+80D	B30+70D	B40+60D	B100

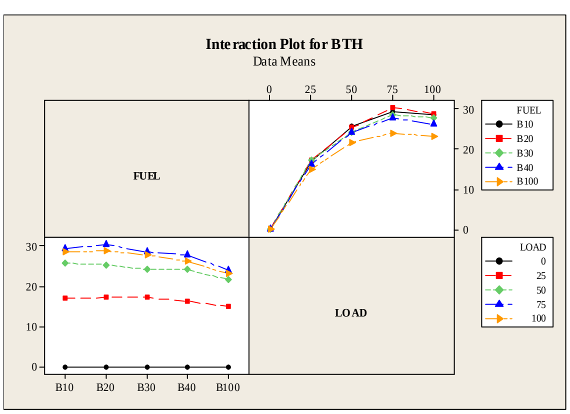

Figure 2. Load Vs BTH

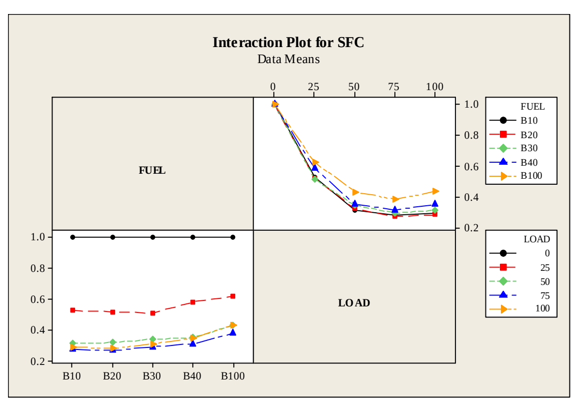

Figure 3. Load Vs SFC

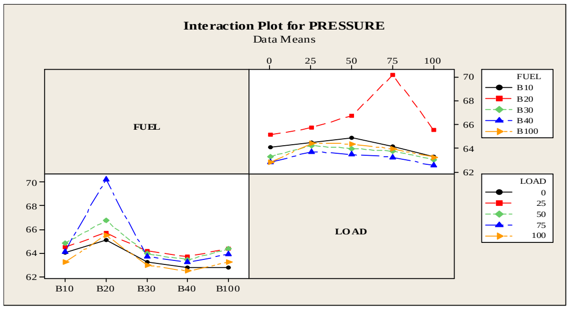

Figure 4.Load Vs Pressure

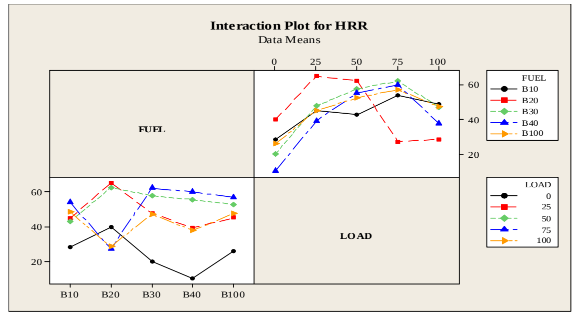

Figure 5.Load Vs Heat Release Rate

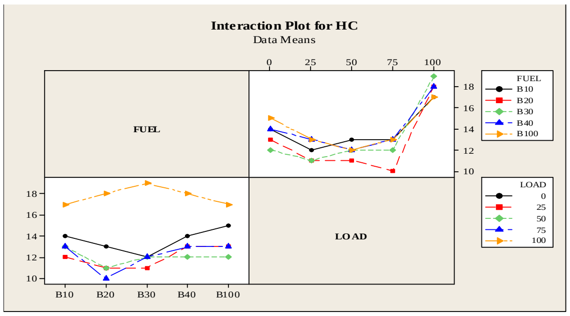

Figure 6.Load Vs HC emission

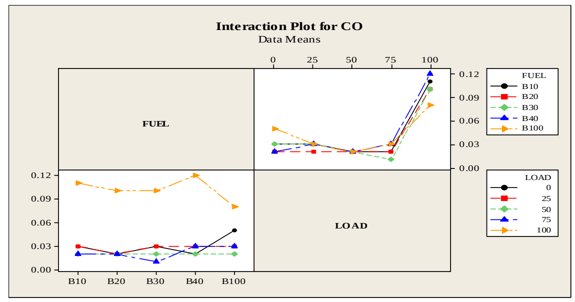

Figure 7.Load Vs CO emission

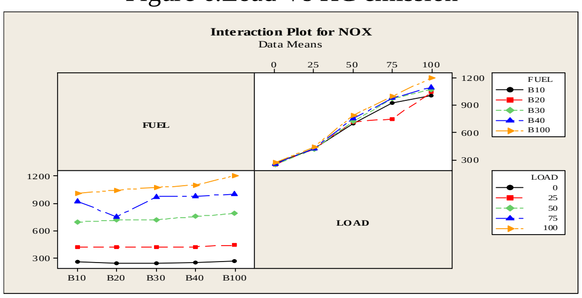

Figure 8.Load Vs NOx emission

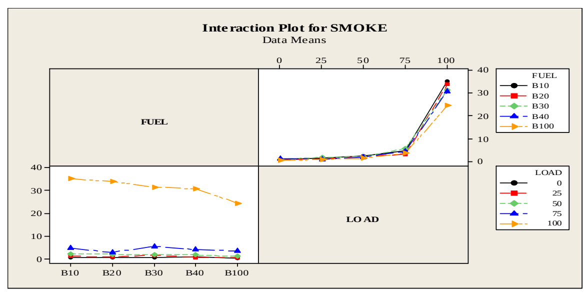

Figure 9.Load Vs Smoke emission

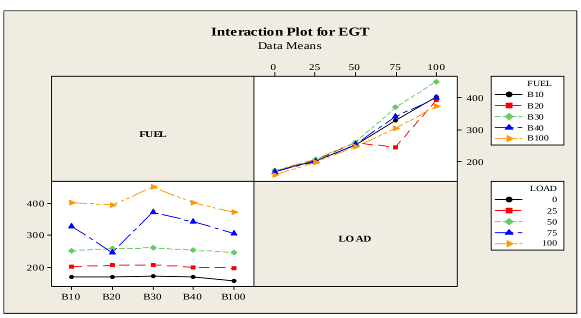

Figure 10.Load Vs EGT

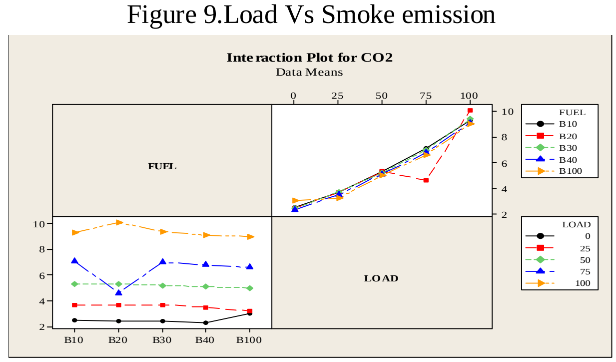

Figure 11.Load Vs CO_2 emission

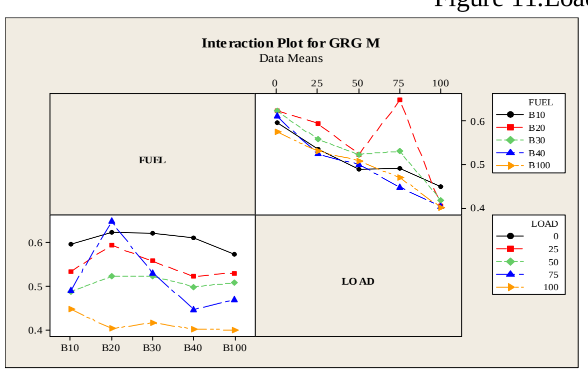

Figure 12.Load Vs GRG analysis

Table 2. Calculated grey relational coefficient and overall GRG

FUEL	LOAD	BTH	SFC	pressure	HRR	HC	CO	NOX	SMOKE	EGT	CO2	GRG
B10	0	0.333333	1	-0.28071	0.427709	0.571429	0.733333	0.969728	0.335893	0.91875	0.9511	0.596056
B10	25	0.533861	0.43605	-0.30852	0.576026	0.8	0.733334	0.733028	0.339806	0.769634	0.73535	0.534857
B10	50	0.76816	0.347558	-0.33698	0.552745	0.666667	0.846154	0.515282	0.346535	0.609959	0.564586	0.488066
B10	75	0.935862	0.335776	-0.28605	0.713524	0.666667	0.846154	0.413689	0.364659	0.462264	0.447641	0.490019
B10	100	0.89186	0.340139	-0.24004	0.62453	0.4	0.354839	0.384862	1	0.374046	0.357208	0.448745
B20	0	0.333333	1	-0.35999	0.520531	0.666667	0.846154	0.995855	0.336538	0.924528	0.974937	0.623855
B20	25	0.536314	0.430923	-0.43016	1	1	0.846154	0.733028	0.338491	0.753846	0.73535	0.594395
B20	50	0.752542	0.349881	-0.63705	0.912479	1	0.846154	0.503933	0.34585	0.592742	0.564586	0.523112
B20	75	1	0.333333	1	0.419657	0.8	0.846154	0.48609	0.351406	0.625532	0.628433	0.649061
B20	100	0.907324	0.337322	-0.40387	0.42821	0.363636	0.37931	0.374076	0.930851	0.382813	0.333333	0.4033
B30	0	0.333333	1	-0.2414	0.378735	0.8	0.733334	1	0.337187	0.913043	0.974937	0.622917
B30	25	0.536693	0.427904	-0.28959	0.612436	1	0.733334	0.735272	0.344488	0.746193	0.73535	0.558208
B30	50	0.708285	0.357038	-0.27529	0.79043	0.8	0.846154	0.501304	0.344488	0.588	0.572901	0.523331
B30	75	0.892962	0.340455	-0.263	0.903073	0.8	1	0.396616	0.37155	0.407202	0.452852	0.530171
B30	100	0.856135	0.3469	-0.2304	0.603646	0.333333	0.37931	0.365538	0.825472	0.333333	0.353958	0.416722
B40	0	0.333333	1	-0.22166	0.333333	0.571429	0.846154	0.985641	0.338491	0.93038	1	0.61171
B40	25	0.519247	0.465989	-0.26163	0.513022	0.666667	0.733334	0.726379	0.337187	0.773684	0.764244	0.523812
B40	50	0.711606	0.360551	-0.24991	0.740881	0.571429	0.846154	0.483644	0.343811	0.604938	0.581465	0.499457
B40	75	0.856135	0.3469	-0.23974	0.446573	0.666667	0.733334	0.394014	0.360825	0.442771	0.463647	0.447113
B40	100	0.785252	0.359138	-0.21235	0.501014	0.363636	0.333333	0.358984	0.795455	0.375959	0.363891	0.402431
B100	0	0.333333	1	-0.22231	0.412188	0.5	0.578947	0.96004	0.333333	1	0.847495	0.574302
B100	25	0.497459	0.490958	-0.30306	0.579141	0.666667	0.733334	0.70818	0.336538	0.786096	0.812109	0.530742
B100	50	0.634804	0.390933	-0.29965	0.687735	0.8	0.846154	0.467185	0.339806	0.622881	0.590288	0.508014
B100	75	0.70657	0.371177	-0.27335	0.772481	0.666667	0.733334	0.387656	0.355691	0.498305	0.474969	0.46935
B100	100	0.677002	0.391351	-0.23991	0.60778	0.4	0.44	0.333333	0.620567	0.404959	0.367328	0.400241

III. RESULTS AND DISCUSSIONS

Experimental Data Using Taguchi Method; Analysis for Grey Relational Grade (GRG) Response curve analysis is aimed at determining influential parameters and their optimum levels. It is a graphical representation of change in performance characteristics with the variation in process parameter. The curve gives a pictorial view of variation of each factor and describes what the effect on the system performance would be when a parameter shifts from one level to another.

Figure 2.represents the brake thermal efficiency with varying load.The results shows that for B20 at 75% load gave the optimum value. The brake thermal efficiency was greater for B20 when compared to that of remaining blends.

Figure 3.represents the brake specific fuel consumption with varying load.The results shows that for B20 at 75% load gave the lower BSFC value. The brake thermal efficiency was lower for B20 when compared to that of remaining blends.

Figure 4 and Figure 5.represents the pressure and heat release rate with varying load.The results shows that for B20 at 75% load gave the max pressure and heat release rate. when compared to that of remaining blends.

Figure 6 to Figure 11 represents the emission maginitude of HC,CO,NOx,Smoke, EGT.CO2,with varying load. The results shows that for B20 at 75% load gave the reduction of emission magnitude when compared to that of remaining blends.

Figure 12.represents the GRG analysis with varying load.The results shows that for B20 at 75% load gave the optimum value for both fuel and laod paprameters when compared to that of remaining blends.

IV. CONCLUSIONS

From this study it is seen that biodiesel is going to be the natural choice for our future transport fuel, agricultural and industrial purpose. From the above study the response parameter i.e., Brake Thermal Efficiency,BSFC combustion analysis and emission magnitude are optimized using Taguchi's methodology to analyse the experimental data. In this particular combination it is predicted from the experimental data that the engine performance is comparable to that of diesel. That means from the used blends of biodiesel and diesel, the B20 blend at 200 bar pressure and 23^obTDC was found to be most suitable blend for use in the diesel engine without any engine modification.

And finally it can be concluded that the biodiesel can be used in a diesel engine without any engine modifications. And from our experimental view, the best blend is the B20 blend where the engine performance is comparable to that of diesel.

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