The Journal of Engine Research

Journal Homepage: www.engineresearch.ir

An experimental study of pre-main injection strategy to optimize TDI diesel engine

A. Yousefzadeh[1*], M. Monfaredi[2], R. Nabavi[3], M. Pourfalah[4], S.M. Mirsalim[5]

[1] *Iran Heavy Diesel MFG Co. (DESA), Amol, Iran,* a.yousefzadeh@desa.ir
[2] *Iran Heavy Diesel MFG Co. (DESA), Amol, Iran,* m.monfaredi@desa.ir
[3] *Iran Heavy Diesel MFG Co. (DESA), Amol, Iran,* r.nabavi@desa.ir
[4] *Iran Heavy Diesel MFG Co. (DESA), Amol, Iran,* m.pourfallah@desa.ir
[5] *Amirkabir University of Technology, Tehran, Iran,* mirsalim@csr.ir
**Corresponding Author*

ARTICLE INFO

Article history:
Received: 20 December 2015
Accepted: 17 February 2016

Keywords:
Diesel
Pre-injection
Soot
BSFC
Peak pressure

ABSTRACT

Reducing emissions and fuel consumption have always been a major concern of engine manufacturers. In recent years, strict emission laws and fast reduction of fossil fuel resources have increased this concern. Main purpose of this work is to optimize D87 diesel engine with consideration of parameters such as amount of soot emission, BSFC and maximum pressure of combustion chamber. Effect of pre injection on engine performance has been investigated experimentally. Test is done for four different load points in constant maximum speed which at each load point 3 up to 7 percent of total fuel mass is considered in pilot injection. Results show that BSFC is decreased with increasing of pre injected fuel. From the other side soot emission and maximum pressure of combustion chamber are increased by increasing of pre injected fuel, but both of them are still in an acceptable level so the optimum point is selected based on the minimum BSFC. In all cases minimum BSFC is reached by considering 7 percent of total fuel mass in pre injection which the minimum amount of BSFC is about 194 g/kW.h at 1000 kW.

1) Introduction

Nowadays, heavy duty Diesel Engines are the main sources of electrical power generation and marine propulsion as well as power generation required for rail traction. Similar to other combustion engines, these engines are the main sources of greenhouse gases and other pollutant emissions like NOx and PM. The higher thermal efficiency of the diesel engine is the most important key for the market economy and reduction in amount of greenhouse gases, but higher thermal efficiency results in higher amount of NOx emission. On the other hand, the environmental regulations against diesel engines are becoming tighter year after year and these engines require further development to meet future standards for gaseous and particulate exhaust emissions [1].

A present conventional engine suffers from high degree of exhaust emissions temperature, low specific power output and relatively high combustion noise [2]. There are several solutions that have been implemented in recent years to achieve this goal. In-cylinder soot reduction techniques remain attractive to reduce or eliminate the aftertreatment usage. One of the commonly method used to reduce in-cylinder soot is the use of post injection. A post injection is a shorter injection that follows the main fuel injection. Post injections have been used for a variety of reasons, including management of exhaust aftertreatment and reduction of unburned hydrocarbons at low temperature combustion conditions [3]. Chryssakis et al studied the effect of multiple injections on combustion process and emissions of a DI diesel engine by using the multidimensional code KIVAIII. The results indicated that employing a post-injection combined with a pilot injection results in soot formation reduction while the NOx concentration is maintained at low levels [4]. Ghodke and Suryawanshi Used engine simulation software tool which has predicted soot and NO_X emissions. Soot and NO_X emissions have been reduced simultaneously with little penalty of fuel consumption when post pilot injection was applied. Post-injection helped in maintaining the temperature of combustion gases at a level that they can burn the later part of soot and release the heat. The increase in post-injection quantity resulted in simultaneously reduction of soot and NOx emission [5]. Benajes and Molina et al has been studied the influence of pre and post-injection on the development of the combustion process, engine efficiency and pollutant emissions. It has been proved that it's possible to reduce fuel consumption with little soot penalty by pre-injection strategy but causing an increase in NOx levels in most engine modes. Beside it, reductions of soot emission without NOx emission and fuel consumption penalty have been proved by post-injection [6, 7]. The mechanisms of soot and NOx emission reduction investigated numerically with the KIVA-II code by Han et al. multiple injection combustion predictions were obtained by a RNG k-ε turbulence model. Multiple injections break the soot-producing rich regions at the spray tip which the result is leaner combustion during the next injections. It was found that NOx reduction with multiple injections is similar to retarded single injection [8].

M. Badami, F. Millo et al. has investigated the effect of pilot injection characteristic. Results showed when the combustion energy of the pilot injection was increased with higher quantities, pressure and temperature of the combustion chamber had increased before the main injection, which it has produced higher NOx emission As well as soot increasing and combustion noise decreasing [2]. T. Thurnheer et al have investigated multiple injection strategy on six cylinder heavy duty diesel. Results show fuel conversion efficiency is decreased with advancing pilot injection as well as NOx emissions are increased with pilot injection [9]. Paolo Carlucci et al have investigated the influence of main injection timing, pilot injection timing and duration, on engine combustion and noise experimentally. Pilot timing exerts a clear influence on noise level only for idling conditions, while for the other tests the influence is less meaningful. For some tests conditions, the pilot timing does not have a significant effect on the ignition delay of the main injection. The analysis showed that the main injection timing and the energizing time of the pilot injection appear to be the most meaningful parameters, as previously seen, for the noise and the vibration level, the influence of the pilot injection timing is less meaningful [10].

Showry and Rajo carried out the effect of triple injection on combustion and pollution of DI diesel engine by FLUENT CFD code which has shown 10° is an optimum delay between the injection pulses for triple injection strategy. It has proved that split injections reduced PM without increasing of NOx level [11]. Jafarmadar and Zehni studied the effect of split injection on combustion and pollution of a DI diesel engine by Computational Fluid Dynamics (CFD) code. The results show that 25% of total fuel injected in the second pulse, reduces the total soot and NOx emissions effectively in DI diesel engines. In addition, the optimum delay between the two injection pulses was about 25ºCA [12]. Bianchi, et al investigated the capability of split injection in reducing NOx and soot emissions Of HSDI Diesel engines by CFD code KIVA-III. Computational results indicated that split injection is Very effective in reducing NOx, while soot reduction is related to a better use of the oxygen Available in the combustion chamber [13]. Patterson, et al used the KIVA-II to study the effect of injection timing, injection pressure and split injection on emissions for a fast rising injection profile. The results showed that to compare single injection and split injection, an additional high temperature region is observed between the Separate spray clouds with split injection, this promotes local NOx formation while enhancing soot oxidation [14]. Ikegami demonstrated that the fuel injection rate has a significant influence on determining the quality of exhaust emissions. The results showed that reduction of initial injection rate and pilot injection lowered both of the exhaust NOx concentration and the noise emission that smoke is significantly reduced by increasing the average injection rate [15].

This investigation to previous works has clarified that multiple injection strategy is known as a significant key to optimize diesel engines in fuel consumption, exhaust emissions and noise emission (peak pressure and rate of pressure). According to this results performance team of D87 has decided to use this strategy to optimize engine performance step by step. This article includes just investigation of pre-injection strategy to optimize specific fuel consumption (BSFC), peak pressure and soot emission. This work was done experimentally on 12 cylinder D87 engine in DESA company test setup.

2) Experimental setup

D87 is a 4 stroke 12 cylinders Turbocharged heavy duty diesel engine with common rail fuel system. Error! Reference source not found. shows a schematic of the engine setup in Test cell.

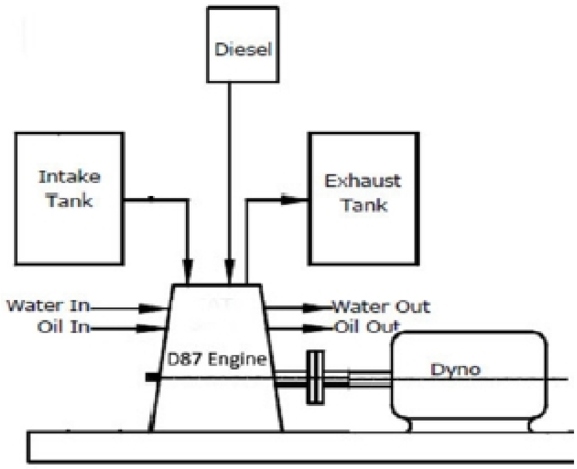

Figure 1: Schematic of the engine setup in test cell

The engine was coupled to a water brake dynamometer and the experiments were carried out at different load points in 1500 rpm constant speed. Engine specification is given in
Table 1 and Figure 2 shows D87 engine in test cell.

Table 1: Engine specification

Engine Max speed	1500 rpm
Bore × stroke	150×180 mm
Engine Max Power	1000 kw
Compression ratio	15:1
Fuel system	Common-rail
Number of nozzle holes	8

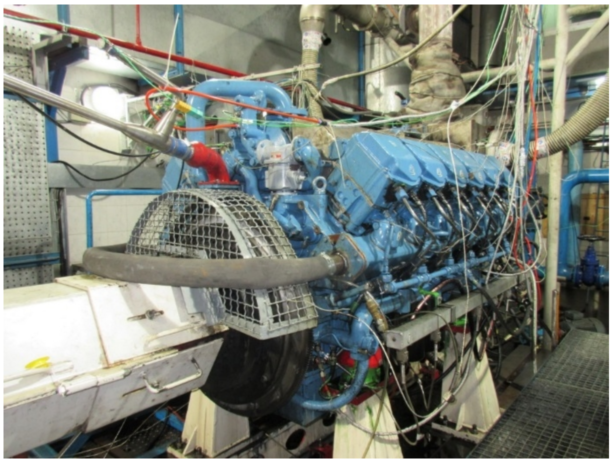

Figure 2: D87 Diesel engine in test cell

Table 2: Load points

	Speed (rpm)	Power (KW)	Pr%(Pre mass quantity percent)
1	1500	1000	7
2	1500	1000	6
3	1500	1000	5
4	1500	1000	4
5	1500	1000	3
6	1500	750	7
7	1500	750	6
8	1500	750	5
9	1500	750	4
10	1500	750	3
11	1500	500	7
12	1500	500	6
13	1500	500	5
14	1500	500	4
15	1500	500	3
16	1500	250	7
17	1500	250	6
18	1500	250	5
19	1500	250	4
20	1500	250	3

3) Results and discussion

In this part effect of pre injection mass quantity has been investigated on three parameters like BSFC, Soot emission and Peak pressure in different load points in constant speed 1500 rpm.

Table 1 shows 20 cases for 25%, 50%, 75% and 100% of maximum power. In each load point Pr% varies from 3-7% of total mass injected.

In this work PrDelay (Delay of PrSOI and mSOI) is fixed 10 CAD (crank angle degree) and mSOI which is known as main start of injection is fixed in 16 degree BTDCF. Pressure of combustion chamber and rate of pressure raise for different amount of pre injection are shown in Figure 3Figure 4 respectively for 1000 kw and 750 kW.

As illustrated in figures, because start of pre and main injection is fixed during the test the maximum of pressure raise rate occurs in the same time for different cases and furthermore by increasing the amount of pre, rate of pressure raise in pre step is increased and in main step is decreased. It should be noted that the maximum of pressure raise for 5,6 and 7% occurs in pre step and for 4 and 3% occurs in main step. Maximum of pressure raise rate is shown in Error! Reference source not found. for 1000 and 750 kW.

In Figure 5 maximum pressures of combustion chamber have been shown. It's obvious that maximum pressure increases when quantity of pre injection increased. The maximum pressure occurs in 1000kw with 7% pre injection which is about 166bar and doesn't pass 180 bar limitation then it is acceptable. Furthermore soot emission has been measured with AVL Smoke meter. According to Figure 6 soot values are shown in two different units to compare these values to the euro standard emissions. According to the Figure 6 it's seen except two cases in other points soot emission is increased in higher quantity of pre injection values.

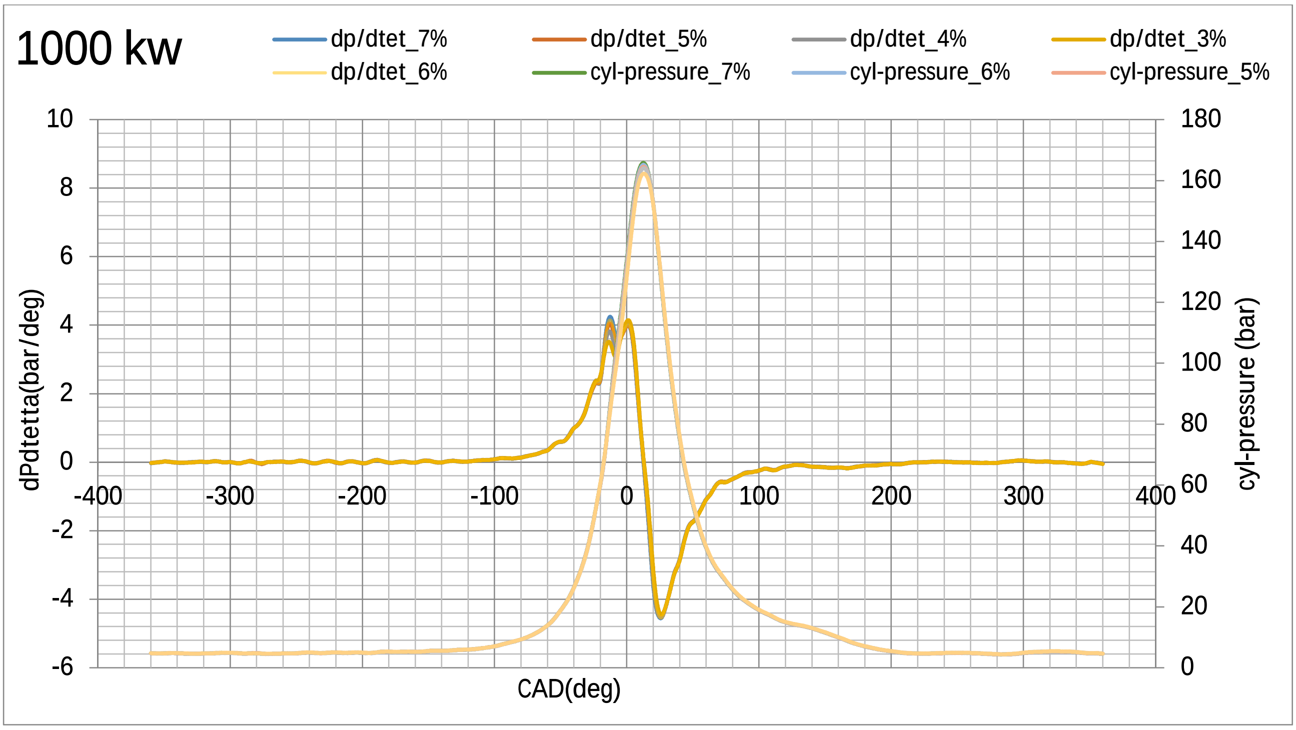

Figure 3: Cylinder pressure and pressure rise rate at 1000 kW

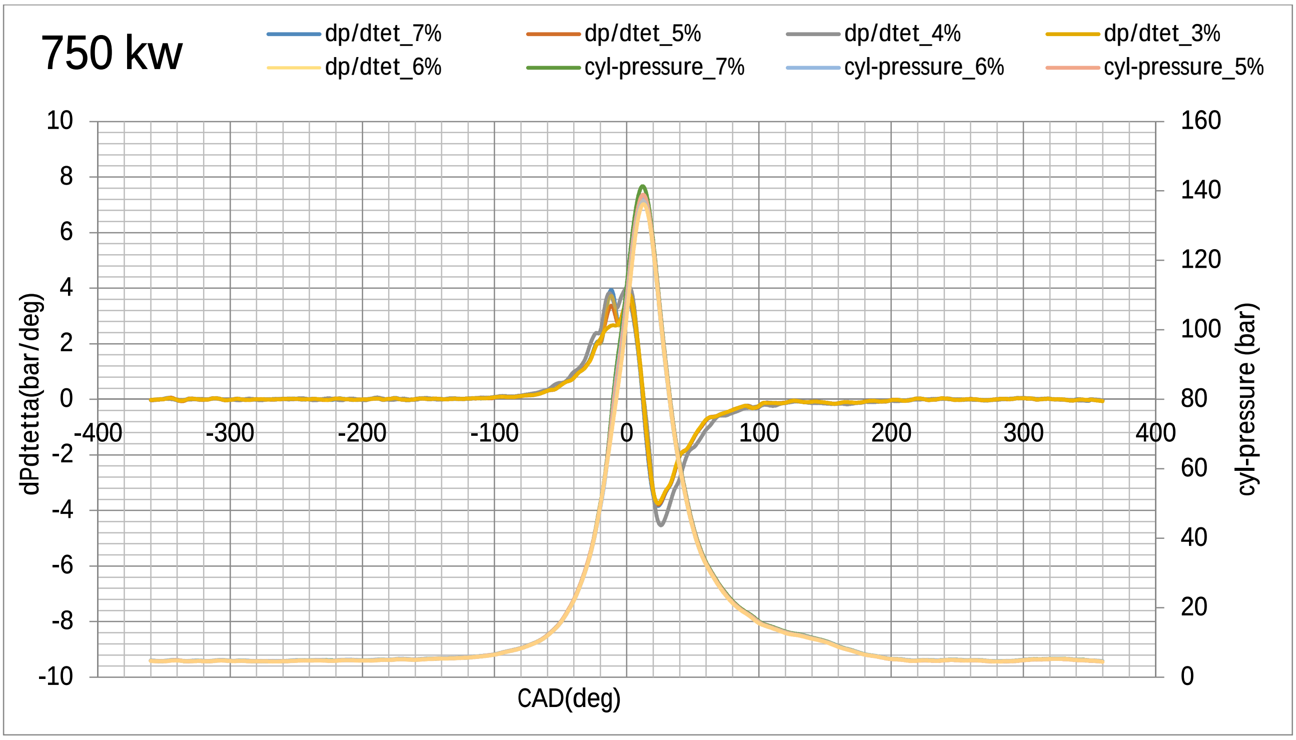

Figure 4: Cylinder pressure and pressure raise rate at 750 kW

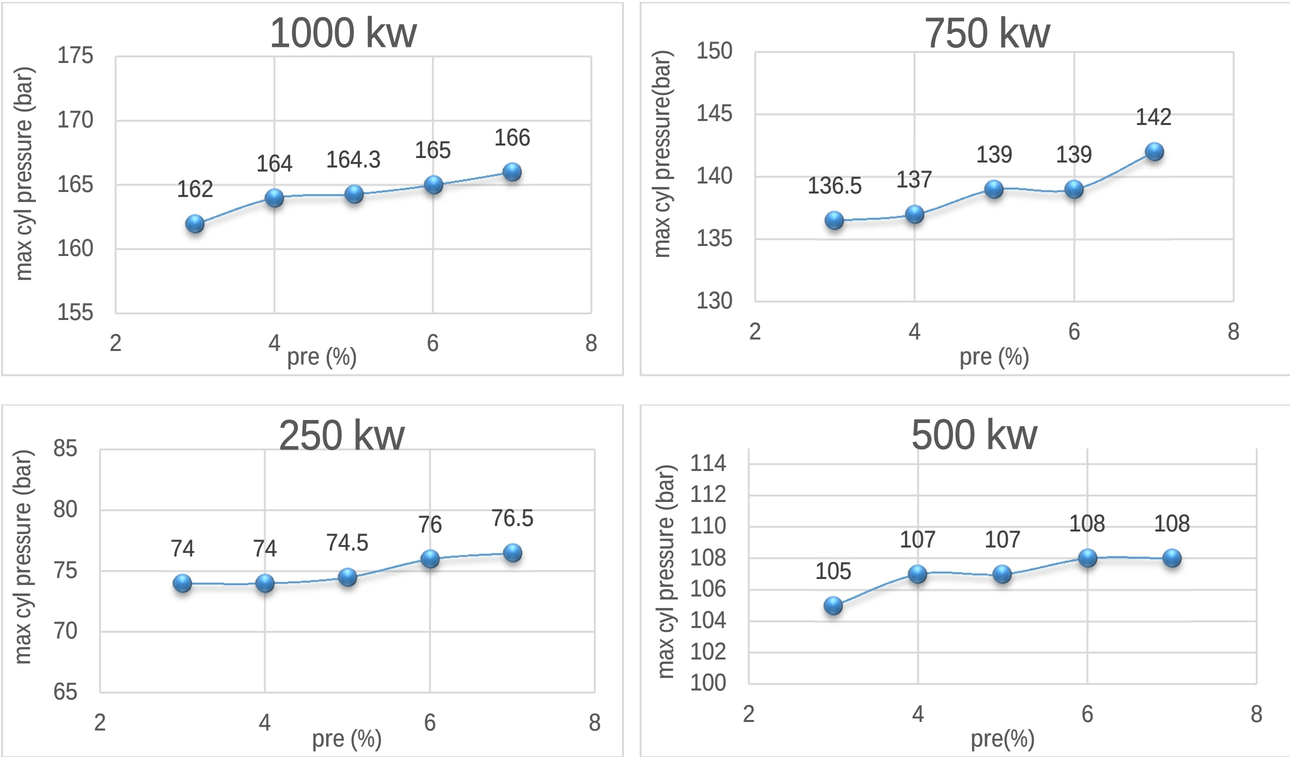

Figure 5: Maximum pressure of combustion chamber-different load points

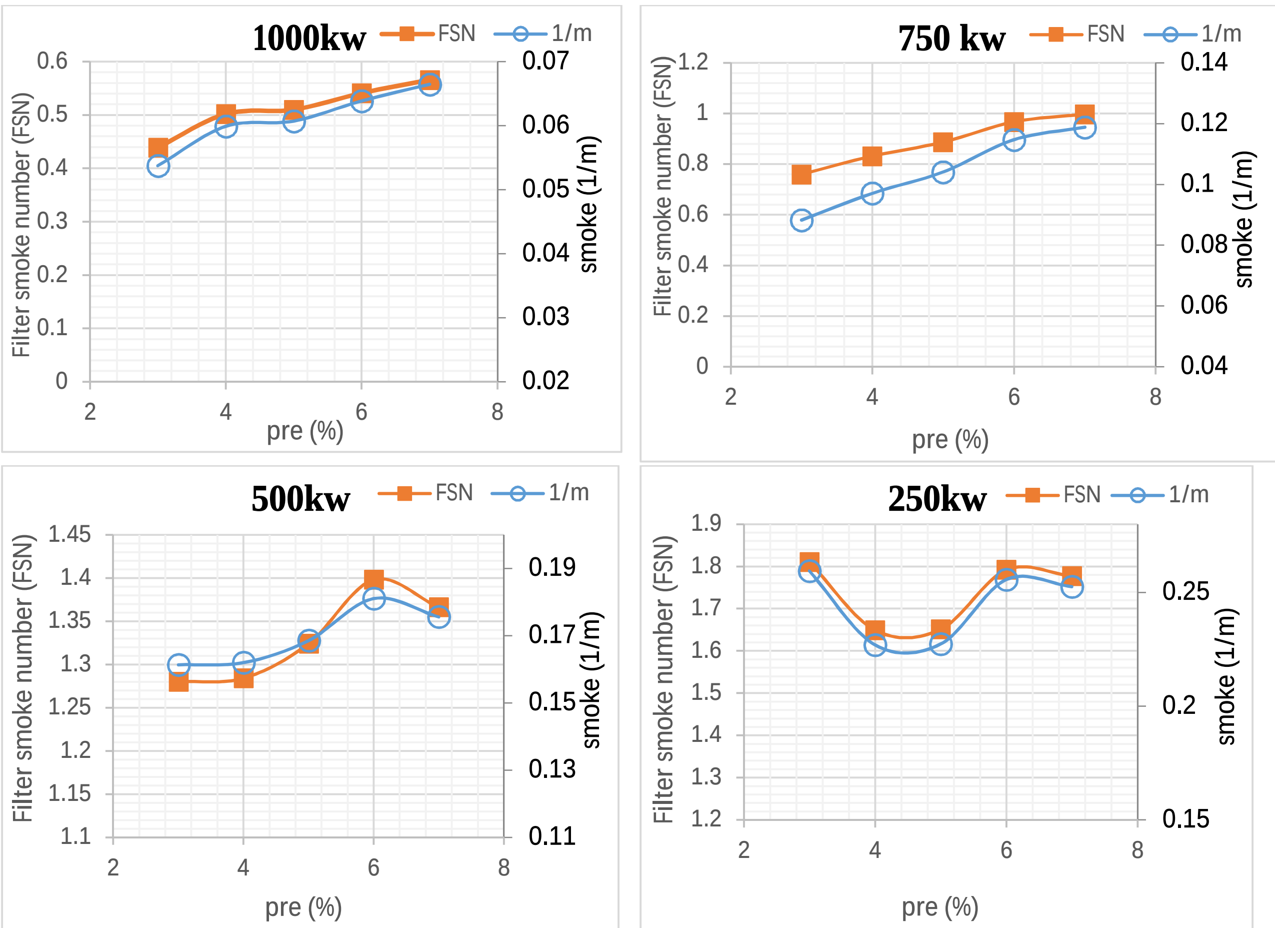

Figure 6: Soot emission values-different load points

This result has been reported in previous works and it was expected that pre injection has negative effect on soot emission but the results show soot emission value is under euro 4 and euro 5 limitation [16]. Although because of AFR decreasing in lower load points, soot emission is increased.

After investigating maximum pressure of combustion chamber and soot emission, this result has been earned that both of these parameters increased with Pr injection enhancement but both of them were acceptable. Then the optimum point is chosen according to least fuel consumption. Figure 7 shows BSFC against Pr% in different load points that as it was expected fuel consumption is reduced in higher pre injection values.

Then according to previous description 7% pre injection is chosen as optimum point for all load points.

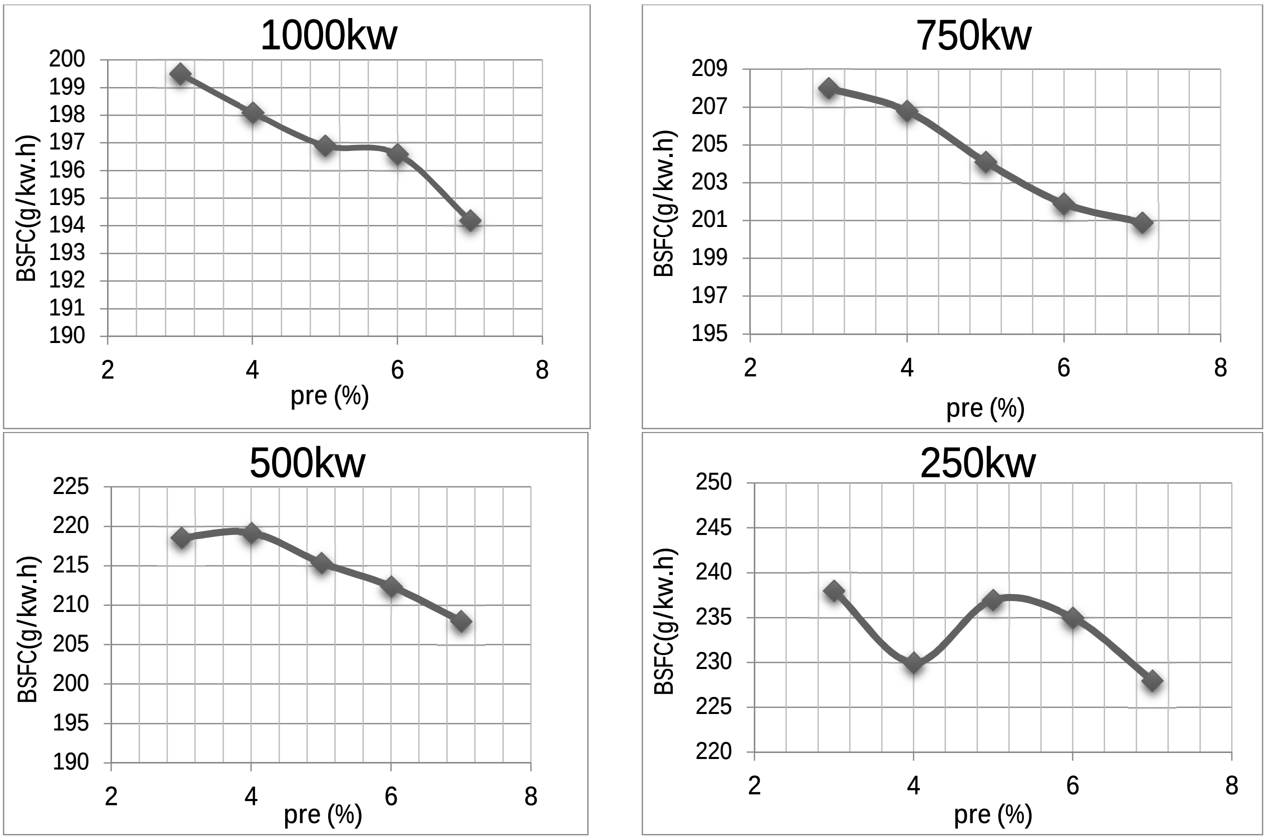

Figure 7-BSFC values-different load points

4) Conclusion

In this study 3 up to 7% of total mass fuel injected in each load points are considered in pre injection step which the results show soot emission and peak pressure of combustion increase with higher amount of Pr% but they are acceptable then optimum point is chosen according to least fuel consumption that Pr 7% with 194.2 g/kWh is announced for all the load points.

References

[1] J. Hlousek, M. Bernhaupt, B. Kogler, Electronically controlled injection rate shaping for medium speed diesel engines. In23th CIMAC Congress, 2001

[2] N.M. Bhatt, P.P. Rathod, A.S. Sorathiya, R. Patel, Effect Of Multiple Injections On The Performance And Emission Of Diesel Engine-A Review Study.

[3] O. Connor, M. Musculus, Post injections for soot reduction in diesel engines: A review of current understanding. No. 2013-01-0917. SAE Technical Paper, 2013

[4] S. Jafarmadar, The Effect of Split Injection on the Combustion and Emissions in DI and IDI Diesel Engines, 2013

[5] P.R. Ghodke, J.G. Suryawanshi, Investigation of multi-cylinder diesel engine to meet future indian emission norms. IJST. May 1; 38(M1):239-52, 2014

[6] J.M. Desantes, J. Benajes, S. Molina, CA. González The modification of the fuel injection rate in heavy-duty diesel engines: part 2: effects on combustion. Applied thermal engineering. 2004 Dec 31; 24(17):2715-26, 2004

[7] J.M. Desantes, J. Benajes, S. Molina, CA. Gonzalez, The modification of the fuel injection rate in heavy-duty diesel engines. Part 1: Effects on engine performance and emissions. Applied Thermal Engineering. 2004 Dec 31; 24(17):2701-14, 2004

[8] Z. Han, A. Uludogan, G.J. Hampson, R.D. Reitz Mechanism of soot and NOx emission reduction using multiple-injection in a diesel engine. SAE Technical Paper, 1996

[9] T. Thurnheer, , et al. Experimental investigation on different injection strategies in a heavy-duty diesel engine: emissions and loss analysis, Energy Conversion and Management 52.1 (2011): 457-467.

[10]P. Carlucci, A. Ficarella, D. Laforgia, Pilot injection behavior and its effects on combustion in a common rail diesel engine, International Workshop on Modeling, Emissions and Control in Automotive Engines MECA 2001 (Vol. 1, pp. 9-10), 2001

[11] K. Showry, A. Raju, Multi-dimensional modeling and simulation of diesel engine combustion using multi-pulse injections by CFD. International Journal of Dynamics of Fluids. 2010; 6(2):237-48, 2010

[12] Jafarmadar S, Zehni A. Multi-dimensional modeling of the effects of split injection scheme on combustion and emissions of direct-injection diesel engines at full load state. Iranian Journal of Engineering, 22(4), 2009

[13] G. M. Bianchi, P. Pelloni, F. E. Corcione, and F. Luppino. Numerical analysis of passenger car HSDI diesel engines with the 2nd generation of common rail injection systems: the effect of multiple injections on emissions. No. 2001-01-1068. SAE Technical Paper, 2001.

[14] M.A. Patterson, S.C. Kong, G.J. Hampson and R.D. Reitz, Modeling the effects of fuel injection characteristics on diesel engine soot and NOx emissions (No. 940523), SAE Technical Paper, 1994

[15] M. Ikegami, K. Nakatani, S. Tanaka and K. Yamane, Fuel injection rate shaping and its effect on exhaust emissions in a direct-injection diesel engine using a spool acceleration type injection system (No. 970347). SAE Technical Paper, 1997

[16]http://www.dieselnet.com/standards/eu/

فصلنامهٔ علمی - پژوهشی تحقیقات موتور
تارنمای فصلنامه: www.engineresearch.ir

مطالعه تجربی پیش پاششِ به همراه مرحله اصلی پاشش جهت بهینه‌سازی موتور پاشش مستقیم دیزلی

علی یوسف‌زاده[1*]، مرتضی منفردی[2]، عبدالرضا نبوی[3]، محسن پورفلاح[4]، سید مصطفی میرسلیم[5]

[1] شرکت دیزل سنگین ایران، آمل، ایران a.yousefzadeh@desa.ir
[2] شرکت دیزل سنگین ایران، آمل، ایران m.monfaredi@desa.ir
[3] شرکت دیزل سنگین ایران، آمل، ایران r.nabavi@desa.ir
[4] شرکت دیزل سنگین ایران، آمل، ایران m.pourfallah@desa.ir
[5] دانشگاه صنعتی امیرکبیر، تهران، ایران mirsalim@csr.ir
[*] نویسندهٔ مسئول

چکیده

کاهش آلاینده‌ها و مصرف سوخت همواره دغدغه اصلی تولیدکنندگان موتورهای احتراق داخلی بوده است. در سال‌های اخیر با کاهش منابع سوخت فسیلی و اعمال مقررات سختگیرانه آلایندگی این دغدغه بیشتر شده است. هدف اصلی این تحقیق، بهینه‌سازی موتور ملی دیزل سنگین د87 از لحاظ مصرف سوخت، آلاینده دوده و بیشینه فشار محفظه احتراق می‌باشد. استفاده از پیش‌پاشش در کنار مرحله اصلی پاشش به عنوان راهکار مدنظر قرار گرفته است. آزمون در چهار نقطه بارگذاری در سرعت ثابت 1500 دور بر دقیقه انجام شد که در هر نقطه از بارگذاری درصد جرم پیش‌پاشش به عنوان 3-7% از جرم کل سوخت پاشش شده در نظر گرفته شد. نتایج نشان از کاهش مصرف سوخت در اثر افزایش مقدار پیش‌پاشش می‌دهد در حالیکه از طرف دیگر مقدار دوده و بیشینه فشار با افزایش مقدار پیش‌پاشش افزایش یافت، اما به این دلیل که هر دو پارامتر آلاینده دوده و بیشینه فشار در محدوده امن قرار دارند و از مقادیر هدف خود تجاوز نکرده‌اند. مبنای انتخاب نقطه بهینه براساس کمترین میزان مصرف سوخت می‌باشد. بر همین اساس در تمامی نقاط کمترین میزان BSFC در حالت پیش پاشش 7% بدست آمد که در توان نهایی 1000 کیلووات، مقدار مصرف سوخت ویژه به 194g/kW.h رسیده است.

اطلاعات مقاله

تاریخچهٔ مقاله:
دریافت: 30 آذر 1394
پذیرش: 29 بهمن 1394

کلیدواژه‌ها:
دیزل
پیش پاشش
دوده
مصرف سوخت ویژه
بیشینه فشار