Effect of dust and sulfur content on the rate of wear of diesel engines working in the Jordanian desert

Ammar A. Al-Rousan
Mechanical Eng. Dept., Faculty of Eng., Mu'tah University, Al-Karak 61710, Jordan
E-mail: alrousana@yahoo.com

The service life of vehicles engines depends significantly on the environmental conditions at which they work. If these engines work in very hostile conditions (such as a dusty environment), this will shorten the engine's service life due to the wear problem of the sliding parts of the engine and consequently the combustion process will be adversely affected as well and the possibility of forming combustion products that might mix with the lubricating oil cause corrosive wear of engine bores due to the formation of sulfuric acid. In this work, the Jordanian environmental conditions which have a very dusty desert (100% silica dust) was studied in detail. Various amounts of sulfur were added to the fuel to study the effect of the combustion products on engine corrosion. The results show that these conditions have a considerable effect on increasing the wear rate of cylinder bore and piston-rings, which agree in behavior to that reported in literature while differ in magnitudes.

يعتمد عمرالخدمه لمحرّكات الاحتراق الداخلي إلى حدّ كبير على الظروف البيئية التي تعمل فيها هذه المحركات. فاذا كانت تعمل في الظروف شديدة القسوه مثل البيئة الغبراء، فان هذا سيقصّر من عمر الخدمة للمحرّك بسبب مشكلة بلى الأجزاء المنزلقة الداخليه وبالتالي فأن عملية الإحتراق قد تكون قاصره ونتيجه لذلك تتكون منتجات احتراق بنسب حامضية مع زيت تزليق المحرك (sulfuric)مما يسبب بلى كيميائياً(corrosion wear) للاجزاء المنزلقة داخل المحرّك. في هذا البحث اجريت دراسة تفصيلية لتأثير البيئة الصحراوية القاسيه في الاردن (١٠٠ % غبار سيليكا) على بلى الأجزاء المنزلقة للمحـــرّك (cylinder and piston-rings) كما تم ايضا اضافة كميات مختلفة من الكبريت (sulfur) إلى وقود المحرك لدراسة البلى الكيميائي الناتج عن نواتج الإحتراق. ولقد اظهرت النتائج بأنّ لهذه الظروف البيئية في الاردن تأثيرا كبيراً على معدل بلى الأجزاء المنزلقة للمحرّك (cylinder and piston-rings) والتي تختلف بمعدلات كبيرة عن الدراسات التي قام بها باحثون اخرون في ظروف بيئية تختلف كليا عن بيئة الأردن.

Keywords: Diesel engine, Dust particles, Wear, Corrosion, Sulfur content

1. Introduction

The improvement of engine efficiency has been of great concern to automotive engineers. The development of new oil additives and the introduction of new techniques of surface treatment lead up in reducing friction losses and wear problems [1, 2]. This friction and wear is caused by particles getting into the system as contaminants, or generated within the system as wear-causing particles. The dust is considered as one of the main sources of these particles which mostly contain silica because silicates make up 80% of the earth's crust [3, 4]. Silica particles are harder than the engine structural materials.

These hard particles erode the sliding surfaces of the engine. In an engine, the aggressive of atmospheric dust takes place primarily through the air intake, despite of using filters in internal combustion engines, efficiency of air filters remove 98-99% of the dust that an engine intakes. The remaining 1-2% (with less than 30 μm) passes through the air filter [5]. The dust will pass between the piston-rings and cylinder liner and eventually becomes suspended in the lubricating oil. Furthermore, some of the dust particles pass to the crankcase causing some scratching of the surface of the lubricated parts.

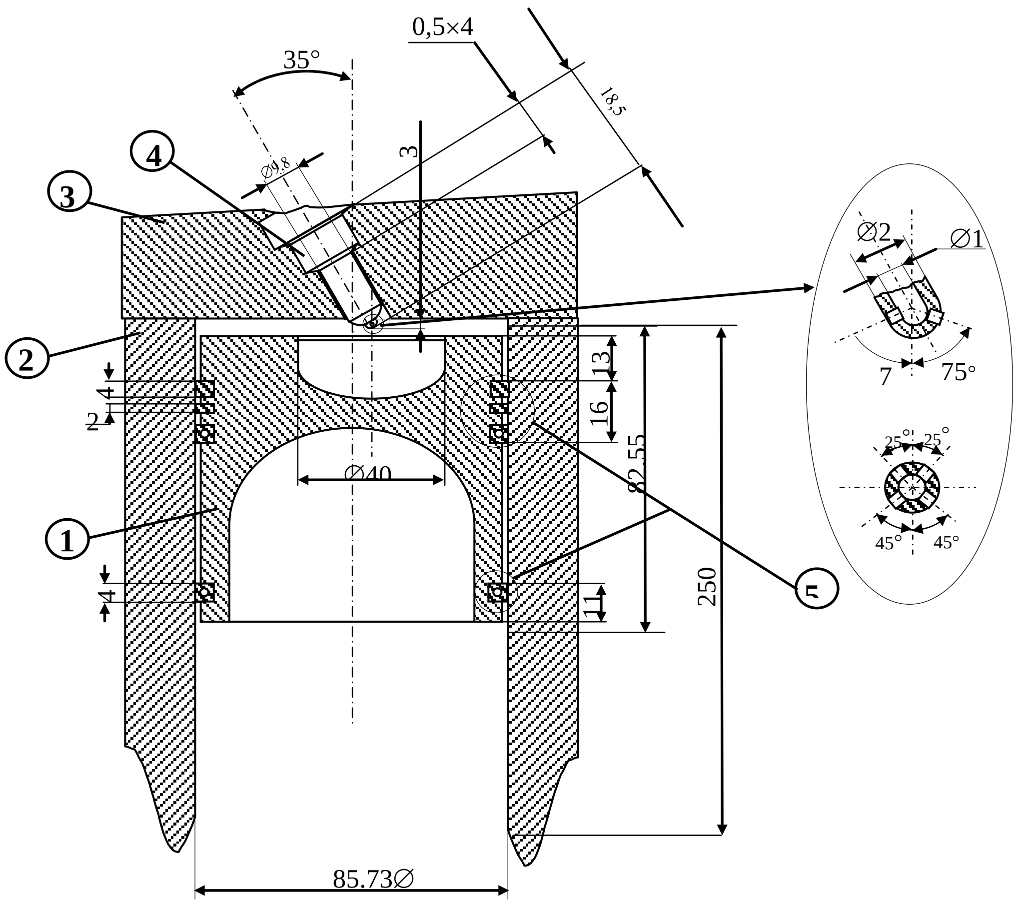
For example, if the dust particles in air are in the range between 0.7 to 1.2 g/m3, this means that 6-23 mg of dust particle enter into the cylinder [5]. Previous studies showed that every 1 gm from the dust entered the cylinder increased the cylinder diameter by 0.01 mm and so increasing the specific fuel consumption by 0.5 % [6].

The other problem of the lubrication in diesel engines is the corrosive wear of piston-rings and cylinder bores caused by sulfuric acid. This type of corrosive wear is known to increase during low-temperature engine operation and when exhaust gas recirculation is used [7]. The high ratio of dust in Jordanian air (100% silica) is considerably high due to wide desert which covers about 91% of Jordan. This leads to high wear in vehicles. Therefore, in this work the experimental studies have been carried out to investigate the wear in cylinder bore and piston-rings of diesel engines caused by dust and combustion products (sulfur) which represent typical working conditions in the Jordanian environment.

2. Experimental details

2.1. The experimental rig

The main part of the experimental rig, which was used in this study, is the Lister LV1 single cylinder air cooled direct injection diesel engine, the sectional view of this engine is shown in fig. 1. The dimensions and other specifications of the engine are shown in table 1.



Where:
1. Piston
2. Cylinder
3. The head of cylinder
4. Injector
5. Rings

Fig. 1. Schematic sectional view of Lister LV1 single cylinder.

Table 1
Specifications of Lister LV1 single cylinder diesel engine

Engine description	3000 r/min, variable speed, fuel stop power, end cover for hydraulic drive.						
Engine speed	rpm	1000	1500	1800	2000	2500	3000
Engine power	kw	2.2	3.5	4.3	4.8	5.8	6.7
Fuel consumption	L/hr	0.7	1.1	1.3	1.5	1.9	2.3
Torque	Nm	22.7	24.8	25	25	24.4	23.5
Service interval	250 hours						
Governing	Mechanical						
Oil capacity	1.3 L						
Rotation	Anti-clockwise						
Start method	Hand						
Cylinder capacity (liter)	0.4765						
Cylinder bore (mm)	85.73						
Stroke (mm)	82.55						
Compression ratio	16.2						

The engine has been arranged to work under different conditions in order to study different factors. Accurate micrometer (accuracy ± 0.001) has been used to measure wear of cylinder bore. The weight loss due to wear of piston-rings has been measured by a very sensitive balance ranging from1 µgm to 500 gm.

2.2. Experimental variables

The dust particles (silica) were entered to the engine using Inlet air cleaning (Dust supply or dust feeder, as recommneded by ref. [8] as shown in fig. 2.

Equipment, for internal combustion engines and compressors-performance testing (International Standard ISO 5011) which have been used as a quide in performing the tests. The samples of dust particles used in this study were brought from Jordanian desert. The sizes of these particles are ranged from 20 to 30 µm which are similar to that present in the Jordanian environmental conditions [9].

The diesel fuel used in experiments has an international standard with maximum of 350 ppm sulfur (JS 195/2005). Extra sulfur was added to the fuel with different proportions ranging from 0.01-0.1%, in order to investigate the effect of sulfur on wear of cylinder bore and piston-rings.

Jordanian diesel fuel has high amount of sulfur ranging from 9000-11000 ppm as recorded by ref. [10]. This will have a great influence on wear of piston-rings and cylinder bores.

The first set of experiments was performed to investigate the effect of the amount of dust particles and sulfur on the wear of the cylinder bore at engine speed of 2000 rpm for 120 working hours. The variables of this set are shown in table 2, and the measured variable was the cylinder diameter (µm).

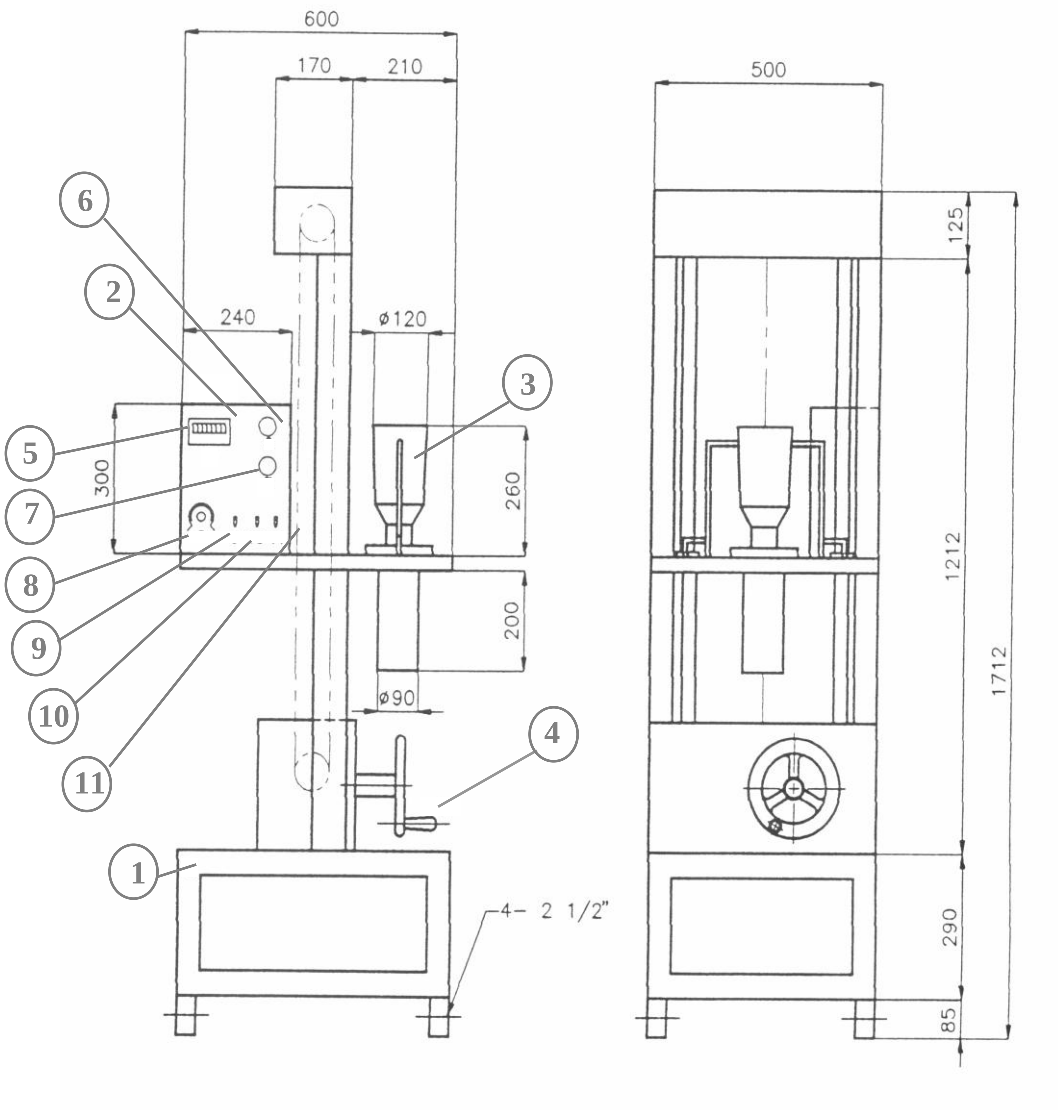
The second set of experiments was performed to study the effect of dust particle size (µm) and sulfur (%) in fuel on wear of the cylinder at engine speeds of 1000, 1500, 2000 and 2500 rpm for 90 working hours. The test variables are summarized in table 3, and the measured variable was the cylinder diameter (µm).

The third set of experiments was performed to study the effects of mass particles (g/hr) and sulfur (%) in the fuel on the wear of cylinder and piston-rings, All variables are as shown in table 4.

3. Discussion of results

3.1. Cylinder wear

Figs. 3-a, 3-b show the effect of dust particles rate variation on wear of cylinder bore. Clearly can be seen that the abrasive wear increases fairly high at Top Dead Center (TDC), little at Bottom Dead Center (BDC) and very little elsewhere along the cylinder bore.



Where:
1. Dust supply equipment frame
2. Control box
3. Standard dust supply box
4. Dust injection up down control handle
5. Digital timer
6. Power lamp
7. Buzzer
8. Dust supply amount control motor rpm volume
9. Buzzer switch
10. Timer switch
11. Main switch

Fig. 2. Dust feeder (Green Industry Company, Korea, 1998).

Table 2
Experiment variables of the first set. For each experiment: working hours=120, engine speed=2000 rpm, particle size entering the cylinder =20 μm.

Experiment No.	Mass of particles entered to the cyl. (g/hr)	Sulfur in fuel (%)	Wear in cyl. TDC (μm)	Wear in cyl. BDC (μm)
1	normal air and fuel	---	0.029	0.013
2	15	---	0.071	0.020
3	20	---	0.125	0.024
4	15	0.10	0.217	0.034
5	20	0.15	0.298	0.042

* Top Dead Center (TDC) ** Bottom Dead Center (BDC)

Table 3. Experiment variables of the second set cylinder).

Table 3.1
For each experiment: working hours=90, mass of particles entered to the cyl. = 20 g/hr, particle size=15 μm

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
6	1000	0.135
7	1500	0.18
8	2000	0.33
9	2500	0.25

Table 3.2
For each experiment: working hours=90, mass of particles entered to the cyl. = 20 g/hr, particle size=25 μm

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
10	1000	0.135
11	1500	0.46
12	2000	0.79
13	2500	0.81

Table 3.3
For each experiment: working hours=90, mass of particles entered to the cyl. = 20 g/hr, particle size=30 μm

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
14	1000	0.135
15	1500	0.98
16	2000	1.60
17	2500	1.81

Table 3.4.
For each experiment: working hours=90, mass of particles entered to the cyl.= 20 g/hr, particle size=15 μm, and sulfur in fuel= 0.03%

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
18	1000	0.135
19	1500	0.36
20	2000	0.46
21	2500	0.49

Table 3.5
For each experiment: working hours=90, mass of particles entered to the cyl. = 20 g/hr, particle size=25 μm and sulfur in fuel= 0.06%

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
22	1000	0.135
23	1500	0.62
24	2000	1.10
25	2500	1.28

Table 3.6
For each experiment: working hours=90, mass of particles entered to the cyl. = 20 g/hr, particle size = 30 μm, and sulfur in fuel= 0.1%

Exp. No.	Engine speed (rpm)	Wear in cyl. (μm)
26	1000	0.135
27	1500	1.33
28	2000	1.98
29	2500	2.41

Table 4. Experiment variables for the third set (piston-rings).

Table 4.1
For each experiment: working hours=120hr, engine speed=2000 rpm, size particle =30μm

Exp. No	Mass of particles entered to the cyl. (g/hr)	Wear (μgm)	
		1st ring	2nd ring
30	0.0	0.059	0.032
31	0.3	0.075	0.049
32	1.0	0.100	0.074
33	1.5	0.118	0.075
34	2.0	0.162	0.101
35	2.5	0.203	0.124
36	3.3	0.240	0.149

Table 4.2.
For each experiment: working hours=120hr, engine speed=2000 rpm

Exp. No	Sulfur in fuel (%)	Wear (μgm)	
		1st ring	2nd ring
37	0.00	0.059	0.032
38	0.05	0.134	0.091
39	0.06	0.139	0.092
40	0.07	0.139	0.083
41	0.08	0.152	0.097
42	0.09	0.171	0.108
43	0.10	0.166	0.113

While figs 3-c, 3-d show that the cylinder wear due to the addition of sulfur and dust to the fuel. These results illustrate that the wear increases dramatically at TDC and little at both BDC and the rest of cylinder bore. This indicates that the TDC wear is much affected by the addition of sulfur due to the formation of corrosive wear in addition to the abrasive wear caused by dust particles. The combined wear at TDC is higher than other regions along the cylinder. This probably due to the severe conditions at this zone which are the very low piston speed (≈zero) and the high temperature (close to the combustion chamber) causing a lubricant starvation and consequently a break down of lubrication theory.

These results are similar in sense to that reported by ref. [11-12]. They stated that the catastrophic effect of abrasive wear is apparent under a very dusty atmosphere (30mg/m3).

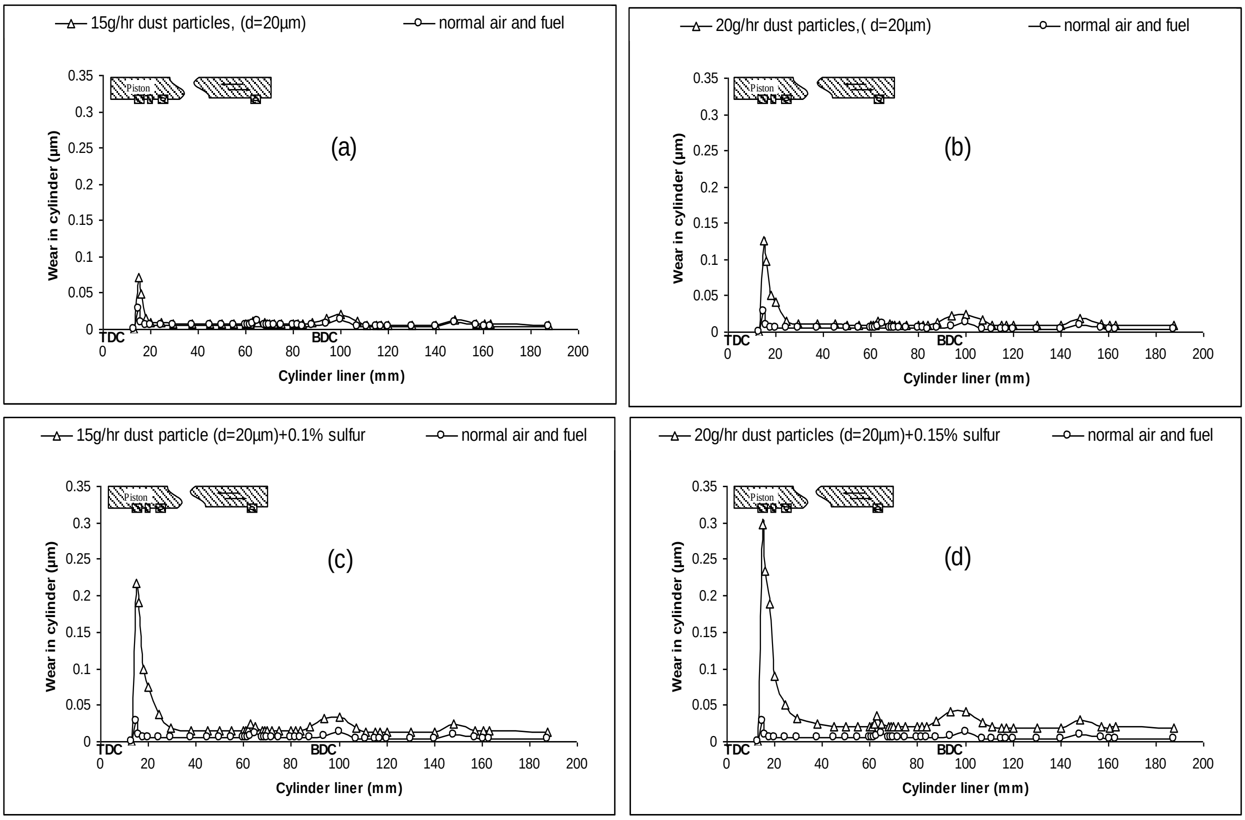


Fig. 3. Cylinder wear (μm) against cylinder liner (mm) for constant engine speed.

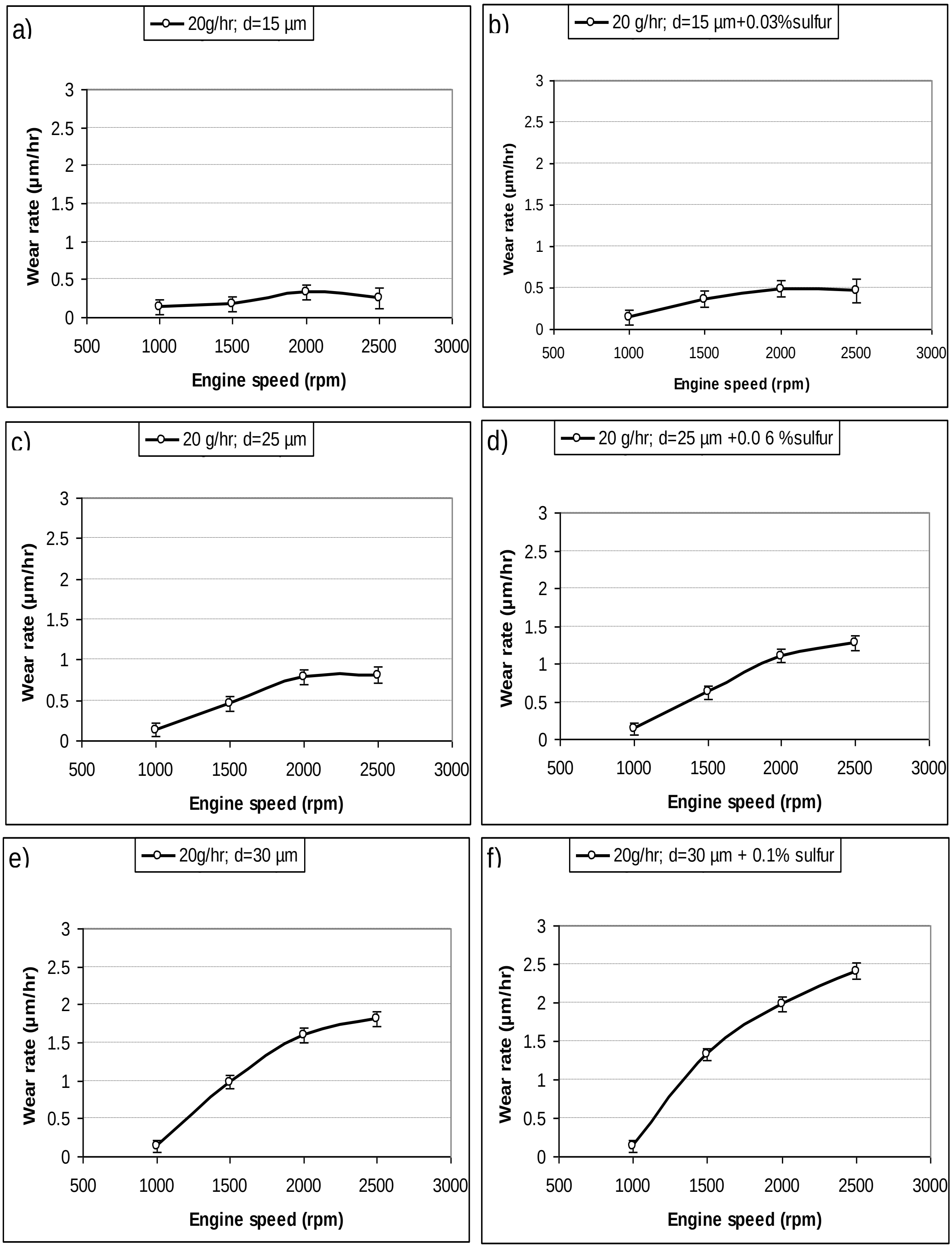


Fig. 4. Cylinder wear rate (µm/hr) against the engine speed (rpm) at different working conditions, standard deviations are shown.

Also it was reported by ref. [13] that decreasing the air filter efficiency from 99.9% to 98%, the amount of wear in the piston-rings was increased four folds.

Tarnok [14], made more exact study showing that the cylinder failure rate is decreased, with improved air filtration, i.e. particle size and concentration. It is also shown the reduction in the frequency of cylinder sleeve failure is greater than that of the bearings. This is because the cylinder is affected directly by dust particles; so increasing the filter efficiency will decrease the amount of dust as well as the size of particle passing to the engine, causing reduction in the frequency of failure. This is also borne out clearly by the results in ref. [15] which shown also the greatest degree of wear is caused by dust particles.

Also with regard to the particles size, it can be seen in figs. 3-a, 3-b, 3-c and d that the maximum wear is caused by particles of size 20 μm + 0.15% sulfur. This result is similar to that reported by [15]. They stated that the maximum wear is caused by dust particles ranging in size from 20-25 μm.

Figs. 4-a, 4-c, 4-e show the wear rate at different locations of the cylinder bore. It is clear that the wear rate increases with non-liner behavior with increasing particles size and also with increasing engine speed. Sulfur has also positive effect in increasing the wear rate of the cylinder as can be seen in figs. 4-b, 4-d, 4-f).

With increasing the engine speed from 1000 to 2500 rpm, the wear rate increased from 0.135 μm/hr (at normal conditions) up to values of 0.25, 0.46, 0.81, 1.28, 1.80 and 2.41 μm/hr when the conditions were:- (dust 20g/hr; d=15 μm), (dust 20g/hr; d=15 μm + 0.03% sulfur), (dust 20g/hr; d=25 μm), (dust 20 g/hr; d=25 μm + 0.06% sulfur), (dust 20 g/hr; d=30 μm) and (dust 25g/hr; d=30 μm +0.1% sulfur), respectively. Also it can be seen that the maximum wear rate was obtained at the conditions where the particles size was maximum (30 μm) with maximum sulfur content (0.1%).

Murakami [7] presented an analysis of the mechanism whereby sulfate ions produced and intermix with crankcase oil. He found that the sulfate ion concentration in the oil and water portion of the blow by condensate increased with a higher sulfur content in the fuel which causes corrosive wear between the piston-rings and cylinder bore.

3.2. Piston-rings wear

Fig. 5 shows the relationship between piston-rings (1st and 2nd ring) wear and dust mass rate. The figure illustrates that the wear of first ring is higher than the wear of second ring that is increasing linearly with increasing the dust mass rate. The rates of increments are 0.075 to 0.24 μgm/120hr and 0.49 to 0.149 μgm/120hr for 1st-ring and 2nd-ring, respectively. This result is expected due to that the 1st-ring bears a very high pressure (load carrying capacity) than the 2nd-ring, therefore will result in a high wear in ring surface.

Fig. 6 shows the wear of the piston-rings (also 1st and 2nd rings) due to the addition of sulfur in fuel. The behavior of the wear is similar to that shown in fig. 5 but with different rates. These rates are 0.13 to 0.16 μgm/120hr and 0.09 to 0.11 μgm/120hr for 1st and 2nd rings, respectively. They are lower than that of fig. 5. which indicates that the dust particles have more affect on wear of the piston-rings than sulfur in fuel, i.e, the abrasive wear rate is higher than the corrosive wear rate.

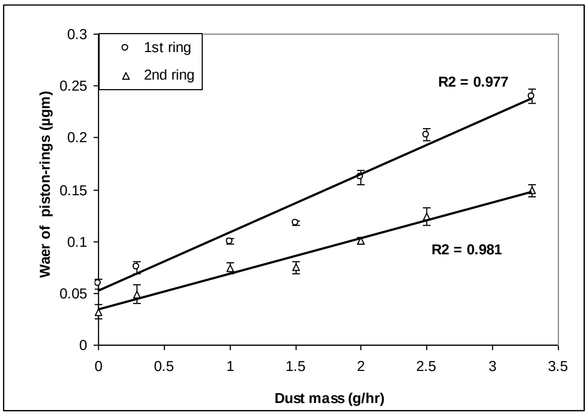


Fig. 5. Wear rate of piston-rings (μgm) against dust mass entering to the cylinder (g/hr) at constant engine speed (standard deviations and regressions are shown).

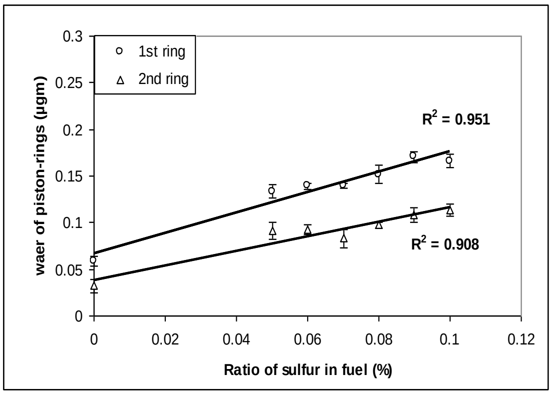


Fig. 6. Wear rate of piston-rings (μgm) against ratio of sulfur in the fuel (%) for constant engine speed (standard deviations and regressions are shown).

These results agreed with results reported by ref. [3, 12, 15, and 16]. The results of their experiments indicate that the abrasive wear increase with increasing the concentration of contaminates in air.

4. Conclusions

From this work, it can be stated that the wear of sliding parts of diesel engines caused by ingress of particles getting into the system as contaminates from the dust (due to insufficient air filtering) will cause a significant wear to these parts. This wear increases with increasing particles amount and size. This wear increases considerably by the presence of sulfur in the fuel due to the mixing of combustion products with lubricating oil. These factors must be considered when estimating the service life of the vehicles engines, on other words the designers must take in their account the working environmental conditions of vehicles. These conditions may reduce the vehicles service life by 50% in comparison with that working in the normal conditions.

Acknowledgments

The author is grateful to the valuable comments made by the reviewers; thanks are also due to Prof. Dr. Saloom for his comments that greatly improved the manuscript.

References

[1] H. Hoshi, "Reducing Friction Losses in Automobile Engines", Tribology International, Vol. 17, pp. 185-189 (1984).

[2] O.K. Kwon, H.S. Kong, C.H. Kim. and P.K. Oh, "Condition Monitoring Techniques for an Internal Combustion Engine", Tribology International, Vol. 20 (3), pp. 153-159 (1987).

[3] J. Fodor, "Improving Utilization of Potential I.C. Engine Life by Filtration", Tribology International, Vol. 12, pp. 127-129 (1979).

[4] E.A. Khorshid, and A.M. Nawwar, "A Review of the Effect of Sand Dust and Filtration on Automobile Engine Wear," Wear, Vol. 141, pp. 349-371 (1991).

[5] V.E. Maev and N.N. Panomarev, "Air Filters for Automobile and Tractors", Moscow, Russia: Machine Building (1971).

[6] V.N. Bobinsky, "Theory of Construction and Calculation for Automobile and Tractors Engines. Ministry of Agriculture", Moscow, Russia (1962).

[7] Y. Murakami, "Analysis of Corrosive Wear of Diesel Engines: Relationship to Sulfate Ion Concentrations in Blow by and Crankcase Oil", JSAE Review, Vol. 16, pp. 43-48 (1995).

[8] Green Industry Company Ltd. 1998. Serial No. 1007 Korea.

[9] Al Janoub Filter Manufacturing Co. LTD Jordan (2006)

[10] Jordan Institution for Standard and Metrology, Ministry of Industry and Trades, Jordan (2006).

[11] B.M. Astashkevich, "Problems of Improving the Wear Resistance of Cylinder Liners and Piston Rings for locomotive Diesel Engine", Vestn. Vses. Nauchno-Issled.Inst. Zheleznodorzhn. Transp, Vol. 6, pp. 35-39 (1968).

[12] Ron. Matthews, "Reduced engine Friction and Wear", The University of Texas (2003).

[13] J. Kapuvary, and R.J. Fodor, "Laboratory and Operation Life-Test on Bus Engines, Proc. Conf. on Tribology from the Aspect of Motor Vehicles", Sci. Soc. Mech. Eng, Budapest, Vol. 12, pp. 327-332 (1976).

[14] K. Tarnok, "Tribology at Budapest Transport Company", Proc. Int. Conf. on Tribology, Friction, Lubrication and Wear Fifty Years on 1987, Institution of Mechanical Engineers, London, Vol. 2, pp. 781-785 (1987).
[15] K. Baczewski, and T. Jaroszczyk, "Filtration Determination of Wear Process in Internal Combustion Engines", Proc. 3rd Int. Tribology Conf, EUROTRIB, Lubricants and their Applications, Poland, Vol. 3/A, Elsevier, Amsterdam, pp. 7-16 (2004)
[16] A.P. MØller, "Field Experience of 2-Stroke Large Bore Diesel Engines Burning Fuel Oil with Lower Sulphur Content", CIMAC CIRCLE, Oslo (2005).

Received April 2, 2006
Accepted July 29, 2006