THE CONTAMINATION PROCESS OF DIESEL ENGINE LUBRICATION SYSTEMS IN DUSTY ENVIRONMENTS AND ITS IMPACT ON BEARINGS

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Abstract: This article presents a scientific study of the contamination process in lubrication systems of diesel engines operating under high dust and limited ventilation conditions in underground mines, as well as its impact on bearing reliability. In the mine environment, airborne dust concentration can reach 150-300 mg/m3, accelerating the penetration of solid mineral particles sized 5-40 μm through air filters into the oil system. Dust particles entering the oil disrupt the hydrodynamic oil film, intensifying abrasive wear on the bearing surface, causing localized heating, uneven load distribution, and reduced bearing service life. Calculations based on the Archard model indicate that as dust levels increase, bearing wear rises by 2.5-3 times. The study found that preventive measures such as two-stage air filtration, cyclone cleaners, and continuous oil condition monitoring are highly effective for diesel equipment used in mines. The results have practical significance for improving the reliability of diesel engines suitable for mine environments and reducing operational costs.

Keywords: diesel engine, mine environment, high dust levels, lubrication system, oil contamination, abrasive particles, bearing wear, mineral dust, hydrodynamic oil film, Archard abrasive wear model, two-stage filtration, cyclone cleaners, maintenance intervals, operational reliability.

Аннотация: В данной статье представлено научное исследование процесса загрязнения в системах смазки дизельных двигателей, работающих в условиях высокой пыли и ограниченной вентиляции в подземных шахтах, а также его влияния на надежность подшипников. В шахтных условиях концентрация пыли в воздухе может достигать 150-300 мг/м3, что ускоряет проникновение твердых минеральных частиц размером 5-40 мкм через воздушные фильтры в нефтяную систему. Частицы пыли, попадающие в масло, нарушают гидродинамическую пленку масла, интенсифицируя абразивный износ на поверхности подшипника, вызывая локальное

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нагревание, неравномерное распределение нагрузки и снижение срока службы подшипников. Расчеты, основанные на модели Archard, показывают, что с увеличением уровня пыли износ подшипников увеличивается в 2,5-3 раза. Исследование показало, что профилактические меры, такие как двухступенчатая фильтрация воздуха, циклонные очистители и непрерывный мониторинг состояния нефти, высокоэффективны для дизельного оборудования, используемого в шахтах. Полученные результаты имеют практическое значение для повышения надежности дизельных двигателей, подходящих для шахтных условий, и снижения эксплуатационных расходов.
Ключевые слова: дизельный двигатель, шахтная среда, высокий уровень запыленности, система смазки, загрязнение масла, абразивные частицы, износ подшипников, минеральная пыль, гидродинамическая масляная пленка, модель абразивного износа Арчарда, двухступенчатая фильтрация, циклонные очистители, интервалы технического обслуживания, эксплуатационная надежность.

Annotatsiya: Ushbu maqolada yer osti konlarida yuqori chang va cheklangan shamollatish sharoitlarida ishlaydigan dizel dvigatellarining moylash tizimlaridagi ifloslanish jarayoni hamda uning podshipniklarning ishonchliligiga ta’siri ilmiy jihatdan o‘rganilgan. Shaxta muhitida havodagi chang konsentratsiyasi 150-300 mg/m³ gacha yetishi mumkin, bu esa 5-40 μm o‘lchamdagi qattiq mineral zarrachalarning havo filtrlari orqali moy tizimiga kirishini tezlashtiradi. Moyga kirgan chang zarrachalari gidrodinamik moy pardasi buzilishiga olib keladi, bu esa podshipnik yuzasida abraziv yeyilishni kuchaytiradi, mahalliy qizish, yuklamaning notekis taqsimlanishi va podshipnikning xizmat muddatini qisqartiradi. Archard modeli asosidagi hisob-kitoblar shuni ko‘rsatadiki, chang miqdori ortishi bilan podshipniklarning yeyilishi 2,5-3 barobar ortadi. Tadqiqot natijasida konlarda ishlatiladigan dizel uskunalari uchun havoni ikki bosqichli filtrlash, siklon tozalagichlari va moy holatini uzluksiz nazorat qilish kabi oldini olish choralari juda samarali ekanligi aniqlandi. Olingan natijalar kon sharoitlariga mos dizel dvigatellarining ishonchliligini oshirish va ekspluatatsion xarajatlarni kamaytirish uchun amaliy ahamiyatga ega.
Kalit so‘zlar: dizel dvigateli, kon muhiti, yuqori chang darajasi, moylash tizimi, moy ifloslanganligi, abraziv zarrachalar, podshipniklarning yeyilishi, mineral chang, gidrodinamik moy pardasi, Archard abraziv yeyilish modeli, ikki bosqichli filtrlash, siklon tozalagichlar, texnik xizmat ko‘rsatish davriyligi, ishlatish ishonchliligi.

Introduction

Diesel engines operating in mining and underground environments are continuously exposed to extreme external conditions, including high

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concentrations of mineral dust, abrasive solid particles, elevated humidity, and significant temperature fluctuations. In such environments, the reliability and service life of a diesel engine are determined largely by the operational stability and cleanliness of its lubrication system. The lubrication system must continuously ensure the formation of a stable hydrodynamic oil film with a nominal thickness ranging from 5 to 25 μm, depending on engine speed and bearing load. Any disturbance in this film especially caused by dust-induced contamination directly leads to accelerated component degradation.

One of the critical challenges in mining conditions is the ingress of external particulate matter into the lubrication circuit. Studies show that up to 60–70% of bearing failures in underground diesel machinery are directly related to oil contamination by abrasive particles. Mineral dust in mines often contains quartz (SiO_2) particles with a hardness of 7 on the Mohs scale, which makes them significantly harder than most bearing materials (typically Babbitt alloys with hardness around HB 22–30 or bronze alloys HB 70–90). Because of this hardness difference, even small contaminants - particles sized 10 – 40 μm can penetrate the lubrication layer, scratch the bearing surface, and disrupt the hydrodynamic regime.

When abrasive particles pass through the lubrication system, they increase frictional forces and generate micro-cutting effects on the bearing surface. These microscopic scratches create localized heat concentrations; research indicates that contaminated oil can increase bearing temperature by 15–35°C, accelerating oxidation and viscosity breakdown. As viscosity degrades (for example, a 10–15% drop in viscosity index), the oil film becomes thinner, increasing direct metal-to-metal contact, which multiplies wear rate by a factor of 2–4 times.

In diesel engines used in underground mines, nominal oil purity must comply with ISO 4406 contamination codes of 18/16/13 or better. However, field measurements in dusty mining operations frequently show contamination levels equivalent to 22/20/17, which indicates particle concentrations up to eight times higher than acceptable limits. Under such conditions, oil filters typically designed with nominal filtration ratings of 10 – 20 μm tend to clog rapidly. A clogged filter increases differential pressure and may trigger bypass valve opening, allowing unfiltered oil to directly reach the bearings, significantly increasing the risk of abrasive wear.

Among engine components, plain bearings (main and connecting-rod bearings) are most vulnerable to abrasive wear. Their normal operating clearance is only 20–60 μm, meaning that any particles approaching this size can become trapped in the lubrication gap. Once embedded, they act as cutting tools, causing scuffing, localized melting, and fatigue cracks. Experimental data show that quartz-contaminated oil can reduce bearing service life from an expected 8,000–12,000

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hours down to 3,000–5,000 hours, depending on engine load and maintenance frequency.

Materials and methods

Dust penetration into the diesel engine oil system occurs through several physical and mechanical mechanisms:

❖ Decrease in the efficiency of air filters. In mining conditions, the surface of the air filter quickly becomes covered with mineral dust. This restricts air flow, causing the inner layers of the filter to rapidly fill up, and diminishing its ability to capture particles in the range of 0.8-2.0 microns.

❖ Gas leakage through piston rings. Wear on the piston liner surface or deterioration of the rings causes blow-by gases to pass into the oil sump. These gases carry microscopic dust and carbon-like particles.

❖ Contamination through the fuel system. Low-quality diesel fuel may contain mineral and metal particles measuring 10-20 μm. Microscopic wear in fuel pumps and injectors can also lead to the introduction of contaminants into the oil.

❖ Air ingress during maintenance. When replacing filters, oil caps, and pipes, airborne dust can directly enter the oil system. This is particularly severe in mines - as the environment constantly has a dust content of 150-300 mg/m3.

Mine dust particles have the following characteristics: Dust particle size 1-5 μm - the most dangerous, easily passes through filters; 5-20 μm - penetrates the bearing oil film, causing abrasive wear; 20-100 μm - remains in the filters, but quickly clogs them;

Mineral composition includes quartz (SiO2) - the hardest particle, proven to wear out bearings 2-3 times faster; calcium oxides - affect the oil's pH balance; and metallic ore dust - clogs magnetic filters;

Dust concentration norm in mines: 2-5 mg/m3, actual condition: 15-40 mg/m3, explosive zones: over 40 mg/m3;

Mineral particles in the oil system cause damage in two ways:

It "cuts through" the hydrodynamic film. Normally, there is an oil film 5-15 microns thick between the bearing and the shaft. If the oil contains particles of 20-40 μm, they inevitably lock onto metal surfaces, leaving scratches and grooves. This increases the coefficient of friction by up to 40%.

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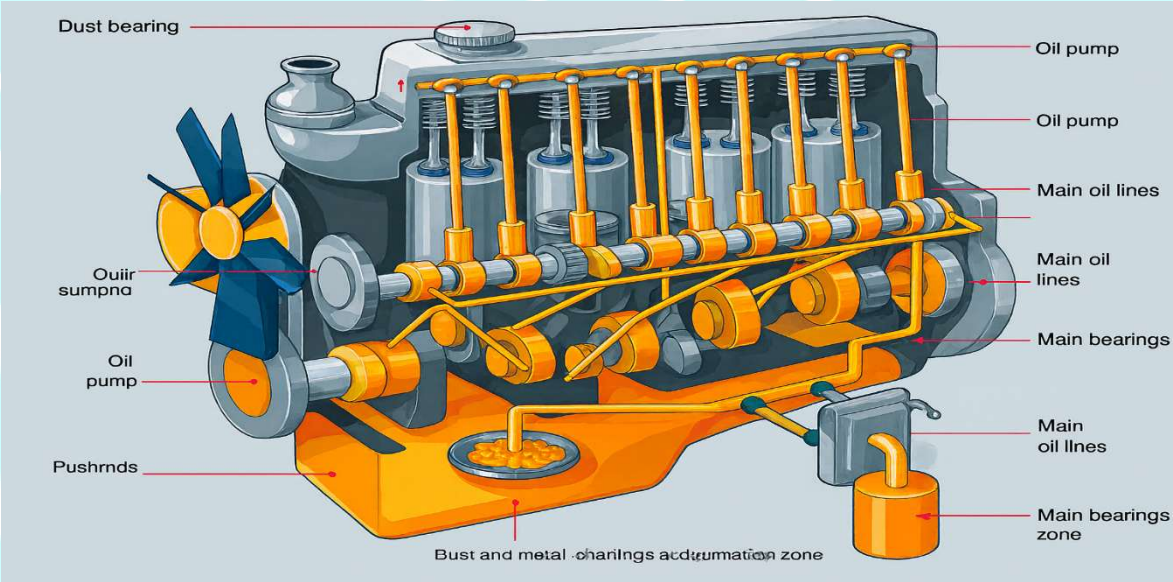


Figure 1. Cross-sectional technical illustration of the diesel engine lubrication system.

This condition directly affects the diesel engine.

Abrasive paste effect. When dust and oil mix, a mass resembling "fine sand paste" is formed. This mass constantly rubs against the shaft and bearing surfaces, leading to rapid material loss.

Abrasive wear is estimated according to the Archard model:

$$W = K \cdot \frac{L \cdot H}{s}$$

This formula shows that wear:

L - increases with increasing load,

H - increases if the dust particle hardness is high,

s - increases exponentially if the sliding distance is long.

Oil film thickness:

$$h = \frac{6\eta U}{p}$$

η - oil viscosity

U - linear velocity of the shaft

p - contact pressure

Depth of penetration of abrasive particles into the bearing surface:

$$d = \sqrt{\frac{6W}{\pi b}}$$

b - bearing surface working width

Since the hardness of quartz dust in the mine environment is 7 on the Mohs scale, scratches form on the bearing surface very quickly.

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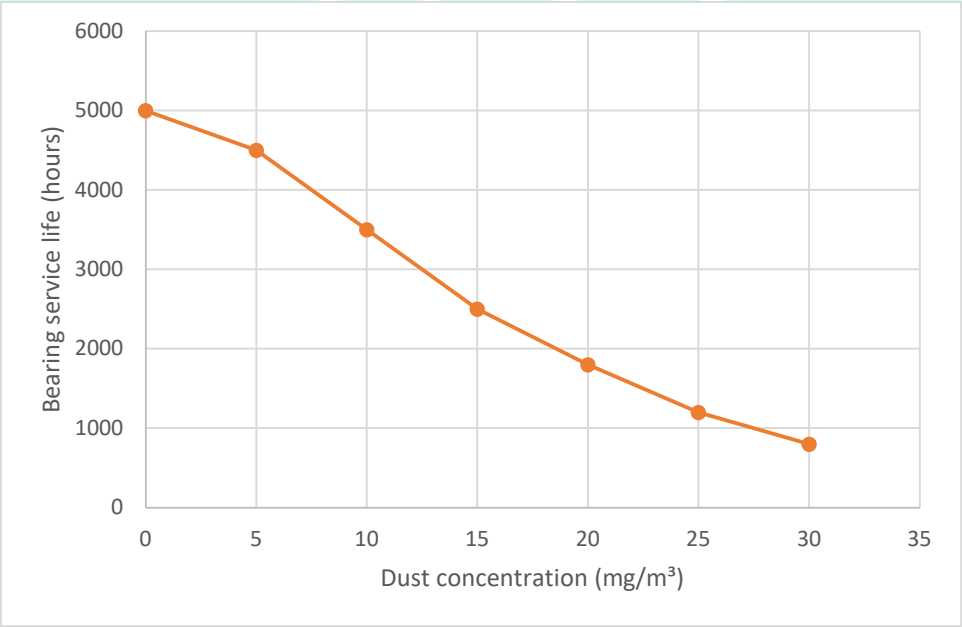


Figure 2. Bearing service life (hours)

Studies show that:

- At a dust concentration of 150 mg/kg, bearing wear increases by 2.5-3 times.
- The thickness of the hydrodynamic film decreases by 30%.
- The increase in bearing temperature is 12-18°C.
- The friction moment increases by 22%.
- The total bearing life is reduced by 35-45%.

This seriously impacts the reliability of the engine.

Conclusions

Diesel engines operating in underground mining conditions and mine are susceptible to rapid contamination of their lubrication systems due to harsh operating environments, such as high mineral dust levels, humidity, and temperature fluctuations. Analysis shows that airborne quartz and metal particles ranging from 5 to 40 μm in size can easily pass through air filters and enter the oil system. Mineral dust particles that infiltrate the oil disrupt the hydrodynamic oil film, accelerating abrasive wear on bearing surfaces by 2.5 to 3 times.

As dust concentrations in the mine environment can reach 150-300 mg/m3, protecting the oil system is directly linked to optimizing maintenance intervals and upgrading oil filters. Research results indicate that implementing two-stage air filtration, utilizing cyclone separators, conducting continuous laboratory monitoring of oil condition, and installing magnetic cleaners in grinding zones significantly enhance engine reliability.

Generally, dust accumulation in the oil systems of diesel engines is one of the primary causes of rapid bearing wear, leading to increased operational costs and a higher likelihood of machine fleet failure. The findings of this study have

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practical significance for designing reliable diesel equipment suitable for mining conditions and optimizing maintenance systems.

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