Risk management of diesel exhaust exposure

SfS Recommendation 049E/2022

SfS
Samarbeid for Sikkerhet

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1. Introduction

Exhaust from diesel-powered equipment is a work environment challenge that affects all segments of the petroleum industry, both on land and at sea. At the same time, there is varying awareness and understanding of the risk associated with exposure to diesel exhaust among various players in the industry, and appropriate systems to identify and control exposure risk have been established to varying degrees.

Like that from diesel engines, exhaust from gas turbines or other combustion sources may result in unwanted exposure, but this is not covered by this recommendation. There are knowledge gaps relating to this problem, for example regarding health risks associated with exposure, particulate content and the composition of the exhaust, which should be further followed up by the industry, see Chapter 9.

2. Purpose

The purpose of this recommendation is to help increase awareness and the level of knowledge in the industry regarding challenges relating to diesel exhaust. Furthermore, the recommendation may be helpful in identifying and establishing appropriate risk-reducing measures, and in establishing control regimes to manage risk associated with exposure to diesel exhaust. This is to ensure that harmful exposure to diesel exhaust is avoided. The recommendation is applicable to both onshore facilities and those at sea.

3. Target group

The target group for this recommendation is risk owners and others who are affected by challenges relating to diesel exhaust, whether in the planning or execution of work in the petroleum industry.

The recommendation also provides information to personnel working with design of new /modification of existing installations, and/or when selecting/operating diesel-powered equipment.

4.Diesel exhaust

4.1 Diesel exhaust

Diesel exhaust stems from diesel combustion. It is a complex mixture of gases, vapours, aerosols and particles, including ultrafine particles, which together and separately may have harmful effects on health. The levels of gases and particles may be independent of each other; low levels of gas will therefore not necessarily indicate correspondingly low levels of particles, and vice versa. When assessing and controlling risk, exposure to both gas and particles must therefore be considered.

The table below shows key components of diesel exhaust:

Gases:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Nitrogen monoxide (NO)
- Sulphur dioxide (SO_2)
- Hydrocarbons (unburned)

Particles:

- Elemental carbon (EC)
- Organic compounds (PAH)
- Trace elements (inorganic sulphates, nitrates, metals, etc.)

Diesel-powered equipment is used in several processes in the petroleum industry. See Appendix 2 for an overview of current sources of diesel exhaust.

4.2 Health effects

Exposure to diesel exhaust can have both acute and chronic adverse health effects.

4.2.1 Acute health effects

Common acute health effects include odour discomfort, respiratory irritation, asthma-like symptoms, chemical pneumonia, eye irritation, headache, dizziness, nausea, fatigue, and worsening of existing allergies.

Of the gases in the exhaust, NO_2 (nitrogen dioxide) in particular is linked to impaired lung function (development of pulmonary oedema). This may occur many hours after exposure. Furthermore, exposure to NO_2 may aggravate asthma and bronchitis.

There isn’t necessarily a correlation between the severity of acute health effects and exposure levels; Some may experience serious health effects even at low levels.

4.2.2 Chronic effects

Exposure to diesel exhaust over a long period of time and at high levels may result in an increased risk of developing respiratory diseases such as asthma, COPD and lung cancer, as well as cardiovascular disease.

Diesel exhaust is classified as carcinogenic for humans by the International Agency for Research on Cancer (IARC). The carcinogenic properties of diesel exhaust are mainly related to the particulate fraction (measured as elemental carbon – EC), while studies have shown that there is not necessarily a correlation between the gas and particulate fractions.

In Norway, STAMI has contributed increased knowledge about the health effects of exposure to diesel exhaust and has also helped to map exposure, se references 1-6.

4.3 Regulations

National exposure limit values have been established for several of the individual components in diesel exhaust, cf. Appendix 1. The limit values are specified in the Norwegian Labour Inspection Authority's regulations on measure and limit values.[9]

The national limit value for diesel exhaust, measured as elemental carbon (EC), is valid for petroleum activities from 21.02.2023. Some companies had already implemented this new limit value when this SfS recommendation was published in March 2022.

4.4 Monitoring and mapping

A control regime should take into account exposure to both gases and particulates. This can be done using a combination of exposure measurements and monitoring at the workplace using direct-reading instruments.

Components such as nitrogen dioxide (NO_2), nitrogen monoxide (NO) and carbon monoxide (CO) are used by several companies as indicators of the gas phase of exhaust pollution. However, studies have shown that such components cannot be used as control parameters alone. The particulate phase of diesel exhaust must also be considered in order to obtain an overall picture of the exposure risk.

Direct-reading instruments can be used to monitor the gas phase. Both personal meters and area measurements can be used. The particulate fraction of the exhaust consists mainly of elemental carbon (EC), and in contrast to the gas/vapour phase has stable compounds with a long decomposition time. Elemental carbon is therefore considered to be a suitable marker for exhaust exposure. To determine the possible level of exposure to combustion particles, an occupational hygiene survey must be carried out. Direct-reading instruments for combustion particles are currently not sufficiently qualified to be used as a control tool in daily operations. The industry is encouraged to develop new, or qualify existing equipment, (f.ex. Droplet Measurement Technologies - Black Carbon Measurements – Particle counter/size distribution) that can be used for direct readings of elemental carbon and particle counts.

4.5 Personal protective equipment

Use of respiratory protection with a P3 filter will stop the largest combustion particles in the exhaust but will not provide sufficient protection against ultrafine particles and several of the gases in diesel exhaust, such as nitrogen dioxide (NO_2), carbon monoxide (CO) and nitrogen monoxide (NO). The use of a filter mask (half/full) and fan-assisted respiratory protection provides limited protection against diesel exhaust and should be used as little as possible, and only for short-term tasks (less than 15 minutes) in levels below the limit value. Only respiratory protection with a fresh air supply provides adequate protection when performing work with exposure to diesel exhaust.

5. Planning activities

Activities that may involve a risk of diesel exhaust exposure to must be planned so that direct exposure of executing personnel and/or indirect exposure of personnel on the periphery of the area is avoided, see Appendix 2 for an overview of the various diesel engines that are commonly used in the petroleum industry.

The occurrence and spread of diesel exhaust will depend on several external variables such as temperature and wind conditions. These must be considered when planning activities.

5.1. Temporary equipment

For activities or work requiring the use of temporary diesel-powered equipment, for example, the following factors should be evaluated:

- Opportunities to select alternative electrical solutions
- Choice of equipment with low emission level
- Location of the equipment in relation to activities in the area
- Possibilities for routing diesel exhaust away from the installation/facility (conversion of diesel exhaust outlet, use of compressor/ejector system, etc.)
- Possibilities to change diesel exhaust outlet in the event of changing winds (e.g. using flexible solutions or two separate outlets facing different directions)
- Need for monitoring of pollution level
- Ensure training in use of and adequate access to equipment to monitor pollution levels
- Ensure training in use of and adequate access to suitable protective equipment

5.2 Activities in areas with risk

When planning activities in areas where there is a risk of diesel exhaust pollution from permanent equipment, the following factors should be considered:

- Possibility of shutting down diesel-powered equipment, possibly replacing this with temporary equipment that is not diesel driven.
- Plan activities during periods when the risk of diesel exposure is reduced or as low as possible (e.g. when the engine load is low or when engines/equipment are partially or completely shut down).
- Possibilities for routing diesel exhaust away from the installation/facility (conversion of diesel exhaust outlet, use of compressor/ejector system, etc.).
- Possibilities to change diesel exhaust outlet in changing wind conditions (e.g. using flexible solutions or two separate outlets facing different directions)
- Need for monitoring of pollution level
- Ensure training in use of and adequate access to equipment to monitor pollution levels

- Ensure training in use of and adequate access to suitable protective equipment

5.3 Mooring of vessels and rig intake

Diesel exhaust from vessels (e.g. supply boats, lifting barges, acid stimulation vessels, etc.) and external drilling rigs / accommodation platforms may contribute to pollution on board the facility. This must be considered when planning vessel arrivals and rig intake processes. In a tender phase, priority should be given to vessels with solutions that avoids exhaust problem avoided priority, e.g. Hybrid solutions or water liquor systems.

When mooring a vessel, the following factors should be taken into account:

- Use of electric power while moored (for vessels with hybrid solutions)
- Positioning of vessels so that vessel diesel exhaust is led away from the facility.
- Need to monitor air quality at air intakes to residential areas and office modules.
- Possibilities for use of e.g. water mist systems or other solutions to reduce diesel exhaust.

In the event of rig intake where an external rig is placed close to the facility, diesel exhaust pollution from the facility may reach the external rig, and vice versa. Modification of exhaust outlets can be considered in order to avoid this issue.

6. Establishment of internal procedures

Companies should prepare written procedures/guidelines describing how to prevent exposure to diesel exhaust. Such procedures/guidelines should include the following elements:

- Risk associated with exposure to diesel exhaust (health risks, location of diesel-powered equipment and possibilities for the spread of diesel exhaust).
- Requirements for training with regard to risk, use of measuring equipment and necessary protective measures (technical and organizational measures, as well as use of personal protective equipment).
- Routines for monitoring pollution levels in the work atmosphere, including logging of measurement results.
- Measure and limit values for exposure/alarm limits for direct-reading instruments.
- Routines and procedures in the event that measure and limit values are exceeded (alarm), including follow-up of exposed personnel.
- Technical and organizational measures to avoid exposure.
- Use of personal protective equipment. Choice of correct protective equipment and restrictions on different types of respiratory protection.
- Routines for regular calibration of measuring equipment (sensors and instruments).

7. Knowledge gaps

7.1 Gas turbines

Gas turbines are normally powered by fuel gas but can periodically (e.g. during process upsets or revision activities), be powered by diesel. Gas turbines powered by fuel gas can also provide unwanted exhaust exposure. However, this is not covered by this recommendation. Fuel gas is produced on the actual installation and will thus have varying components. Furthermore, there are several different turbine types (e.g., low NOx turbines), which will provide different emissions.

Gas turbines that drive generators are in regular operation and may generate large amounts of exhaust. Unlike diesel exposes, turbine exposes will often be released at higher levels, and thus provide a lower risk of exposure. Turbine exhaust can still be a challenge, for example for personnel who work in the derrick.

Like diesel exhaust, turbine exhaust will also contain nitrous gases. The composition of particles and any other components in turbine exposes is little known, and this should be followed up in the industry.

7.2 Direct measurements of elemental carbon

The industry is encouraged to develop, or possibly qualify existing equipment, which can be used for direct measurements of elemental carbon. This in order to have a tool for operational control of exposure risk.

8. Abbreviations

AGCIH	American Conference of Governmental Industrial Hygienists
Cetane number	Flammability for fuel oils (how easily the diesel ignites)
COPD	Chronic obstructive pulmonary disease
EC	Elementary carbon
EGR	Exhaust gas recycling
HVO diesel	Hydrotreated vegetable Oil (Biodiesel)
IARC	International Agency for Research on Cancer
IDLH	Immediate danger for life and health

MGO	Marine gas oil / Marine diesel
PAH	Polycyclic aromatic hydrocarbons (organic compounds)
PM	Particle matter
SCR	Selective catalytic reduction
STAMI	The Norwegian Institute for the Working Environment
STEL	Short term exposure level
UHC	Unburned hydrocarbons

9.References and links

1. STAMI: Diesel exhaust in the work atmosphere in the Norwegian oil and gas industry – The current exposure picture
2. STAMI: What are workers who breathe in a lot of diesel exhaust exposed to?
3. STAMI: Mapping of exposure to diesel exhaust particles in Norwegian working life using elemental carbon as a marker
4. STAMI: New doctoral degree: Health effects of diesel exhaust in the work environment
5. STAMI: Diesel exhaust, biomarkers and toxic mechanisms
6. STAMI: Diesel particles and carbon black nanoparticles are almost equally dangerous to inhale
7. Management regulations Section 18 Analysis of the working environment
8. Activity Regulations Section 33 Facilitation of work
9. Regulations on action and limit values
10. Activity Regulations Section 36 Chemical health hazards
11. Regulations on work performance
12. Regulations on organization, management, and participation (risk assessment)
13. Templates for risk assessment (Norwegian Labour Inspection Authority)
14. Information on respiratory protection (Norwegian Labour Inspection Authority)
15. The work environment portal

16. Air quality (National Institute of Public Health)

Appendix 1 Limit values per 01.12.2021

Component	Limit values [9] 8/12 hours	Limit value recommended by ACGIH 8/12 hours	IDLH - value
CO	20 / 12 ppm	25 / 15 ppm	1200 ppm
NO_2	0.5 / 0.3 ppm	0.2 / 0.1 ppm	13 ppm
NO	2.0 / 1.2 ppm	25 / 15 ppm	100 ppm
CO_2	5000 / 3000 ppm	5000 / 3000 ppm	40000 ppm
Diesel exhaust*	0.05 mg / m^3/ 0.03 mg / m^3		

* National limit value for diesel exhaust, measured as elemental carbon, is valid from 21.02.2023.

Appendix 2 Sources of exhaust – Overview of machines and power

There are several machines that produce exhaust emissions on an installation. Normally, the volume of exhaust will increase with power, but larger machines are often more efficient than smaller ones. Furthermore, there are several other factors that affect the level and toxicity of exhaust emissions (e.g. fuel type, load rating, start-up vs. constant operation, additives, engine settings, etc.)

A common dilemma when it comes to exhaust is that machines optimized for low NOx emissions (late 'injection timing') unfortunately result in greater emissions of hazardous particles and increased consumption/CO_2 – if exhaust gas cleaning and smart/modern engine management are not used. Appendix 1 provides an overview of common gases and particles in the exhaust, and chapter 4.2 describes possible negative health effects.

In addition to 'self-produced' exhaust, facilities may be exposed to exhaust from nearby supply vessels, flotels, etc.

<u>Sources of exhaust</u>

Sources of diesel exhaust exposure in the petroleum industry may include diesel trucks and cranes, main power generators, cement units, fire pumps, emergency units (diesel units), lifeboat testing, ships (loading and unloading of supplies for offshore installations or at quays for onshore facilities), diesel generators for flotels, turbines and equipment brought by contractors (e.g. units connected to power supply for well intervention).

<u>Overview of machines and power (offshore)</u>

- Fire pumps. Usually 2-4 on each installation. Approx. 1000-2000 kW
- Emergency generators. Usually 1-2 on each installation. Approx. 1500-3000 kW
- Power generators. From 0-2 on each installation. Up to 4-5000 kW each.
- Propulsion/thrusters on mobile facilities (typically drilling rigs). Up to 8 machines on each facility. Approx. 3-6000 kW per machine.
- Generator for cement unit / drilling equipment. From 0-4 per facility. Approx. 2400 to 6300 kW each.
- Cranes. Usually 1-2 on each facility. Approx. 200 to 600 kW
- Lifeboats. Usually 2-10 on each facility. Approx. 40 to 280 kW
- MOB boats. Usually 1-2 on each facility. Up to approx. 280 kW
- 'Black starters' (diesel engines with air compressor to restart facility if main power is out), usually 1-2 on each facility. Approx. 30 to 50kW

Appendix 3 Technical solutions affecting diesel exhaust

In this appendix, we have gathered general information about technical solutions that are relevant as of 01.01. 2022, and which may affect the volume and contents of diesel exhaust.

Choice of fuel and additives

Choice of diesel types

- The 'most common' offshore diesel is MGO (marine gas oil / marine diesel) with 500 ppm sulphur content (S). It has a higher max. density (0.8600) than 'onshore diesel' and heavier mixing components. Sulphur content limits some exhaust gas cleaning solutions.
- Plant diesel (meets EN590 specs) has max.10 ppm S, a lower max. density (0.8450), lighter mixing components (vs. MGO), and gives reduced emissions. Low S enables the use of exhaust gas cleaning solutions.
- HVO diesel ('advanced biodiesel') may provide even lower emissions and enable the use of exhaust gas cleaning solutions. Since HVO is a refined product that is based on organic waste (slaughter waste, oil from food waste, etc.), it also provides a typical solid net (life-cycle calculated) CO_2 reduction of 80-90%, and has good combustion/use properties. Available volumes are however limited. A test report from Marintek for the NHO/NOx fund (& DNV-GL) shows clear emission reductions for HVO diesel.

Additives (additives in diesel)

- Advanced, tested additives with a documented effect provide improved engine condition/maintenance, reduced emissions (soot/PM, UHC, CO, NOx) and fuel savings (less CO_2).
- Available/used soot-reducing additive normally used for land transport can be added to diesel. This can lower the burn-off temperature for PM/soot by up to approx. 200 degrees (burns off to CO_2).
- Typical sub-components that may be included in an additive package:
    - Ignition enhancer (increases Cetane number / ignition readiness and reduces soot production at start)
    - Detergent for nozzle maintenance/function/spray and delivery volume (to maintain engine power)
    - Anti-corrosion (tanks/pipes, diesel system)
    - Storage additive (reduces deposits, tank/filter problems)
    - Self-lubrication in injection system (lubricity)
    - Combustion enhancer
    - Soot burn-off
- A well-designed (and tested) additive package can enable the use of exhaust gas cleaning solutions such as particulate filters (soot/PM)

Engine measures

Ensuring a good engine condition provides efficient combustion, reduced consumption/CO_2 and reduced soot/particulate emissions (EC), but increased NOx emissions. The opposite is true for a 'tired' engine.

- Adjustment to earlier injection reduces soot, fuel consumption and CO_2, but will give increased NOx.
- Modern engine technology can result in lower and significantly reduced emissions and consumption of fuel (and CO_2). Retrofittable modern high-pressure injection equipment / better turbochargers can both significantly reduce fuel/CO_2 consumption (10-12% or more) and reduce other emissions (soot/particles, unburned HC/diesel, NOx).
- EGR (exhaust gas recycling) is an affordable and simple solution that is widely used in land transport and reduces NOx. A partial flow of exhaust from the engine is returned to the air intake in the engine via an EGR valve, and since CO_2 is a 'dead gas' (completely burned) and the main component in the exhaust, it will lower the combustion temperature and reduce NOx formation. Engine sooting, EGR valve function and lubricating oil sooting are downsides, and EGR is not common on larger engines (used offshore).
- Turbocharger with 'electro assist', or 'peak shaving' will reduce emissions/PM during start-up and in the event of a sudden increase in load. Peak shaving will 'shave' away the energy peaks in the consumption curve, thereby ensuring even power utilization by the main engines. The energy can then be used as reserve energy for power-intensive operations, by using battery, capacitor or flywheel storage of energy.
- Injection of water and cooling gives reduced NOx but more pollution in the exhaust due to less complete combustion and therefore more particles (UHC) in the exhaust.

Diesel exhaust cleaning

There are many filters and solutions that can clean the exhaust – and many of these can be retrofitted:

- Particulate filters can reduce soot/particle emissions – from 90% to over 99% (depending on the technology). Some are self-regenerating, and some are dependent on additives to lower the soot burn-off temperature in order to regenerate (burn off soot to CO_2). Are sensitive to sulphur.
- Oxidation catalysts reduce CO and UHC (semi-combusted exhaust), and to some extent soot/PM. Are usually a built-in component of particle filters. Are sensitive to sulphur.
- SCR catalysts can reduce NOx emissions – from 80% to over 90% (depending on the technology). Require a urea/Adblue system (included in the SCR package).
- SCR combined with early injection provides both low soot/PM emissions and low NOx emissions, as well as optimal combustion and reduced consumption/CO_2.
- Combined solutions are available (particle filters + SCR catalyst / NOx reduction)
- Filters can be installed at air intakes (for example on cranes)

NB: SCR systems can pose a health risk (exposure to isocyanic acid and ammonia) if the system is not properly operated and maintained.

Location and design of exhaust emissions

- Consider leading the exhaust elsewhere / further away from work areas / air intakes
- Consider releasing the exhaust at a different height
- Consider the shape of the exhaust pipes (pipes cut at a 45 degree angle have given lower emissions)
- Consider installing a compressor / ejector system to ‘shoot’ the exhaust further away

Other measures

- Establish a ‘water curtain/mist’ (if exhaust is led under the rig/facility)
- Turn movable installations so that the exhaust is not blown towards the work area
- Monitor exhaust gases continuously / at selected load points when engines are running. One can then monitor any developing faults that result in increased emissions
- Introduce ‘live’ (and historical) consumption measurements. This may also indicate the development of faults that may lead to increased emissions.
- Consider cleaning the intake air (highly effective solutions are available, which are also effective in cleaning the air of viruses and bacteria)

Appendix 4 Design of new facilities

When designing and engineering new installations, or when modifying existing installations, diesel exhaust exposure must be taken into account.

In this appendix, we have collated learning points that can be used when designing new facilities. From a working environment perspective, the selection of electrical machines is the best choice, since they do not emit exhaust.

Here are possible options that should be considered during the design phase:

- Clean-burning and efficient motors and generators with high efficiency.
- Engine technology/control that can interface with exhaust gas cleaning solutions.
- Exhaust gas cleaning solutions, possibly setting aside space for these.
- Continuous monitoring of exhaust gases, possibly at selected load points when engines are running, and continuous consumption measurement. Both these measures provide an opportunity to follow up any developing faults that may result in increased emissions.
- Location of air intakes and design of exhaust system so that the exhaust is routed away from work areas and air intakes, to ensure that the exhaust cannot find other air currents it can follow back to the moonpool, derrick or other areas. The goal is segregation and sufficient distance.
- More built-in work areas with ventilation from areas without exhaust.
- Plan power generators, switchboard rooms and power consumers so that a ‘single bus configuration’ can be run, thereby avoiding the splitting of power supplies and switchboard rooms to supply only dedicated areas with power. You can then choose which machines to use, depending on whether the exhaust is routed to starboard or port aft. You can also run fewer machines at a higher load, thereby improving fuel combustion.
- Use a power management system that contains all standard functions such as load-dependent start/stop, load sharing, synchronization, load separation, etc., and which has a design featuring advanced options that will reduce distribution losses, increasing energy availability for optimal operation with reduced exhaust emissions.
- Evaluate hybrid solutions with battery storage solutions integrated into the vessel’s power system (peak shaving). These provide fuel savings, lower emissions and reduced operations and maintenance, and provide optimized utilization of existing diesel generators in connection with start-up, operation and sudden load increases.