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Using the diesel engines in machines and vehicles in underground mine workings, especially in explosive atmospheres

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Abstract:

Efficient transport of materials and personnel is crucial for an efficient operation of a mining plant. Transport powered by diesel engines is widely used in mines due to its mobility. This article outlines the requirements that diesel engines operating underground must meet. These requirements particularly impact the design of engines operating in mine workings with a potentially explosive atmosphere. Due to operation in confined spaces, the quality of the engine's exhaust gases is also crucial, and increasingly stringent requirements have been imposed over the years. This article discusses the design of a diesel engine intended for operation in potentially explosive atmospheres, in light of the current requirements. Commonly used methods for improving the exhaust gases quality in surface engines are discussed, as well as the technical challenges associated with adapting them to engines operating underground. An example engine introduced to the market by a leading mining machinery manufacturer is presented.

Keywords: combustion engine, mine, exhaust gas quality, transport, ATEX

1. Introduction

Due to the specific working conditions in underground mine workings, use of the combustion engines there is conditioned by specific requirements. These requirements stem primarily from the hazards present in such workings, where operating diesel engines can pose a threat to the health and life of mining crews. Nevertheless, the widespread use of diesel engines, particularly in transport, stems from their numerous advantages, including, above all, their high mobility. These factors caused that the diesel-powered transport equipment replaces, and in even completely displaces the alternative means of transport (e.g., rope-driven or pneumatic-driven transport, or electric wire-powered transport) [1, 2, 3].

Depending on the type of mine working where diesel engines operate, we distinguish those at risk of methane and/or coal dust explosion. Safe use of diesel powered equipment, especially in mines with methane and/or coal dust explosion hazards, requires meeting numerous specific requirements during designing, manufacturing and operation. All of these requirements apply to the engine and its accessories, including the intake/exhaust system and control system [4].

2. Use of diesel engines in mine workings with potentially explosive atmosphere

Transportation, broadly defined, plays a key role in the process of mineral extraction in underground mines. This involves transporting ore, materials, machinery, and equipment from the mine surface to the underground workings (walls, faces, chambers, etc.). People (employees) are also moved to and from their workplaces in underground workings. Underground railway, suspended and floor-mounted railway as well as self-propelled mining machines (carts and vehicles) are the most common types of transportation in underground mines in hard coal mines, transport by underground railways, suspended and floor-mounted railways, generally dominates, while in copper ore mines, transport by self-propelled mining machines (carts and vehicles) dominates [5].

The last two decades have seen the dynamic development and use of mining machinery, including those for transport and people movement, powered by diesel engines. Use of self-propelled mine machines – diesel powered machines, in underground transport in 2024, are presented in Table 1.

Table 1. Number of transportations means in Polish mines

	Underground mining plant	Underground railway	Suspended monorail and floor-mounted railway	Self-propelled mine machines	
				carts	vehicles
1.	Hard Coal mines	150	620	-	2
2.	KGHM Polska Miedź S.A (cooper mines)	15	-	303	722
3.	Other mining plants	3	2	-	-
	TOTAL	**168**	**622**	**303**	**724**

3. Legal requirements regarding the quality of exhaust gases

3.1. Legal and normative regulations related to safety of use

Polish underground mining industry, depending on the type of raw material extracted, can be divided into three main sectors: copper ore, rock salt, and hard coal mining. Among these, coal mines are of high level of explosion hazard caused by the presence of methane and/or coal dust.

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Due to these specific conditions, applicable legal regulations impose strict requirements on underground machinery manufacturers regarding the design of explosion-proof protection systems, on the other hand accept some easing in the exhaust emission standards for diesel engines used in such conditions.

The most popular methods for explosion-proofing machinery and equipment include the following types:

type "d" flameproof enclosures [6],

type "e" reinforced enclosures [7],

type "i" intrinsic safety [8].

These protection methods require implementing the appropriate solutions at the designing stage of basic components, such as additional temperature sensors or special electronic circuit design. Therefore, without the appropriate support and involvement of the manufacturers of diesel engines themselves, it is very difficult to adapt the mostly advanced market designs for use in potentially explosive atmospheres, which translates into the aforementioned ease in exhaust emission requirements in this branch of underground mining.

The documents being in force in the European Union and regulating the use of diesel engines in the mining industry are the following:

- Directive 2006/42/EC, the so-called Machinery Directive [9] (implemented into Polish law by the Regulation of the Minister of Economy of 21 October 2008) – in all types of underground mining industry,

- Directive 2014/34/EU, the so-called ATEX Directive [10] (implemented into Polish law by the Regulation of the Minister of Development of June 6, 2016) – in mining industries at risk from the presence of flammable gases and/or dust.

According to the adopted concept, the Directive of the European Parliament and of the Council is a legal act setting a goal that must be achieved by all EU countries. The goals described therein are general in nature, covering the largest possible group of products. Specific requirements for each product group and products are contained in the standards harmonized with the directives. The basic standards for the use of diesel engines in the mining industry are the following:

- PN-EN 1679-1+A1:2011 Reciprocating internal combustion engines - Safety - Part 1: Compression ignition engines [11] – in all types of underground mining industry

- PN-EN 1834-2:2002 Reciprocating internal combustion engines - Safety requirements for design and construction of engines for use in potentially explosive atmospheres - Part 2: Group I engines for use in underground workings susceptible to firedamp and/or combustible dust – [12] – in the mining industry threatened by combustible gases and/or dust.

3.2. Requirements regarding the quality of exhaust gases

The quality of exhaust gases emitted into the atmosphere is an important aspect in underground mine workings (both with and without explosive atmosphere hazards). Detailed requirements in this regard depend on the engine power and are described in the PN-EN 1679-1+A1:2011 standard [11]. Table 2 presents the requirements of the above standard regarding the permissible content of substances in emitted off gases for diesel engines installed in underground machinery.

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Tabel 2. Permissible content of substances in emitted off gases [11]

Engine power P	Carbon monoxide CO	Hydrocarbons HC	Nitrogen oxides NOx	Solid particles PM
[kW]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]
$37 \leq P < 75$	6.5	1.3	9.2	0.85
$75 \leq P < 130$	5.0	1.3	9.2	0.70
$130 \leq P < 560$	5.0	1.3	9.2	0.54

The emission limits for harmful substances emitted by diesel engines operating in underground workings are also defined in Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 [12]. This regulation repealed the previously applicable provisions of Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 – the so-called Exhaust Gas Directive [13], regarding gaseous and particulate emissions from diesel engines, and is also a superior document to the standards.

Unlike the previous Directive 97/68/EC, the above regulation imposes different requirements on engines used in potentially explosive atmospheres compared to the engines operating outside such atmospheres, resulting in different treatment of specific types of underground mining. Engines operating in mines outside the potentially explosive atmosphere belong to the general category of mobile machinery not moving on public roads (NRE category - Non-Road mobile machinery Engines) and should meet the requirements of Table 3. In the light of Article 35(5) of Regulation (EU) 2016/1628, the engines intended for operation in potentially explosive atmospheres are special purpose engines (SPE) in relation to the NRE category and should meet the requirements shown in Table 4. The presentation of requirements for both above cases is limited to the engine power range from 37 kW to 560 kW.

Tabel 3. Emission limits for NRE category engines at stage V [12]

Stage of emission	Engine sub-category	Engine power range	Type of ignition	CO	HC	NOx	Mass of particulate matter	Number of particulate matters
[-]	[-]	[kW]	[-]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	number/kWh
Stage V	NRE-v-4 NRE-c-4	$37 \leq P < 56$	CI	5.0	(HC + NOx ≤ 4.70)		0.015	1×10^{12}
Stage V	NRE-v-5 NRE-c-5	$56 \leq P < 130$	all	5.0	0.19	0.40	0.015	1×10^{12}
Stage V	NRE-v-6 NRE-c-6	$130 \leq P \leq 560$	all	3.5	0.19	0.40	0.015	1×10^{12}

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Table 4. Special Purpose Engine (SPE) Emission Limits [12]

Stage of emission	Engine sub-category	Engine power range	Type of ignition	CO	HC	NOx	Mass of particulate matter
[-]	[-]	[kW]	[-]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]
SPE	NRE-v-4 NRE-c-4	37 ≤ P < 56	CI	5.0	4.7		0.4
SPE	NRE-v-5 NRE-c-5	56 ≤ P < 130	all	5.0	4.0		0.3
SPE	NRE-v-6 NRE-c-6	130 ≤ P ≤ 560	all	3.5	4.0		0.2

Table 5 presents the dates for implementation of the above requirements, set out in the Regulation (EU) 2016/1628, together with their updates resulting from the following subsequent regulations: Regulation (EU) 2020/1040 of the European Parliament and of the Council of 15 July 2020 [14] and Regulation (EU) 2021/1068 of the European Parliament and of the Council of 24 June 2021 [15]. The "Type-approval (EU) 2016/1628" column indicates the date from which manufacturers should obtain EU type-approval for Stage V and SPE-compliant engines. The "Placing on the market (EU) 2016/1628" column indicates the date after which only engines that meet Stage V or SPE requirements may be placed on the market, without a transition period. Regulation (EU) 2020/1040 introduced a 12-month postponement of the market entry dates for most engine categories, due to the impact of the COVID-19 pandemic. This data is included in the "New introduction date (EU) 2020/1040" column. A further postponement, resulting from Regulation (EU) 2021/1068, concerned the selected engine subcategories and is included in the "New introduction date (EU) 2021/1068" column. The final date until which machinery with engines not yet meeting the Stage V or SPE was permitted to be placed on the market results from Article 58 of the Regulation (EU) 2016/1628 and its modifications by the above-mentioned legal acts. This date is calculated by adding the postponed transition period (standard 18 months) to the new market entry date – the final result is presented in the "Latest date for placing on the market (including adaptation period)" column.

Table 5. Dates of using the Regulation 2016/1628 for the engines of the NRE category (including SPE) [12, 14, 15]

Stage of emission	Engine sub-category	Engine power range	Number of Regulations				Final date of commercialization (including adaptation period)
			2016/1628		2020/1040	2021/1068	
			Homologation type (UE) 2016/1628	Commercia-lization (UE) 2016/1628	New date of implementation (UE) 2020/1040	New date of implementation (UE) 2021/1068	
[-]	[-]	[kW]	[date]	[date]	[date]	[data]	[date]
SPE	NRE-v-4 NRE-c-4	37 ≤ P < 56	1 January 2018	1 January 2019	1 January 2021	-	1 January 2022
SPE	NRE-v-5 NRE-c-5	56 ≤ P < 130	1 January 2019	1 January 2020	1 January 2021	1 June 2022	1 January 2023

SPE	NRE-v-6 NRE-c-6	130 ≤ P ≤ 560	1 January 2018	1 January 2019	1 January 2021	-	1 January 2022

Requirements for exhaust gas quality are also indirectly specified by the regulations on air quality in underground mine workings and specified in the Regulation of the Minister of Energy of November 23, 2016, on detailed requirements for the operation of underground mines [16].

According to §142 of the above Regulation, all mine workings should be ventilated, so that the amount of oxygen in the air is at least 19% by volume, and concentration of the following gases in the air should not exceed:

1) carbon dioxide: 1%,

2) carbon monoxide: 0.0026%,

3) nitrogen oxide: 0.00026%,

4) sulfur dioxide: 0.000075%,

5) hydrogen sulfide: 0.0007%.

In contrast, §635 of the aforementioned Regulation, which directly addresses exhaust gases emitted by engine exhaust systems, limits carbon monoxide emission to 500 ppm in a methane-free atmosphere and 1,800 ppm when the methane concentration is up to 1.5%.

According to the above Regulation, the number of vehicles and machinery operating simultaneously in a mine working is determined to ensure that the permissible concentrations of harmful gases in the air are not exceeded.

In light of the applicable regulations, it can be stated that compliance with the requirements of Regulation (EU) 2016/1628 of the European Parliament and of the Council [12] guarantees compliance with the requirements of the PN-EN 1679-1 standard. Furthermore, in accordance with the Regulation of the Minister of Energy of November 23, 2016, on detailed requirements for the operation of underground mining plants [16], diesel engines operating in underground mine workings must not cause exceedances of permissible concentration of pollutants in the air. These requirements can be met by either reducing the number of vehicles or increasing ventilation of the workings. Reducing the number of vehicles reduces mining efficiency, while increasing ventilation necessitates thus construction of more efficient, and therefore more expensive, ventilation systems or increasing the cross-sections of the workings.

4. Methods for combating the toxic exhaust components, particularly in the aspect of using the diesel/ engines operated in the workings with paternally explosive atmosphere

Diesel engines are commonly used in the machines operating in underground mine workings. For safety reasons, only compression-ignition engines are used there [Journal of Laws 2017, item 1118, § 635.1]. For the engines operated in workings not at risk of explosive atmospheres, such as copper mines, the requirements in the Act do not affect the design of the engine itself or its accessories, allowing the use of engines commonly available on the surface. However, for the engines used in workings at risk of explosive atmospheres, like hard coal mines, the design of such an engine and its accessories is determined by current regulations and standards. These requirements specify requirements for the engine design and the need for additional accessories (Fig. 1).

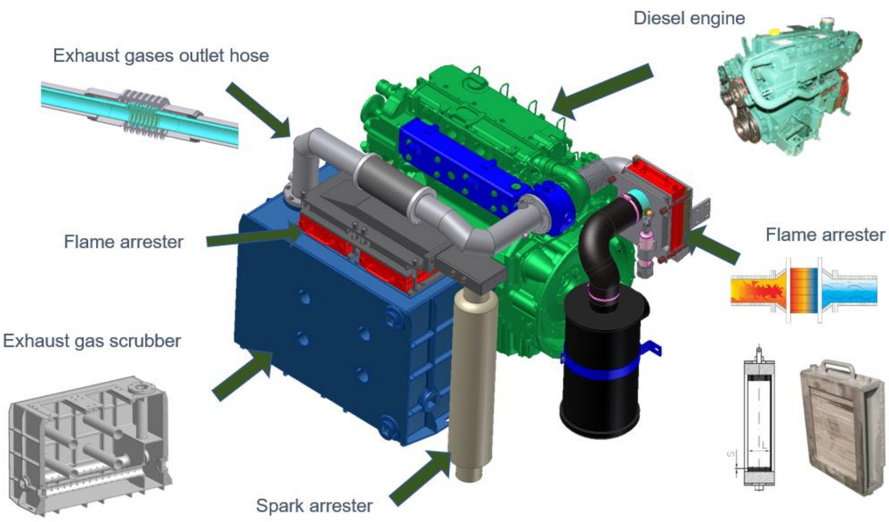

Fig. 1. Diesel engine for use in a potentially explosive atmosphere [17]

The most important requirement for diesel engines intended for use in workings with a potentially explosive atmosphere is the requirement to maintain a maximum external surface temperature of 150°C. This is due to the presence of combustible dust in the workings. However, if the device is operated in underground workings where combustible dust is not present, the maximum surface and exhaust gas temperature referred to above should not exceed 450°C. This requirement applies to all engine components accessible to the surrounding atmosphere under the most unfavorable operating conditions.

The intake-exhaust system is significantly modified compared to surface-mounted solutions, equipped with flame arresters at the boundary between the hazardous and non-hazardous areas [EN 1834-2]. The section of the exhaust system between the intake and exhaust flame arresters must also meet the requirements for a flameproof enclosure, which should be designed in accordance with the requirements for Group I gases specified in EN 50014:1997. The maximum temperature requirement also applies to the exhaust gases located directly downstream of the flame arrester, that is why heat exchangers or exhaust gas scrubbers are installed in the exhaust system.

The useful work generated by a diesel engine is a result of internal combustion of the fuel-air mixture. This process produces exhaust gases, the main toxic substances of which are: HC – hydrocarbons, CO – carbon monoxide, NOx – nitrogen oxides, and PM – particulate matter. The exhaust gas components emitted into the atmosphere pose a serious health risk.

The methods used to reduce the number of toxic substances in exhaust gases can be divided into two groups:

- Methods improving the combustion process in the engine cylinder,
- Methods with using the exhaust gas treatment in the exhaust system.

A commonly used solution for reducing nitrogen oxide (NO_X) emission is the exhaust gas recirculation system (EGR). This system lowers the maximum temperatures during the combustion process (NO_X are produced at temperatures above 1800ºC). Some of the exhaust gas is fed back into the combustion chamber with fresh air. The resulting fuel-air mixture has–lower oxygen content thus reducing combustion temperature to avoid NO_x generation. Efficiency of the EGR system is improved by additionally cooling the exhaust gases before they enter the combustion chamber. A special case is internal recirculation, which delays the closing of the exhaust valves during the intake stroke, while leaving the intake valves open. Requirements for mining diesel engines limit the maximum exhaust gas temperature emitted into the environment, so exhaust gas recirculation also has a positive effect on the exhaust gas temperature at the end of the exhaust system (lowering it). Therefore, introducing only an exhaust gas recirculation system reduces nitrogen oxide (NO_x) emissions, but increases emissions of incomplete combustion products. Developments in engine fuel systems also impact exhaust gas quality. Fuel systems commonly used in older engines, based on mechanically controlled in-line injection pumps, UIS (unit injector system), or UPS (unit pump system), have been replaced in modern engines meeting the highest standards with common rail fuel injection systems. State-of-the-art fuel injection systems enable precise adjustment of fuel delivery and injection timing to engine operating conditions. This allows for a more stable and efficient combustion process, which translates into reduced emissions of nitrogen oxides (NO_x) and particulate matter (PM). Furthermore, precise and independent injection control is necessary during the cyclical combustion of the particulate filter, which raises its operating temperature. The difficulty of using such fuel systems in mines with a potentially explosive atmosphere stems from the need to provide appropriate explosion protection for the electrical components of the system. Exhaust gas treatment methods incorporated into the exhaust system primarily include catalytic exhaust gas treatment for nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) filters. These systems generally do not affect the combustion process, and their function is to convert or store toxic substances.

Current diesel engines operating in mines use a water-based exhaust gas scrubber to ensure maximum temperature is not exceeded. According to various sources, water scrubbers can also positively impact exhaust gas quality. In various configurations, they remove approximately 20% of particulate matter, 50-80% of sulfur dioxide (SO_2), and up to 20% of hydrocarbons. The conversion of carbon monoxide (CO) and nitrogen oxides (NO_x) is virtually imperceptible [18].

Catalysts are divided into:

a) oxidizing,

b) reducing.

Oxidation and reduction reactions are two opposite reactions. This causes problems in the exhaust gas cleaning process, as the high oxygen content, which is beneficial for the oxidation of carbon monoxide (CO) and hydrocarbons (HC), adversely affects the amount of nitrogen oxides (NOx), and vice versa.

Three-functional catalytic converter (TWC) eliminates CO, HC, and NO_x, but requires a stoichiometric mixture is a special solution. Compression ignition engines operate on a lean mixture ($\lambda >> 1$), what means that these types of catalytic converters, as well as reduction catalytic converters, are not suitable for diesel engines. The only suitable catalysts are oxidation catalytic converters, which burn carbon monoxide (CO) and hydrocarbons (HC).

An important parameter characterizing the catalytic converter is its operating temperature. The reliable operating temperature for a catalytic converter is 250ºC-900ºC. This significantly exceeds the requirement for the maximum external surface temperatures of mine diesel engines. The use of catalytic converters in engines in potentially explosive mining operations would require heating them to the required operating temperature while ensuring an external surface temperature not exceeding 150°C.

Nitrogen oxides are the main problem with exhaust gas treatment in diesel engines. Their removal requires using the special methods that allow for their conversion in the exhaust gas with a high oxygen content. Three basic methods can be distinguished in nitrogen oxide (NO_x) removal processes:

a) SCR – Selective Catalytic Reduction using an aqueous urea solution; conversion rate 65-90%

b) LNC – Lean NOx Catalyst – reduction of nitrogen oxides (NO_x) using hydrocarbons (HC-SCR); conversion rate 10-50%

c) LNT – Lean NOx Traps – absorption of nitrogen oxides (NO_x) inside the catalytic converter, followed by cyclical removal; conversion rate 50-80%.

Selective catalytic reduction, commonly used in diesel engines, uses an additional agent injected into the exhaust system, which reacts with nitrogen oxides (NO_x) reducing them to nitrogen (N_2). Ammonia is used in industrial installations for this purpose. Ammonia (a toxic substance) in gaseous form could not be used in mobile systems for safety reasons. Therefore, it was replaced with an aqueous solution of urea, which is non-toxic and liquid. Tests on the possibility of using SCR in the engines operating in explosive mining atmosphere showed a significant impact of external surface cooling on the NO_x reduction process [19].

5. Examples of the engines used in underground mine workings

In Poland, Becker-Warkop Sp. z o.o is one of the leading manufacturers of diesel engine-powered machines for use in mining areas with potentially explosive atmospheres. With the current requirements in mind, in 2024, Becker-Warkop introduced the KP-104 diesel-powered suspended monorail locomotive, which meets exhaust emission standards (EU Regulation 2016/1628). The locomotive is a driving unit for suspended monorail used for transporting machine parts, materials, and moving people in underground mines (Fig. 2). The locomotive runs on approved I155 (I140E) and I140V95 profile tracks and can be configured in the following three drive design versions:

- KPCS – locomotive equipped with friction drives;
- KPZS – locomotive equipped with HZA gear drives;
- KPCZ – locomotive equipped with HZAO type friction and gear drives.

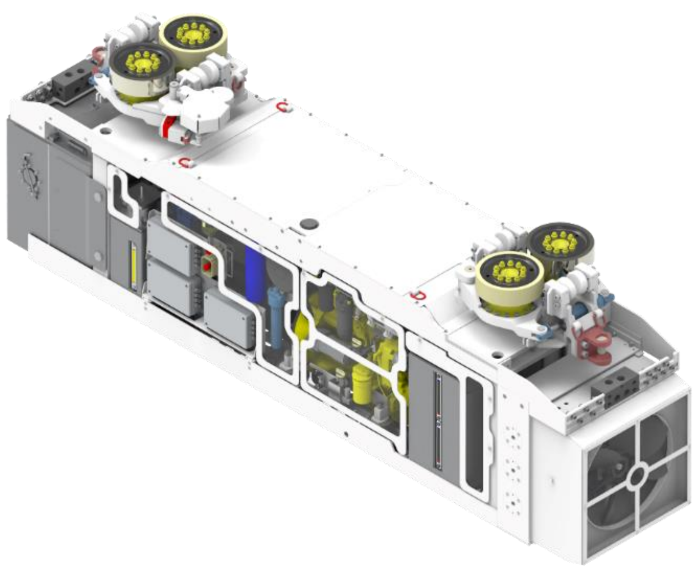

Fig. 2. KP-104 Locomotive [20]

The KP-104 locomotive is equipped with an explosion-proof BWJD.(X) Ex diesel engine, available in three maximum power outputs: 104 kW, 93 kW, and 86 kW (Fig. 3). Engine parameters are summarized in Table 6. The engine was designed by Becker-Warkop engineers based on a John Deere industrial engine commonly used in off-road surface equipment. The air, fuel, and control solutions

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implemented in the base engine allow it to meet the Stage IIIA exhaust emission standard without the need for additional exhaust aftertreatment components. When designing the BWJD.(X) Ex engine, Becker-Warkop engineers adapted the original equipment and retrofitted the base engine with the necessary components, enabling the safe operation in mining areas with a potentially explosive atmosphere, thereby meeting the requirements of the ATEX directive for IM2 equipment. This was achieved by using flame arresters in the intake and exhaust systems, thermal shielding of the exhaust system components, and the use of a water-based exhaust gas scrubber. Power supply and control units were also modified to apply proper explosion protection.

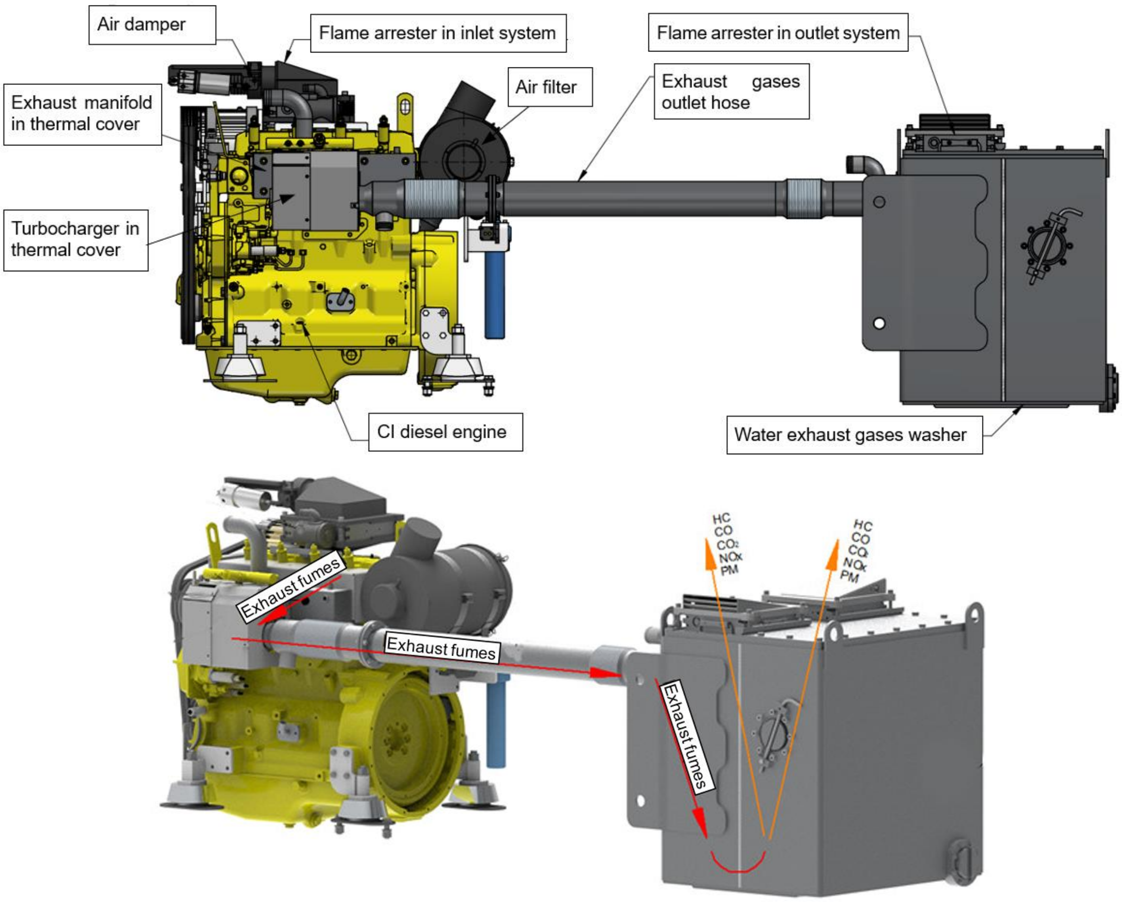

Fig. 3. Design of BWJD.(X) Ex engine [20]

Table 6. Technical parameters of BWJD.(X) Ex engine

Design	four-cylinder, in-line,
Power	86 kW, 93 kW, 104 kW
Total displacement	4500 cm^3
Cooling	forced water system
Capacity of the engine cooling system	60 dm^3
Emission stage	SPE
Fuel supply system	Common rail
Intake system	Turbocharging with air cooler
Exhaust system	Cooling the exhaust gases in water

The BWJD.(X) Ex engine is a special-purpose engine designed for installation in off-road mobile machinery that may be used in a potentially explosive atmosphere. Therefore, it is subject to an exemption under Article 34(5) of Regulation (EU) 2016/1228 and must meet the Stage SPE exhaust emission standard (which, in terms of limit values, overlaps with the Stage IIIA standard). Compliance with this exhaust emission standard was confirmed by the BOSMAL Institute of Automotive Research and Development sp. z o.o. Within the engine commercialization procedure, the engine manufacturer obtained the following documents:

- an EU type approval certificate for an engine type or its series, intended for off-road mobile machinery in accordance with Regulation (EU) 2016/1628 (EU-type approval number: e20*2016/1628*2022/992EV5S/D*0004*00).

- a certificate of authorization for placing the replacement engines on the market in accordance with the Act of 15 July 2020 on EU-type approval and market surveillance systems for diesel engines intended for off-road mobile machinery.

In accordance with the Act of 15 July 2020 on EU-type approval and market surveillance systems for diesel engines intended for off-road mobile machinery, referred to in Article 34, paragraphs 5 and 6 of Regulation 2016/1628, are covered by an EU type approval certificate and authorization.

The engine is marked with a nameplate in accordance with the requirements of Regulation (EU) 2017/656, which includes the EU type-approval number and an exclusion code. These markings indicate compliance with the applicable exhaust emissions standard and that the engine is only being placed on the market for installation in off-road mobile machinery intended for use in a potentially explosive atmosphere as defined in Article 34. 2 Item 5 of Directive 2014/34/EU of the European Parliament and of the Council (Fig. 4).

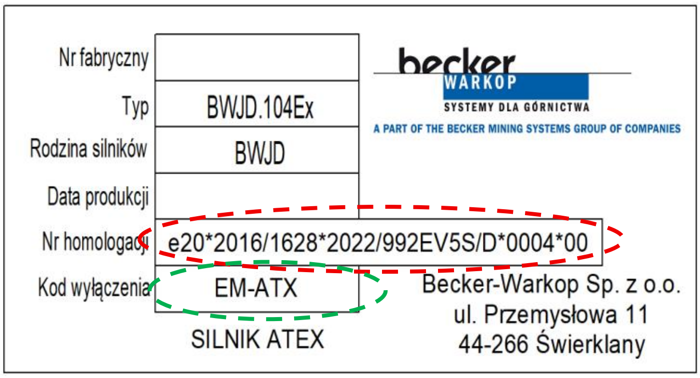

Fig. 4. Nameplate with homologation number and exclusion code [20]

6. Conclusions

Machinery and equipment powered by diesel engines require meeting a number of requirements, both regarding the engine design and quality of the exhaust gases. Engines operating in a potentially explosive atmosphere are a special case, requiring a specific approach during the designing and manufacturing stages. These requirements are defined by the legal provisions contained in the ATEX Directive and the harmonized standards.

To ensure safe engine operation it is not possible using the standard, surface-mounted diesel engines that meet the latest exhaust emission standards and are generally available on the market. Adapting an engine to operate in potentially explosive atmospheres primarily concerns the intake and exhaust system and the electrical and electronic components. Modification of the following components is required:

- all types of sensors (pressure, temperature, crankshaft position, etc.),
- injectors, which in current solutions are electronically controlled,
- the engine management system (computer, ECU),
- the engine intake and exhaust systems,
- the exhaust manifold, and the turbocharger.

These conditions result in a different approach to exhaust emission requirements for engines used in potentially explosive underground workings compared to those in non-hazardous workings. Taking into account the technical limitations of diesel engines operating in workings at risk of explosive atmospheres, the legislature has allowed for reduced upper limits for toxic exhaust emissions compared to engines of the same power and similar applications on the surface. In addition to a type approval certificate, engines for operation in potentially explosive atmospheres are special-purpose engines (SPE Stage) and require a marketing authorization certificate that includes information about the restrictions regarding their use in potentially explosive atmospheres.

References

[1] Drwięga A., Pieczora E., Suffner H.: Nowe rozwiązania górniczych urządzeń transportowych z napędem spalinowym. Masz. Gór. 2007 nr 3 s. 34 - 40.

[2] Kaczmarczyk K.: Ekologiczne aspekty eksploatacji górniczego napędu spalinowego. Masz. Gór. 2013 nr 4 s. 56-62, ISSN 0209-3693.

[3] Pieczora E.: Prognoza rozwoju szynowych systemów transportowych stosowanych w podziemiach kopalń węgla kamiennego. Gospod. Surow. Miner. 2008 nr 1/2 s. 221-232.

[4] Brzeżański M., Pieczora E., Kaczmarczyk K.: Rozwiązania napędów spalinowych do zastosowań w wyrobiskach podziemnych węgla kamiennego. Solutions of disel drives for use in underground workings of hard coal mine. Siln. Spalin. 2010 nr 3 s. 28-40.

[5] Antoniak J.: Urządzenia i systemy transportu podziemnego w kopalniach. Katowice: Wyd. Śląsk, 1976.

[6] PN-EN 60079-1:2014-12 Atmosfery wybuchowe - Część 1: Zabezpieczenie urządzeń za pomocą osłon ognioszczelnych „d".

[7] PN-EN 60079-7:2016-02 Atmosfery wybuchowe - Część 7: Zabezpieczenie urządzeń za pomocą budowy wzmocnionej „e".

[8] PN-EN 60079-11:2012 Atmosfery wybuchowe - Część 11: Zabezpieczenie urządzeń za pomocą iskrobezpieczeństwa „i".

[9] Dyrektywa 2006/42/WE Parlamentu Europejskiego i Rady z dnia 17 maja 2006 r. w sprawie maszyn, zmieniająca dyrektywę 95/16/WE.

[10] Dyrektywa Parlamentu Europejskiego i Rady 2014/34/UE z dnia 26 lutego 2014 r. w sprawie harmonizacji ustawodawstw państw członkowskich odnoszących się do urządzeń i systemów ochronnych przeznaczonych do użytku w atmosferze potencjalnie wybuchowej.

[11] PN-EN 1679-1+A1:2011 Silniki spalinowe tłokowe - Bezpieczeństwo - Część 1: Silniki o zapłonie samoczynnym.

[12] PN-EN 1834-2:2002 Silniki spalinowe tłokowe - Wymagania bezpieczeństwa dotyczące projektowania i budowy silników przeznaczonych do stosowania w przestrzeniach zagrożonych wybuchem - Część 2: Silniki grupy I przeznaczone do stosowania w pracach podziemnych zagrożonych występowaniem metanu i/lub palnego pyłu.

[13] Rozporządzenie Parlamentu Europejskiego i Rady (UE) 2016/1628 z dnia 14 września 2016 r. w sprawie wymogów dotyczących wartości granicznych emisji zanieczyszczeń gazowych i pyłowych oraz homologacji typu w odniesieniu do silników spalinowych wewnętrznego spalania przeznaczonych do maszyn mobilnych nieporuszających się po drogach, zmieniające rozporządzenia (UE) nr 1024/2012 i (UE) nr 167/2013 oraz zmieniające i uchylające dyrektywę 97/68/WE.

[13] Dyrektywa 97/68/WE Parlamentu Europejskiego i Rady z dnia 16 grudnia 1997 r. w sprawie zbliżenia ustawodawstw Państw Członkowskich odnoszących się do środków dotyczących ograniczenia emisji zanieczyszczeń gazowych i pyłowych z silników spalinowych montowanych w maszynach samojezdnych nieporuszających się po drogach.

[14] Rozporządzenie Parlamentu Europejskiego i Rady (UE) 2020/1040 z dnia 15 lipca 2020 r. zmieniające rozporządzenie (UE) 2016/1628 w odniesieniu do jego przepisów przejściowych w celu uwzględnienia wpływu kryzysu związanego z COVID-19.

[15] Rozporządzenie Parlamentu Europejskiego i Rady (UE) 2021/1068 z dnia 24 czerwca 2021 r. zmieniające rozporządzenie (UE) 2016/1628 w odniesieniu do jego przepisów przejściowych dotyczących niektórych maszyn wyposażonych w silniki o zakresach mocy co najmniej 56 kW i nie większym niż 130 kW oraz co najmniej 300 kW, w celu zaradzenia skutkom kryzysu związanego z COVID-19.

[16] Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych (Dz.U. 2017 poz. 1118 z późn. zm.).

[17] Kaczmarczyk K., Brzeżański M.: Problemy ekologiczne silników spalinowych eksploatowanych w wyrobiskach podziemnych węgla kamiennego. Prace Naukowe - Monografie KOMAG nr 46, Instytut Techniki Górniczej KOMAG, Gliwice 2015 s. 1-107; 6,47 ark. wyd., ISBN 978-83-60708-87-3.

[18] Szlązak N., Borowski M.: „Wentylacyjne aspekty stosowania maszyn z silnikami spalinowymi w kopalniach podziemnych” Szkoła Eksploatacji Podziemnej, Kraków 2002.

[19] Kaczmarczyk K., Brzeżański M.: Impact of flameproof exhaust system on efficiency of selective catalytic reduction. Combust. Engines 2015 nr 4s. 26-33, ISSN 2300-9896.

[20] Information provided by Becker-Warkop Sp. z o.o.

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