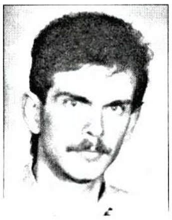

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The experimental research on particulate solid emission from 7RND90M main diesel engine of the m/s KATOWICE II

SUMMARY

The experimental research on particulate solid emission from 7RND90M main diesel engine of the merchant ship KATOWICE II is presented. The basic information on the tested engine and test conditions are given.

Concentration of particulate solid in exhaust gases and their rates of emission are presented in function of engine load, fuel oil quality and onboard fuel treatment.

The paper was presented at the XIX International Symposium Ship Propulsion Plants held in Szczecin on 16 to 17 October 1997

INTRODUCTION

All the matter, either solid or liquid, organic or inorganic, accumulated on the absolute filter after passing the exhaust gases through it at a determined temperature is considered the *particulate solids* (solid particles) in accordance with the definition. The mass of the so accumulated substance is determined as the total mass of particulate solids and is called Total Particulate Mass (TPM). It consists of soot and non-combusted hydrocarbons absorbed on its surface, metals and water soluble sulphates together with accompanying water.

The solid particles of various shapes and forms are of small dimensions (more than 90% of emitted particles are smaller than 1μm) [1], and therefore they remain in the atmosphere for a long time and are easily absorbed by the breathing system. Thus they form a carrier of heavy metals, sulphur and nitrogen compounds and hydrocarbons, among which direct or indirect carcinogenic substances can be found. Therefore it is necessary to limit particulate solid emission in the case of the engines exploited in land transport. The particulate solid emission limitation now concerns also the low-speed diesel engines applied to the land-based electric power plants.

However in the field of marine combustion engines only a draft of the standard for limitation of emission of sulphur and nitrogen oxides, i.e. the substances of a broad range of proliferation, is under elaboration so far, although ecological reasons are more and more important for marine environment too. Till now fouling the elements of low-speed marine diesel engines and mechanisms co-operating with them has been more important as it is connected with lowering the total efficiency, increasing the fuel consumption, repair and maintenance cost, and sometimes causes serious failures leading to violation of safety at sea.

The fouling is caused by depositing the particles on the walls of the outlet passage, turboblowers and exhaust gas heat utilizing devices such as heat exchangers, power turbines etc. It is considered, although the deposit formation mechanism is not yet fully recognized, that the shape, state of surface and temperature of a fouled element, exhaust gas temperature and velocity, as well as kind and number of solid particles contained in the gases are the main factors decisive of the deposit layer thickness and content, and its growth rate.

The exploitation problems connected with heavy fuel oil combustion which were faced by shipowners especially during operating main engines at lower loads and lack of data on the rate and character of solid particle emission were the starting point for extensive investigations on particulate solid emission, initiated by the team of the Department of Combustion Engines and Compressors.

Emission measurements on the 7RND90M Sulzer main diesel engine built in AESA Works, Manises, Spain, carried out at the end of the 1980s during a regular voyage of the KATOWICE II, owned by Polish Ocean Lines, Gdynia, was one of the stages of the investigations. The research was aimed at the determination of influence of loading the engine working in accordance with the service propeller curve, as well as of kind of combusted fuel and way of its advance treatment, on the rate of emission of solid particles.

OBJECT OF INVESTIGATION AND MEASURING CONDITIONS

The investigated object was the 7RND90M Sulzer, low-speed, two stroke, turboblower charged main engine installed on the KATOWICE II. Basic technical specification of the engine is included in Tab.1.

The measurements were carried out within the speed range of 97 to 116 rpm and power range of 7000 to 12 700 kW (40 to 75% N_{en}) which corresponded to the change of the engine mean effective pressure within the range of 625 to 975 kPa.

Particular measurement series were performed at different service propeller curves, however differences of external loading conditions were not significant and therefore not so important to make comparison of the obtained measurement results of solid particle concentration impossible. Detail information on the engine's working parameters during carrying out the measurements can be found in [1,2].

Tab. 1. Basic technical specification of 7RND90M diesel engine

Cylinder bore	[mm]	900
Piston stroke	[mm]	1550
Number of cylinders	[-]	7
Nominal power	[kW]	17243
Nominal speed	[rpm]	122
Mean effective pressure	[kPa]	1229

During the tests the engine was supplied with the following fuel oils (Tab.2) to determine influence of fuel oil kind and its advance treatment on solid particle emission :

- A1 and A2 heavy fuel oil one-stage purified in a purifier, hereafter marked A1P and A2P respectively
- A1 heavy fuel oil two-stage purified in a purifier and clarifier working in series, hereafter marked A1P/K
- diesel oil marked A3.

Tab. 2. Properties of the fuel oils combusted in the 7RND90M engine

Fuel oil symbol		A1P	A1P/K	A2P	A3
Treatment method		Purified	Purified/ /Clarified	Purified	-
Density at 15°C	kg/m³	986	986	977	873
Viscosity at 50°C	cSt	367	367	217	4.7
CCAI index	-	848	848	844	810
Heat value	kJ/kg	39860	39860	40080	41810
Conradson number	% m/m	16.20	16.38	11.10	-
Ash content	% m/m	0.06	0.06	0.04	-
Water content	% v/v	0.30	0.06	0.03	-
Asphaltene content	% m/m	10.1	10.0	3.5	-
HF- deposit content	% m/m	0.004	0.003	0.003	-

MEASUREMENT METHOD

Detail description of the measurement method and test stand can be found in [1,2].

Solid particles were separated from the flow of the unthinned exhaust gases by filtering. An original measurement stand was designed to this end by the investigation team.

Exhaust gases were taken from the engine exhaust gas collector by means of a sounder fixed in the collector manhole cover. The sounder inlet was located in the zone of exhaust gases inflowing from the turbocompressor. After leaving the sounder the exhaust gases flew to the measurement filter unit through the insulated piping made of stainless steel. At the beginning of each measurement the temperature of 170 to 180°C was maintained in front of filter. After separating the solid particles on the measurement filter the exhaust gases were directed into the cooler unit. The exhaust gas flow rate was measured by means of the diaphragms and volumetric flowmeter installed at the outlet from the measurement stand. The needle valve made changing the exhaust gas flow rate possible.

Solid particles mass was determined by using the gravimetric method recognized as the most accurate [3]. Weighing was performed with 0.05 mg accuracy at the mean total mass of the particles of a few dozen mg collected on the filter paper. Before weighing the filters were seasoned at a constant temperature and relative air humidity for at least 24 h. Weighing of the filter together with the solid particles collected on it, was allowed at the air humidity not differing more than ± 4% from the conditions of weighing the clean filter. The obtained result was corrected by taking into account the allowance determined in result of the seperate measurements [1].

The solid particle concentration in exhaust gases was expressed by the ratio of the mass of the particles deposited on the measurement filter and that of the exhaust gases which flew through the filter during measurements :

$$c = \frac{m_{cz}}{m_{sp}} \tag{1}$$

where :

c - solid particle concentration in exhaust gases [g/kg]
m_{cz} - mass of solid particles [g]
m_{sp} - mass of exhaust gas [kg]

Hourly emission of solid particles was calculated as a product of the solid particle concentration in exhaust gases and hourly exhaust gas flow through the engine :

$$E_m = 10^{-3} c \cdot G_{sp} \tag{2}$$

where :

E_m - hourly emission of solid particles [kg/h]
G_{sp} - hourly exhaust gas flow rate [kg/h]

The specific solid particle emission was calculated as the ratio of the hourly emission and the effective engine power :

$$e_m = \frac{E_m}{3.6 \cdot N_e} \tag{3}$$

where :

e_m - specific solid particle emission [g/kWh]
N_e - effective engine power [kW]

EMISSION OF SOLID PARTICLES IN STEADY OPERATION STATES OF THE ENGINE AT CHANGEABLE LOADING IN ACCORDANCE WITH SERVICE PROPELLER CHARACTERISTICS

Results of measurements of solid particle concentration in exhaust gases, taken in the instants of steady operation state of the engine versus changeable loading in accordance with service propeller characteristics are presented in Fig.1.

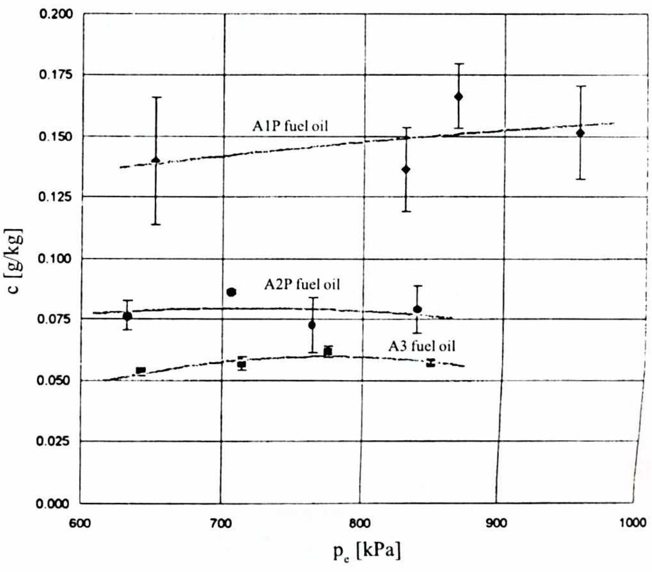

Fig. 1. The solid particle concentration in exhaust gases, c, versus engine loading - the effective combustion pressure p_e

In each measurement point the segment was depicted which corresponded to the mean standard deviation of the concentration in the point. The measurement results were approximated by means of a second-order polynomial with the use of the least squares method.

The solid particle concentration in exhaust gases of the engine in question (Fig.1.) in the range of the mean and higher loading slightly varied, and the difference of the maximum and minimum values related to the mean value at a given point was contained within 8 to 10 % range. The course is similar for all the fuel oils combusted in the engine. However it should be stressed that the scatter of the measurement results, expressed as the mean square deviation, varied together with the quality of the applied fuel oil. It was the largest with A1P fuel oil of the highest density (Tab.2.), lower with A2P fuel oil of a higher quality and the smallest with the A3 diesel oil. The observation revealed that the lower the quality of fuel oil the higher the engine working process instability.

Courses of the specific and hourly solid particle emission in accordance with the expressions (2) and (3) are of a different character. They were determined on the basis of engine producer's data as it was not possible to directly measure the mass rate of exhaust gas flow through the engine during the investigations. The emission was calculated by assuming the mean solid particle concentration value at a given measurement point as well as the mean specific fuel oil consumption value. Therefore values of the mean standard deviation and measurement points were not shown in Fig.2 and 3.

The course of the specific solid particle emission (Fig.2) from the engine in question is rather flat over the investigated loading range. The emission variation is contained within 0.1 g/kWh ; it slightly increases when A1 fuel oil is used as the engine load increases and it decreases when A2 and A3 fuel oil is applied.

The relatively flat course of the solid particle concentration and specific emission indicates that no considerable differences of air-fuel mixture formation conditions and of combustion process itself occur.

However the hourly solid particle emmission (Fig.3) increases as the engine load increases. It results from the growing mass of the combusted fuel oil and growing exhaust gas flow rate along with the increasing engine load.

INFLUENCE OF KIND OF FUEL OIL AND OF ITS ADVANCE TREATMENT ON EMISSION OF SOLID PARTICLES

The courses of the solid particle concentration and of their specific and hourly emission, shown in Fig.1,2 and 3, clearly demonstrate that the emission level and kind of the fuel oil combusted in the engine are strongly related to each other. The highest particles emission occured with A1P heavy fuel oil (corresponding to IF 360 viscosity class) a lower emission with A2P heavy fuel oil (corresponding to IF 180 viscosity class) and the lowest emission with A3 diesel oil.

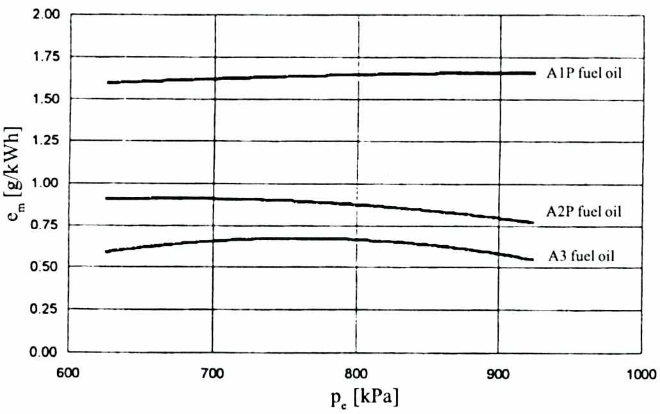

Fig.2. The specific solid particle emission e_m versus the effective combustion pressure p_e

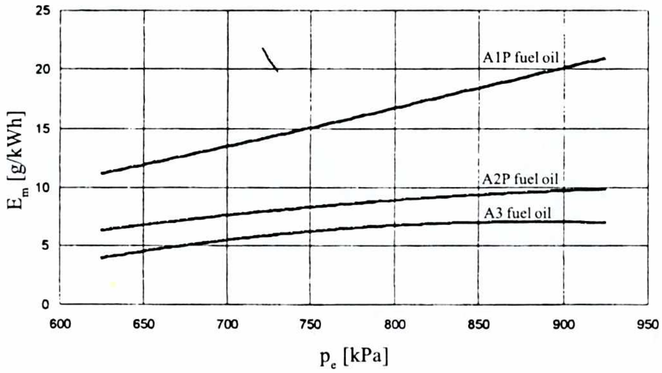

Fig.3. The hourly solid particle emission E_m versus the effective combustion pressure p_e

Values of the particle emission occurring during combustion of particular fuel oil kinds were related to the basic values determined during A3 fuel oil combustion to obtain values of the relative emission and thus make comparisons easier (Fig.4).

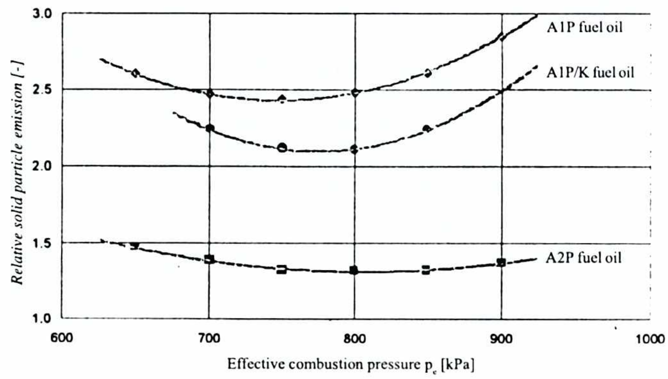

Fig.4. Influence of the kind of fuel oil and of its advance treatment on solid particle emission

It can be observed, when analyzing the results shown in Fig.4., that the solid particle emission with the of A1P fuel oil of the highest density, Conradson's number value and asphalt- resin compounds content, was 2.5÷3 times greater than that with the diesel oil. However the emission when the engine was supplied with A2P fuel oil of a lower density, moderate Conradson's number value and relatively low asphalt-resin compounds content, was only 1.3÷1.5 times greater than that with of the diesel oil.

It was demonstrated in several publications, e.g. [4], that the content of aromatic hydrocarbons in fuel oil has an important influence on the solid particle emission. It results from the analysis performed in [1] that the aromatic carbon content c_{ar} (i.e. the share of the number of carbon atoms contained in aromatic rings in the total number of the carbon atoms contained in one fuel oil particle) was 30% and 27% for A1P and A2P fuel oil respectively, against about 20% for diesel oil on average. It can serve as an explanation of the much greater particle emission with the heavy fuel oils in comparison to that when the diesel oil is supplied to the engine.

Compounds of multi-ring structure and the asphalt-resin structures, which subject to thermal decomposition during combustion, undergo pyrolysis i.e. the decisive process in starting the carbon black formation [5], play a specific role in the mechanism of building the solid particles. Therefore much greater particle emission occured with combustion of A1P fuel oil containing about 10% of asphaltenes than with the A2P fuel oil which contained 3.5% of asphalt-resin compounds only.

One of the aims of the investigations performed on the KATOWICE II was to determine the influence of the way of fuel oil advance treatment on the particle emission level. The investigations had to provide premises on the choice of a method of fuel oil purification depending on fuel oil properties. The assessment parameter was the number of solid particles emitted by the engine combusting the fuel oil treated in a given way, but not the amount of waste removed from the fuel oil, and this was an important novelty. However, for operational reasons comparison of only two purification methods was possible. Therefore it was decided to carry out the investigations supplying the engine with A1 heavy fuel oil purified as follows :

- in one stage – by using one purifier operating with the output covering daily fuel oil consumption by the engine (A1P fuel oil)
- in two stages – by using a purifier and clarifier operating in series, each with the output covering daily fuel oil consumption by the engine (A1P/K fuel oil).

The two-stage purification makes removing small particles (e.g. Si and Al compounds) from fuel oil possible, as well as it prevents from letting the fuel oil not fully purified into service fuel tanks in the case of irregularities in purification process.

Results of the investigations are presented in Fig.4 where the values related to the emission from the diesel oil are given. Comparison of the relative emission with A1P fuel oil purified with the use of the purifier only and that with the A1P/K fuel oil purified with the use of the purifier and clarifier working in series indicates that the two-stage purification makes it possible to lower the solid particles emission by about 13% against the emission at combustion of one-stage purified fuel oil.

CONCLUSIONS

The performed investigations revealed that :

- The solid particle concentration and specific emission varies rather slightly within the range of average and higher load of the engine independent of a kind of fuel oil.
- However the hourly solid particle emission increases as the engine load increases, and it is two times greater at 75% N_{en} of the engine than that at 40% N_{en}.
- The investigation results indicate that the particle emission level strongly depends on the fuel oil kind combusted in the engine. The emission with combustion of the heavy fuel oil of 986 kg/m^3 density corresponding to IF 360 viscosity class was 2.5 to 3 times greater than that with combustion of diesel oil, and – 1.3 to 1.5 times greater with combustion of the heavy oil of 977 kg/m^3 density corresponding to IF 180 viscosity class.
- Application of the two-stage purification of fuel oil with the use of the purifier - clarifier set working in series made it possible to lower the solid particle emission by about 13% relative to the emission with the use of the fuel oil purified by one purifier only.

NOMENCLATURE

c - solid particle concentration in exhaust gases
e_m - specific solid particle emission
E_m - hourly emission of solid particles
G_{sp} - hourly exhaust gas flow rate
m_{cz} - mass of solid particles
m_{sp} - mass of exhaust gas
N_e - effective engine power
N_{en} - effective engine power rating
p_e - effective combustion pressure

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Appraised by Andrzej Balcerski, Assoc.Prof.,D.Sc.,M.E.

Current *report*

TECHNICAL UNIVERSITY OF GDAŃSK
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SOFTWARE FOR CALCULATING THE SHIP SHAFTLINE TRANSVERSE VIBRATIONS

A software system for calulating the ship shaftline dynamic parameters (critical revolutions, vibration amplitudes, internal moments and forces, dynamic stresses etc) which can be used for assessing the dynamic state of the shaftline, was elaborated by the team of the Mechanics and Strength of Materials Department, Mechanical Faculty, Technical University of Gdańsk, under coordination of Zbigniew Walczyk, D.Sc., Assoc. Prof. The software can be applied to improve the shaftline dynamic state (e.g. by preliminary alignment of the shaftline on the bearings, change of stiffness of the supporting structure i.e. hull, double bottom etc) first of all during the design stage of the propulsion system but also on ships in operation.

The software consists of programs for :

- statical calculations of the ship shaftline
- calculations of forced vibrations inclusive of critical revolutions at resonance states
- calculations of free vibrations inclusive of natural vibration forms and frequencies

and is applicable to analyzing the shaftline dynamics within the range of transverse (flexural) vibrations. The ship structure is modelled by substructures such as propulsion shafts, bearing supports and ship hull (double bottom) as well as the lubricating oil layer (film) in the bearings.

The method of dynamic interaction of the substructures (flexibility of ship hull and bearing supports, elastic and damping characteristics of the substructures) was applied to solve the dynamic problem of the complex system in question. The phenomenon of the so called „additional mass of water" which changes inertial, damping and flexural characteristics of the propeller was also taken into account. The forces exerted on the propeller acting in non-uniform water flow behind the ship stern are used as the propulsion system excitations. Static and dynamic problems of the shaftline are solved with the use of physical, discrete-continuous models and the transfer matrix method.

The programs are user-friendly due to editors applied to input data pre-processing and due to very short time of execution of the calculations.

In the design stage the software system makes it possible :

- to carry out multi-variant calculations of the propulsion system in question together with sensitivity assessment of the system dynamic state to change of its parameters
- to calculate influence of the assembling parameters (preliminary alignment heights of the bearing supports) and of bearing stiffness on the dynamic state of the shaftline.

In the operation stage it is possible to improve the dynamic state of the propulsion system by tuning-off the resonance revolutions, decreasing the vibration amplitudes etc.

The software can be used as a theoretical basis for dynamic state diagnosing process of the ship propulsion systems (it can be applied to obtaining the diagnostic relationships as well as identifying the system's parameters).