Giuseppe LANDRI, Antonio PACIOLLA, Augusto POLLETTA, Franco QUARANTA

# THE PROBLEM OF EXHAUST EMISSIONS OF MARINE DIESEL ENGINES

## ABSTRACT

Environmental decay can be considered as one of the most strongly felt problems of modern life on the planet: there is no place of earth where the problem of pollution does not affect the quality of life in the medium and long term when it does not already determine a sensible worsening of life conditions of the living beings in contact with it.
As it is well-known, the problem of pollution of the marine environment is strictly connected with the energy transformation and, in this framework, with the diffusion of internal combustion engine.
The aim of the present paper is to offer an overview of the position of the naval field in relation to the risk of pollution, of the possibility to check the emissions of marine engines, of the regulations which will probably take root following the ones already applied or in development for the road traction.
In the likely hypothesis that the regulation on the marine exhaust will follow those in the terrestrial field, we indicate the terms of the transfer of the experiences made on the engine for road traction in the marine reality, with the necessary distinctions due to different "missions" that these two applications are called upon to carry out.

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## Preface

The problem of air pollution has been denounced in California since 1941; war events have postponed its study while that US State has always been advanced in the fight against environmental decay.
In each State and in international organisations (UNO, EEC, OCSE), there are official institutions whose task, inside their own provinces, is to take care of the environmental preservation promoting the formulation of compulsory rules. Even mass media, because of political plans, of cultural fashion or simply to enhance their audience, deal a lot with environmental problems, often in a melodramatic way.
Today it is necessary to become conscious of the objective situation, leaving out the soundness of the reasons that determine it: from now on any project of practical initiatives in industrialised societies will have to take into account, among the "boundary conditions", regulations for the protection of the environment.
The result of these regulations could as well be very heavy: in the USA the rules on car emissions, issued in the early sixties and getting periodically stricter, took to projecting, already in the mid-seventies, spark ignition engines essentially different from those produced in Europe in the late eighties; in California it is practically impossible to put in circulation diesel cars whose engines were manufactured following technologies available at the moment.
Sea pollution, although different from the terrestrial one, risks to be no less heavy at least for some coasts; the large merchant ports, for instance, where the simultaneous presence of large tonnage ships, equipped with high power engines, can create problems of high concentration of toxic substances released in the air by exhaust gases, or the piers of smaller ships which, if working at the same time, can rise the pollution levels in these places beyond the threshold of tolerability.
As for road transportation, the first and strictest restrictions in sea transportation, even if at local level, have been taken in the most frequented areas, where a number of factors sum up:

- high number of vessels;
- need for these vessels to operate not at their best but reduced running;
- simultaneous presence of other pollutants, like factories and cities.

It is not by chance that the most inhabited areas in the world are Gibraltar, Honk-Kong, Singapore and Naples, urban areas that are clearly oriented towards commerce and port activities and therefore also industry.

The development of regulations on polluting emissions will probably go on in times depending as much on the political situation as on the happening of alarming environmental events, even in limited areas, capable of alerting the public opinion.
The experience made in the critical analysis of the process of formation and development of the rules limiting polluting emissions of engines for road traction helped focusing the main elements for a rational proposal of similar regulations, as follows:

- the knowledge of the phenomena originating the problem;
- the "human implications" of such phenomena, i.e. the consequences interfering with human interests and which, therefore, man wants to limit;
- the logic or, in other words, the "philosophy" presiding over the choice of the negative consequences to be limited in the phenomena generating the problem;
- technical measures, industrially feasible, to limit the negative consequences of the above phenomena;
- procedures, either already normalised or not, practically applicable to determining the choice of parameters for the evaluation of the "polluting characteristics" of the engine;
- criteria to be followed in fixing the numerical value of the above parameters.

In the naval field the situation is, briefly, as follows: on the majority of vessels the propulsion is due to internal combustion engines (ICE) whose emissions does not only contain the products of hydrogen and carbon oxidation ($H_2O$, $CO_2$) but also a number of other substances, some of which are noxious. The available fuels do not only contain some hydrogen and carbon compounds but also other substances, like impurities which cannot be easily and economically eliminated and others, particularly lead in the less frequent case of gasoline engines, which are added to get peculiar characteristics in the fuels themselves.
Even lubricants are present in the combustion chamber and, because of their chemical-physical properties, originate processes of defective combustion.
The negative consequences for man and environment are felt both in restricted areas close to the heavier traffic places, and in a larger sphere. In fact, some substances can reach such levels in the local atmosphere as to be dangerous to health (carbon monoxide CO, nitrogen oxides $NO_x$, aromatic polinuclear hydrocarbons PAH, sulphur dioxide $SO_2$, particulate) other become noxious because in peculiar physical environments can evolve, so as to generate irritant compounds: (hydrocarbons HC and also nitrogen oxides $NO_x$). Others ($SO_2$, $NO_x$), moreover, contributing to acid rains even on long distances, have negative consequences in general, leaving out of consideration the local concentration.
Recently, in addition to the chemical species considered as noxious for the comprehensively emitted masses rather than for the local concentration, carbon dioxide ($CO_2$) and methane ($CH_4$) have been indicated as dangerous, since their average concentration in the earth atmosphere has been estimated as growing with the consequent danger of the greenhouse effect.
Finally, in the number of pollution sources, one cannot forget the emission "water side" of liquid and solid substances in sea, lake, river environment, etc. due mainly to the washing of tanks, double bottoms, and bilges in ships; near the coasts such a type of pollution can create direct, immediate and huge damages.

ICE emissions

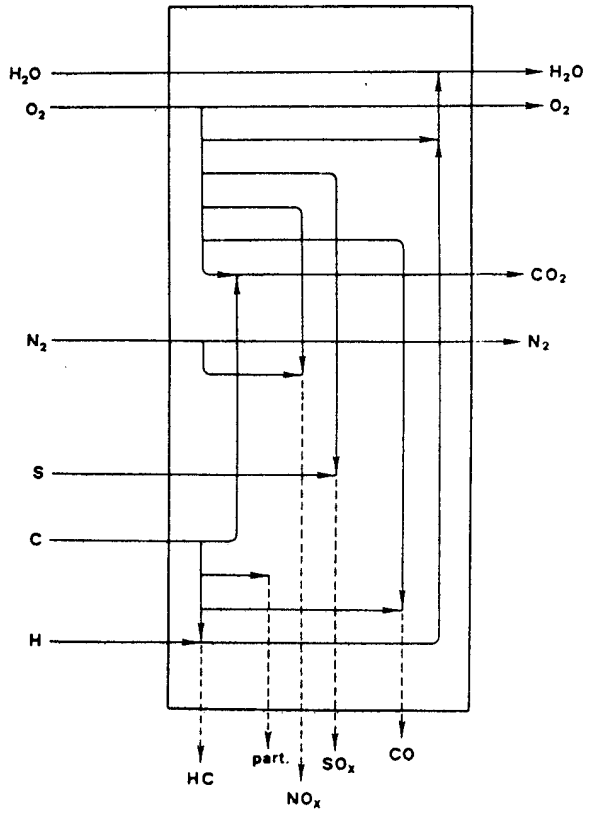


FIG 1

Fig. 1 gives a schematic diagram of the flow of substances involved in combustion: the oxygen in the air reacts with carbon, hydrogen and sulphur forming $CO_2$ and $SO_2$; nitrogen, water and exceeding diatomic oxygen flow in the engine as cooler; sulphur dioxide is the basis of the formation of $SO_3$ (into which almost the 3 to 4% turns) and $H_2SO_4$. Other products of combustion are $NO_x$, unburned hydrocarbons, CO, ashes and various residues.
The main noxious substances present in diesel emission are given in table I together with some information on the genesis and the negative effects on the environment.

Approach to the problem in the field of road traction

Since possible procedures and regulations on investigation, analysis and limiting methods of emission of naval engines will for sure make use of the know-how matured on road traction engines, it seems appropriate to recall briefly the main points of the latest experiences on such engines.
Pollutants whose emission is determined and subject to regulations are at present: CO, THC, $NO_x$, PT (only for diesel).
The nitrogen oxides and the particulate have been regulated in successive and different times; the regulation of carbon dioxide is now on the way.
Since the mass flow of the various components of exhaust gases is a function of the dynamic and thermic load of the engine, the total mass of each polluting factor emitted during a sequence of dynamic and thermic conditions ("mission") is taken as a parameter to evaluate the

"polluting tendency". Such a total mass is referred to the "useful output" of the mission that is the length of the distance covered (simulated on the chassis dynamometer) by a vehicle (in the case of cars and light vehicles) or, alternatively, the amount of brake work developed by the engine, in the case of heavy vehicles (trucks, busses). The mission is defined in such a way as to result representative of the real use of a vehicle in the area where the emissions are to be limited. So the routes (simulated on the chassis dynamometer for the cars have their specific driving schedules as speed versus time (cycles), so as to represent the different realities of the traffic.
The mission, which in heavy duty vehicle engines originally included only steady state conditions both in Europe and in the USA, nowadays includes transient dynamic runnings as well.

TABLE I

| CHEMICAL COMPOUND | SYMBOL | CONDITIONS OF FORMATION | NOXIOUS EFFECTS |
|---|---|---|---|
| Nitrogen oxides | $NO_x$ | high temperature and high pressure combustion | harmful to the vegetation californian smog acid rains |
| Sulphur dioxides | $SO_x$ | sulphur in the fuel | respiratory system irritations |
| Carbon dioxide | $CO_2$ | regular combustion product | greenhouse effect |
| Carbon monoxide | CO | defective combustion | destructive actions on hemoglobin |
| Total unburned hydrocarbons | THC | defective combustion | including aromatic hydrocarbons that are mutagen californian smog |
| Particulate | PT | low combustion temperature and/or defective combustion | possibility of carring THC and keeping them in contact with the respiratory system running the risk of activating their mutagen properties |

Finally, the allowing limits for the parameters characterising the emissions of each pollutant have been become stricter during the time, referring in turn to values checked on the current production and those checked on the prototypes equipped with de-polluting devices suitable for industrialisation; further the values of the limits nowadays imposed to the ICE emissions will be given according to the directives now in force in the EEC for road traction.

Mission profiles for marine traffic

The first problem to be faced in transferring the experiences developed in the road traction to sea traction is namely defining the mission for the various unities operating in this field: merchant shipping (for the transport of people or goods) is characterised by some peculiar aspects according to which there will be a definition of the mission profiles for engines subject to this application:

- length of the route and thence percentage of the engine working at full load in comparison to the reduced one;
- time needed to the landing;
- type of navigation (off shore, coastal, river and lakes).

A separate question regards coast navigation: it is easy to foresee in the future years its further development in relation to highly inhabited urban areas mainly for passenger transport, as an alternative to the clogged road traffic; such development will require a larger and larger use of fast and very frequent craft (such connection have been already adopted in the gulf of Naples for some time between Naples, the islands and the resort places on the Sorrento and Amalfi coasts; such areas are not only developed from the point of view of tourism but are also chosen by a remarkable number of people as permanent residence).

The increasing of the high speed applications needs taking into careful consideration its characteristics in order to lay out a profile of mission properly representing the specifications of fast navigation.

Influences of the working characteristics of naval engines on the exhaust emissions

In limiting the horizon of this work on diesel engines, it must be said that they cover a very large power range and are employed differently and with various philosophies of installation.

Marine plants equipped with 2-stroke, low speed diesel engine matched with a fixed pitch propeller are generally adopted in large vessels with high ratio between the steady state periods and the transient runnings; the 4-stroke, medium speed engines with gearbox is, in general, the main engine of mean and large ships, often with more than one engine matched with variable pitch propellers.

High speed engines fit out a very large range of propulsion plants and gensets and are installed on various types of vessels, like working ships, pleasure craft, fast ferries, military craft etc. From the point of view of exhaust emissions, then, it is necessary to distinguish vessels on the type of motion: displacement and planing. The relative questions are totally different both because the two types of motion imply distinct emission modes and because they match with different mission profiles.

Three different "classes" of vessels can be recognised, within which each individual is characterised by sufficiently homogeneous emission conditions. For each procedures it is possible to foresee a different approach to the problem of exhaust emission:

- medium and high tonnage cargoes, displacing, equipped with a low or medium speed diesels, of medium-high power, medium long routes, high ratio steady state/transient (long carriers, oil etc.)
- passenger ships ferries and cruise ships, displacing, with medium speed diesels (also diesel-electric), short or medium routes mostly close to the coast, frequent landing and medium to low ratio steady state/transient.
- planing craft, equipped with high or medium speed diesels delivering medium - low power, short routes, very frequent landing, low or very low ratio steady state/transient (pleasure craft, fast ferries, patrol boats etc.).

Clearly some ships are left out from such a narrow schematization; however, we will refer to this classification to face the subject under question.
The first class consists of ships that cover long routes, their presence next to urban areas is therefore limited to brief periods; but the situation becomes worse because of other attendant circumstances. First of all, the sizes of the engines are such as to cause the emission of large amount of exhaust gas and then, proportionally, of large quantities of noxious substances; moreover, they are generally fed with low quality fuels, which obviously increases the amount of exhaust noxious substances. Once in the port, if not provided otherwise, the engines driving the alternator on board must be kept in operation (and under load) with the consequent no-stop emission of exhaust gas.
Supposing that for this category of ships one would want to pursue the approach of reducing the emissions only near urban areas, there is nothing else to do but towing the ship into the port with the engine at the idle speed, fed with clean fuel and eventually keeping on the systems - if any - meant for lowering the noxious exhaust substances.
For the means of the second class the situation is definitely more complicate because even if the size of the engine is still rather large, the periods of maneuvring, stop and go close to urban areas and to areas of landing (unavoidable in this case since towing into the port is impossible because of the necessity to curb the navigation period) are considerably increased. In such conditions the polluting risk arises and the intervention aiming at reducing the harmfulness of the emissions must be radical.
Some favourable circumstances help lessening the effects of such situation like the curve of power delivery in "cubic" (and often with variable pitch propeller) which is less stressing on the engine, together with the use of fuels that are cleaner than those normally used in 2-stroke engines.
The planing craft divide into a number of categories all of which are characterised by a power in "quadratic", unfavourable for the exhaust emissions.
Pleasure craft, in great number but, generally, equipped with small engines and sailing almost always close to the coasts, does not have the assistance to navigation granted by a specialised crew as it happens for the larger size ships. This means it is necessary to adopt very reliable systems which can be managed by non-specialised personnel. Possible reductions in exhaust emissions must be obtained with systems always in operation and easy to maintain, as it happens with the new generation cars.
The situation is less definite regards the high speed crafts (planing and semi-planing) for the transportation of passenger and goods (generally cars) next to the coasts; their working in quadratic makes it difficult to drop the emissions, which could be overcome with systems limiting the level either during the whole navigation or simply next to the urban areas.
As regards the problem of the emissions as a function of the running condition of the hull, figure 2 shows in a qualitative way the theoretical towing power curve for a displacing vessel (curve 1) and for a planing one (curve 2) on an equal MCR.
The quantities are given in the percentage of their nominal value. The graphic also shows in a qualitative way the zone of normal running of the engine and the one of overload; in this area the air supply is difficult because of the "air hole" which could happen in the supercharged engines (especially if on high level of supercharging). It is easy to understand that planing conditions are more critical because the working points are closer to the limit curves.

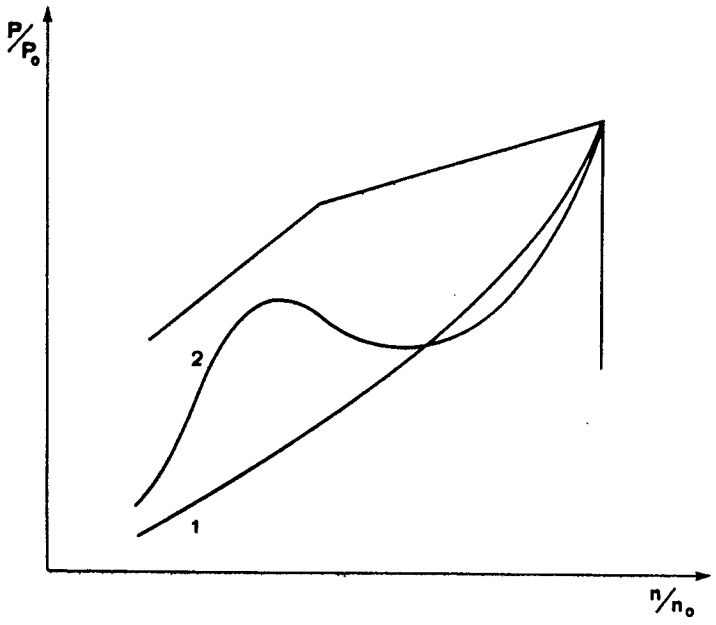


FIG 2

Methods for lowering the emissions

The reduction of the emissions of pollutants can be obtained in two ways:

- acting on the various aspects of propulsion mechanisms so as to face the problem at its source;
- assuming shipping techniques which would "remove" the sources of pollution from the areas considered at environmental risk.

The study of the pollution due to diesel engines indicates that substances that have to be checked more urgently for the emitted quantity and dangerousness are the nitrogen oxides, among which first of all NO and $NO_2$ composing almost the whole of the nitrogen oxides produced.

The order of magnitude of this phenomenon results to be as follows: a 4-stroke or 2-stroke diesel engine, fed with today's fuels, produces a quantity of $NO_x$ of about 1000 - 1500 ppm where the maximum allowable limit is about 100 - 200 ppm (it is impossible to give more precise values because there are no clear regulations indicating the maximum tolerable concentration $NO_x$); this means, therefore, a remarkable quantity to be kept down and moreover, since nitrogen comes mostly from the intake air, it is not possible to knock down the flow in the combustion chamber and then reduce the quantity at the source.

In order to keep down the concentration of exhaust $NO_x$ in large diesel engines many ways have been attempted among which we quote the following:

- Selective Catalyst Reduction (SCR): using the ammonia cycle to reduce NO, $NO_2$ and $NH_3$ (in presence of $O_2$) in $H_2O$ and $N_2$; notably reduces the quantity of $NO_x$ (they say, more than 90%) but it creates big problems in installation, costs, managing and safety [1]
- variation of the injection timing: it has been noted that, by reducing the timing of the injection, the combustion temperature is lowered and so is the $NO_x$ emission; but the efficiency of the combustion is worsen and the fuel specific comsumption rises (figure 3,[2])

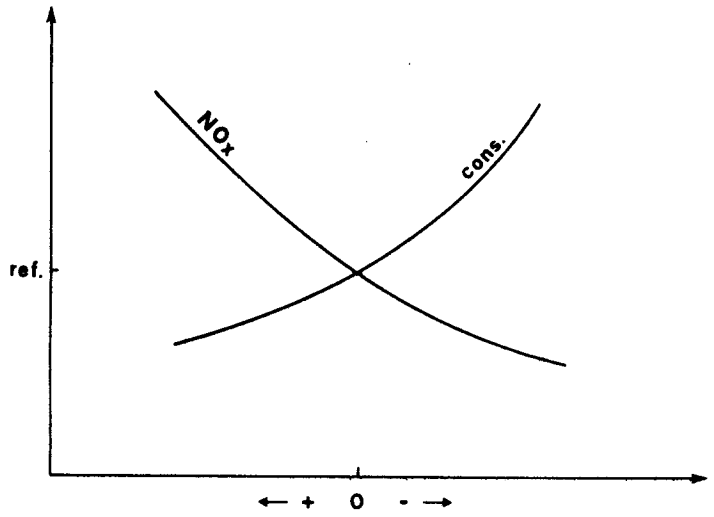


FIG 3

- inlet of water into the fuel: this lowers the combustion temperature and consequently the $NO_x$ emissions: this requires specifically equipped plants (especially pumps and injectors) and makes it practically impossible their working both with dry and hydrated fuels.

Because of the above problems, such systems are very far from the wide application which could result (as it happened for the car catalyst) from a higher efficiency of the exhaust purification plant.

Lowering the $SO_x$ has become important especially using heavy fuels which contain high quantity of sulphur and are responsible for the growth of emission of $SO_3$ and, hence, $H_2SO_4$. The presence of sulphur in the combustion chamber catalyzes the forming of particulate. The methods that have been traditionally adopted to keep down the production of sulphur compounds are the balancing of the TBN of the oil for the separate lubrication (2-stroke engines) to fight the acidity in the combustion chamber and consequently the forming of sulphuric acid; however the best way seems to be lowering the rate of sulphur in fuel which can be obtained with today's technologies but increases the price of the product.

A number of methods to remove CO, $CO_2$, PT and THC are under study at the moment, even if the attention is mainly focused on lowering the $NO_x$.

As regards the particulate, the best way seems to be the fluidized bed catalyst which, like SCR, requires the presence of large plants and, thence, creates similar problems to those described in catalyzing the ammonia cycle.

Lately, ceramic filters have been experienced to lower the particulate [3]; they showed, however, considerable problems caused by dimensions of the plant and, most of all, by the shortness of their working cycle with the consequent need of frequent regeneration of the filter.

The carbon monoxide creates less problems (mostly in dual-fuel engines); it can be oxidated into $CO_2$ by using after-burners.

The approach to the problem of emissions can - and maybe must - also involve the type of marine operations; from this point of view, in order to limit the polluting emissions of merchant ships only in urban areas it is possible:

- to foresee the possibility of a reduced running of the engine, preferring to keep down the polluting emission to efficiency;

- to trust the port maneuvring to tugs, rather than to the ship engine.

The need to protect the environment from noxious emissions of naval propulsion engines should induce to favour the better running of such engines along the route of the ship; this means the possibility to use fuels as close as possible to fixed standards along the route, since the optimisation of the vessels as regards the emissions implies good combustion conditions and requires, practically, a good agreement engine-fuel.
In such framework, the management of queues due to unloading operations in the most congested ports is very important since such waiting implies that the main engine is kept working close to urban areas.

Regulations in the field of emission of naval engines: reality and perspectives

The problem of imposing limits to gas emission of naval engines, and the proposal and definition of regulations regarding methods of tests, analysis and measurement of the emission, have engaged operators of the field with a large delay in comparison to road traction, under the pressure of world public opinion which has grown thanks to the impact of environmental movements and bodies.
In the seventies, the energetic crises created some worries about the fuels derived from oil. Such worries supported and favoured, in the engine manufacturing, both the efforts towards the optimisation of the specific consumption by intervening on the engine project and the tendency to use heavy fuels and running schedules so as to minimize the management costs of the vessels.
Under the impact of the world public opinion some more or less fast legislative mechanisms have been set into motion in order to protect the preminent interests of the community (among which the environment preservation is not the least); therefore even the parts clashing against each other are now interested in being involved in the process of law-making, indeed in accelerating their definition, in order to have some fixed points to orientate their productive activities for the present and the future.
Within the ISO, the development of regulations regarding the emissions of marine ICE has been entrusted to the sub-committee SC8 (Exhaust Emission Measurement) depending from the Technical Committee TC70 (Internal Combustion Engines).
In particular, the sub-committee SC8 is appointed to the definition of the testing procedures to measure emissions of industrial reciprocating internal combustion (RIC) engines, through the ISO-8178 regulation. Such regulation, named RIC Engine-Exhaust Emission Measurement, is composed of the following 5 parts:

- 1 Test bed measurement of gaseous and particulate exhaust emissions from RIC engines
- 2 At site measurement of gaseous and particulate exhaust emissions from RIC engines
- 3 Exhaust smoke, definitions, method of measurement under steady conditions
- 4 Test cycles for different engine applications
- 5 Reference fuels

Such regulation proposals evidently derive from those in force in the field of road traction. The SC8 activity covers the matter regarding all the so-called industrial engines, i.e. "off-highway", stationary and marine applications.

Part 4 has been planned with the purpose of measuring the emissions produced in a sequence of steady states by an engine having a certain mission profile at the brake.
The common "father" to all the cycles nowadays proposed for the various categories of engines and ranges of employment listed below, is the well-known cycle named "13 modes cycle" and defined by the current legislation for road traction. (ECE - ONU R49 Directive EEC 88/77).
Test cycles type:

- A For reference only - suorce ECE R49
- B Universal (to be used only for the calculation of emissions in other test cycles)
- C Off-road vehicles, industrial (C1 medium/high load - C2 low load)
- D Constant (D1 power plants - D2 Gensets with intermittent load)
- E Marine applications (E1 pleasure craft engines - E2 constant speed engines for ship propulsion - E3 heavy duty marine engines)
- F Rail traction
- G Utility, lawn and garden

As regards the limits of exhaust emission of each kind of pollutant, the current limits defined in the EEC 88/77 are given below as reference in tab. II

| | HOMOLOGATION | CONFORMITY |
|---|---|---|
| CO | 11.2 | 12.5 |
| HC | 2.4 | 2.6 |
| $NO_x$ | 14.4 | 15.8 |

TABLE II

However, the EEC 91/541 directive (1/10/91) modifies in a restrictive sense, the above limits and moreover adds limits for the particulate (PT) in conformity to the following table:

TABLE III

| | FROM 1/7/92 TO 1/10/95 | | AFTER 1/10/95 | |
|---|---|---|---|---|
| | HOMOLOGATION | CONFORMITY | HOMOLOGATION | CONFORMITY |
| CO | 4.5 | 4.9 | 4.0 | 4.0 |
| HC | 1.1 | 1.23 | 1.1 | 1.1 |
| $NO_x$ | 8.0 | 9.0 | 7.0 | 7.0 |
| PT | 0.36 * | 0.4 * | 0.15 | 0.15 |

* = for engine whose power is less than 85 kW the given limit can be multiplied by the factor 1.7

Finally, in tab IV some cycles proposed for marine applications are compared (ISO 8178 project, Austria-Switzerland-Germany agreement for the navigation in internal waters) with the one of 13 modes provided for road traction.
It is meaningful that in such agreement the allowed emission for engines whose power exceeds 100 kW, coincides with the 13 modes one.

Conclusions

The delay in deepening the social, scientific and legislative aspects of the exhaust emissions of marine diesel engines has to be covered in a short time. Such a suggestion is now evident in the pressure on the sector which requires a clear answer to such questions:

- which limits must be set to the flowing of noxious substances in the open sea ?
- which limit must be set to the concentration of noxious substances next to urban areas ?
- how much sacrifice, in terms of the growing of specific consumption, can be reasonably imposed to the to shipowners and managers to get cleaner emissions ?
- how can we grant the observation of imposed regulations and limits ?

Many bodies operating in the marine sector are involved today in completing the difficult understanding of the phenomena under study and consequently in giving definite suggestions on the answers to be given to such questions. In this framework, there is a cooperation agreement going on between the CNR Istituto Motori of Naples and the Department of Naval Engineering of the "Federico II" University of Naples; such collaboration has, in brief, the following aims:

- to participate to the efforts of the national and international legislative bodies (to which the Researchers of both Institutes belong) through experimental activities aiming at the research in the abovementioned problems;
- to define the methods of a "Round Robin Test" on the emissions of engines specifically meant for marine applications compatibly with those of other Institutes;
- to study the characteristics of solubility of both exhaust gases and particulate emitted by small to medium size marine engines in seawater; this aims at giving practical information on the emissions in that kind of vessels which, because of the cooling, present a mixture of exhaust and seawater, with the consequent great difficulty of a direct evaluation of the emissions.

| 13 MODES[1] | | | | PROJECT ISO 8178 | | | | | | PROJECT AUSTRIA SWITZERLAND GERMANY[4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $E_1$[2] | | $E_2$[3] | | | | | | | |
| | V | P | WF | | WF | | V | P | WF | | V | P | WF |
| 1 | M | 0 | 0.25/3 | 5 | 0.40 | | | | | | | | |
| 2 | I | 10 | 0.08 | - | - | | | | | | | | |
| 3 | I | 25 | 0.08 | 4 | 0.25 | | | | | | | | |
| 4 | I | 50 | 0.08 | 3 | 0.15 | | | | | | | | |
| 5 | I | 75 | 0.08 | 2 | 0.14 | | | | | | | | |
| 6 | I | 100 | 0.25 | - | - | | | | | | | | |
| 7 | M | 0 | 0.25/3 | - | - | | | | | 9 | $n(P_{max})$ | $P_{max}$ | 0.05 |
| 8 | R | 100 | 0.10 | 1 | 0.06 | 1 | 100 | 100 | 0.20 | 8 | n(nom) | $P_{nom}$ | 0.05 |
| 9 | R | 75 | 0.02 | - | - | 2 | 91 | 75 | 0.50 | 7 | 0.9 nom | 0.7884 $P_{nom}$ | 0.05 |
| 10 | R | 50 | 0.02 | - | - | 3 | 80 | 50 | 0.15 | 6 | 0.8 nom | 0.5724 $P_{nom}$ | 0.05 |
| 11 | R | 25 | 0.02 | - | - | 4 | 63 | 25 | 0.15 | 5 | 0.7 nom | 0.4100 $P_{nom}$ | 0.2 |
| 12 | R | 10 | 0.02 | - | - | - | - | - | - | 4 | 0.6 nom | 0.2789 $P_{nom}$ | 0.1 |
| 13 | M | 0 | 0.25/3 | - | - | - | - | - | - | 3 | 0.5 nom | 0.1768 $P_{nom}$ | 0.1 |
| | | | | | | | | | | 2 | 0.4 nom | 0.1012 $P_{nom}$ | 0.1 |
| | | | | | | | | | | 1 | ralenti | 0 | 0.3 |

(1) **ECE/ONU R.49 Dir. 88/77/CEC for diesel engines for cat. M2, M3, N2, N3 vehicles**
**Agreement AUSTRIA-SWITZERLAND-GERMANY for $P_{max}$ > 100 kW**
(The power is percentage of maximal power)

(2) **"PLEASURE CRAFTS"**: speed and power are the same as for the "13 modes" (on the same line)

(3) **"MARINE HEAVY DUTY"**

(4) $P_{max}$ < 100 kW

LEGENDA: V = speed; P = power; WF = weighting factor; M = idle; I = intermediate; R = rated

TABLE IV

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