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Technical and Environmental Aspects of Shipboard Incinerators Design

Summary

The main aim of this article is to present and to clarify some details of shipboard incinerators and to show how to satisfy their basic design requirements. In this sense, technical and ecological aspects for the design and construction of shipboard incinerators are described. In scope of this, operating requirements are discussed that have to be satisfied in order to accomplish the efficient thermal destruction of wastes.
Incinerators considered are those intended for thermal destruction of garbage and other shipboard wastes generated during the ship's normal service, with capacities up to 1500 kW and without the flue gas heat recovery.
Calculations are presented that are derived for the case of a typical ship's waste classification according to IIA (Incinerator Institute of America). Results of a case calculation for the incinerator capacity of 80 kg/h of liquid and solid ship's waste are presented, too.

Key words: ships, incinerators, wastes, sea pollution prevention

1. Introduction

International Convention for the Prevention of Pollution from Ships (MARPOL) adopted by International Conference on Pollution on Seas in November 1973, and modified thereafter by the 1978 Protocol and a number of amendments, relating thereto MARPOL 73/78, provides regulations for prevention of pollution from ships.

Annex 1 of MARPOL 73/78 gives rules relating prevention of pollution by oil and oily wastes from ships. Annex 5 of MARPOL 73/78 defines rules relating to the prevention of pollution by garbage, while Annex 6 consists of regulations relating to the prevention of air pollution from ships. In order to reduce problems of discharging of garbage and other wastes generated during the ship's normal service, ships should be equipped with adequate incinerators that have to be designed in a manner to satisfy all requirements related to such a special service.

The mentioned rules make the base for technical and ecological aspects to be considered and implemented during the design and construction of shipboard incinerators. They are introduced in the Standard Specification for Shipboard Incinerations that are adopted by the Marine Environment Protection Committee, MEPC.40/21

The aim of this article is to present and to clarify some details of shipboard incinerators and to show how to satisfy basic design requirements.

Incinerators considered in this article are those intended to incinerate garbage and other shipboard wastes generated during ship's normal service, with capacities up to 1500 kW, without the flue gas heat recovery. Also, special shipboard incinerators for burning various chemicals and other industrial wastes are not considered in this article.

2. Technical Requirements for Shipboard Incineator Design

Capacity

The capacity of an incinerator can be defined as the maximum mass rate of the wastes (kg/h) or as the heat rate (kW) released by wastes and supplementary fuel to be burned in the furnace. The supplementary fuel is needed to assure continuous and safe burning of introduced low heat value wastes. Generally, the shipboard incinerators should be provided for combined burning of solid and liquid wastes arising during normal ship's services. The design of incinerator itself and of the appertained auxiliary equipment has to satisfy this basic requirement.

Compositions and heat values of typical wastes should be known in order to calculate the heat released during the combustion and also for the approval test performing. For this purpose, the waste classification by IIA (Incinerator Institute of America) can be used, as shown in the following Table 1.

Table 1 – Typical ship's waste characteristics

Type of waste		Composition Mi(%)(% by weight)	Average low heating value HL,i(kJ/kg)
Typical liquid waste	Heavy fuel oil sludge	75	36.000
	Waste lubricating oil	5	36.000
	Emulsified water	20	(-) 2500

Typical solid waste	Food waste1)	50	5.700
	Paper	15	14.300
	Cardboard	20	14.300
	Rags	5	15.500
	Plastic2)	10	36.000

Food wastes are any spoiled or unspoiled victual substances, such as fruits, vegetables, dairy products, poultry, meat products, food scraps, food particles and other materials generated abroad ships, principally in the galley and dining room.

Plastic waste means solid materials which contain as an essential ingredient one or more synthetic organic high polymers and which is formed during either manufacture of the polymer or the fabrication into a finished product by heat and/or pressure.

Operating requirements

In order to accomplish the main basic function, i. e. the efficient thermal destruction of wastes, incinerators should be designed and constructed for the operation in following conditions:

Maximum combustion chamber flue gas outlet temperature: 1200 0C

Minimum combustion chamber flue gas outlet temperature: 850 0C.

The efficient thermal destruction means a complete and smoke free incineration, including that of plastic and other synthetic materials while minimizing dioxine and VOC (Volatile Organic Compounds) emissions.

Because the combustion chambers of the shipboard incinerators usually are not designed as water cooled, the maximum combustion chamber flue gas outlet temperature (1200 0C), at defined capacity, should be realised by cooling with an adequate inlet air quantity which will be capable to reduce the flue gas temperature to the defined limit. From this requirement, the needed capacity of the fan for combustion air is to be derived.

The defined minimum of flue gas outlet temperature (850 0C) from the combustion chamber should be maintained in order to assure the efficient thermal destruction of wastes. For this reason, heating of the combustion chamber during starting of incinerator and the maintenance of defined temperature limit has to be ensured by supplementary firing of normal quality fuel. An another operating requirement, important for efficient thermal destruction of wastes, derives from the needed retention time of products in the combustion chamber, which has to be above 2 sec. (based on 2 % oxygen content in flue gas), according to the good practice and experience (Ref. 2). This criterion is important to define the size and dimensions of the combustion chamber in connection to the incinerator capacity.

Safety requirements

Here are some of major safety requirements that have to be fulfilled by the design and construction of shipboard incinerators.

Outside surface temperature of the incinerator casing should not exceed 20 0C above the ambient temperature, i.e. maximum 60 0C. In order to fulfil this condition, incinerator walls are to be protected with an adequate insulation layer or with a cooling system like double jacket with air flow in between.

In order to prevent possible hazardous events (explosions), the burner management system has to assure a sufficient pre-purge of combustion chamber before the ignition. This condition should be accomplished with least four air changes in the chamber including the stack, but not less than during 15 seconds. This are to be respected between restarts, too. Alike, a sufficient post-purge after shut-off fuel oil should be done in the period longer than 15 seconds after the closing of the fuel oil valve.

The negative pressure in the combustion chamber should be provided with the adequate draft to prevent leakage of hot gases into the operating ambient. This is to be achieved by the exhaust fan with a sufficient capacity.

In order to avoid building-up of dioxins, the flue gas should be shock-cooled to maximum 3500C near to the combustion chamber outlet. This can be achieved by suction of ambient air into the flue gas duct, what requires an adequate capacity of the exhaust flue gas fan.

Safety devices

The incinerator should have a flame safeguard control consisting of a flame sensing element and associated equipment for shut-down of the unit in the event of ignition failure and flame failure during the firing cycle.

Two control solenoid valves on the main supplement fuel and liquid waste line to each burner should be provided in series to assure safe closing in cases of shut-down event.

A combustion temperature controller, with a sensor placed in the combustion chamber, should be provided that will shut down the burner if the combustion chamber temperature exceeds the maximum temperature.

A flue gas temperature controller, with a sensor placed in the flue gas duct, should be provided that will shut down the burner if the flue gas temperature exceeds the pre-set temperature.

A negative pressure switch should be provided to monitor the draft and the negative pressure in the combustion chamber, which should activate before the negative pressure rises to atmospheric pressure.

Environment requirements and emission control

Shipboard incinerators should be designed and built to satisfy IMO (International Maritime Organization) standard, what include emission standards to be verified by the test before getting the approval certificate.

The following Table 2 contains major required emission standards for shipboard incinerators.

Table 2 – Emission standards for shipboard incinerators

Controlled parameter	Required value	Remarks
O2 in combustion chamber exit	6 to 12 % (by volume)	Measured during the combustion period and not during the preheating or cooling
CO in flue gas (maximum average)	200 mg/MJ	
Soot number (maximum average)	3 (Bacharach) 1 (Ringelman)	Higher soot number is acceptable during very short period as starting up
Unburned components in ash residues, maximum	10 % (by weight)	

Incinerators assigned for passenger (cruise) ships are expected to have a capacity more than 1500 kW, operating continuously over longer periods, burning waste with higher content of plastic and synthetic materials and often operating in very sensitive coastal areas. Such operating conditions require the detail consideration of an additional installation for flue gas after-cleaning system to minimize emissions of hydro-chlorine compounds (HCl), sulphur-oxide (SOx), particulate matters and nitrogen oxide (NOx).

3. Basic Correlations for the Incinerator Design

Waste heating value

Basing on the typical ship's waste composition and characteristics (as shown in Table 1), the low heating value of solid and liquid waste can be derived as presented in the following Table 3 and Table 4. Heating values of typical waste for the thermal destruction should be known to define the capacity of the incinerator (in thermal (kW) or mass (kg/h) units).

Table 3 – Low heating value of typical liquid ship's waste

Type of waste	Mass share Mi (kg/kg)	Heat share HL= Mi . HL,i (kJ/kg)
Heavy fuel oil sludge	0,75	0,75x36 00 =27 000
Waste lubricating oil	0,05	0,05x36000=1 800
Emulsified water	0,20	0,2x(-2 500)=(-) 500
Low heating value		28 300

Table 4 – Low heating value of typical solid ship's waste

Type of waste	Mass share Mi (kg/kg)	Heat share HL= Mi . HL,i (kJ/kg)
Food waste	0,5	0,5x5 700=2 850
Paper	0,15	0,15x14 300=2 145
Cardboard	0,2	0,2x14300=2 860
Rags	0,05	0,05x15 500=775
Plastic	0,1	0,1x36 000=3 600
Low heating value		12 230

Air for combustion and flue gas quantities

Air for combustion and flue gas quantities are calculated for defined typical ship's wastes, depending on excess air. The results and presented graphically on following diagrams.

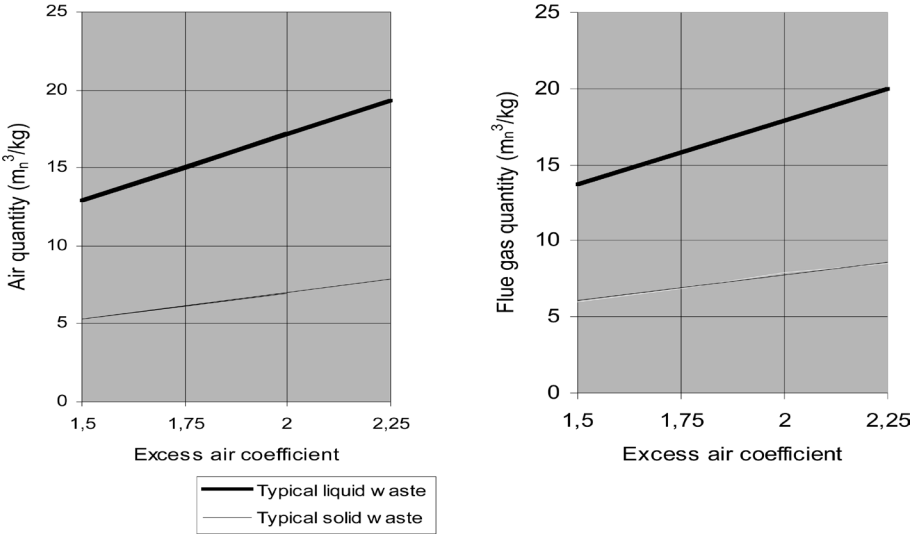

Fig. 1 - Air and flue gas quantities in burning of standard ship's waste

The combustion chamber of the incinerator is lined by a corresponding thermal insulation and it is not cooled by water wall as the case is in steam boilers. Neglecting heat losses through the thermal insulation and casing, all heat developed in the combustion chamber transfers to flue gases. The temperature at the combustion chamber exit can be calculated by the expression derived from the heat balance equation:

$$t_F = \frac{\eta_F H_L}{V_G C_G} + t_A \tag{1}$$

where:

ηF	is efficiency of combustion chamber (taking in account heat losses through insulation, ηF~0,97)
HL(kJ/kg)	is lower heating value of waste material for burning
VG(mn3/kg)	is flue gas quantity per 1 kg of burned waste
CG(kJ/mn3K)	is specific heat capacity of flue gas
tA (0C)	is inlet air temperature to the combustion chamber

Taking into account the expression (1), the dependence of combustion chamber temperature on excess air in combustion process and on waste quality (heating value) can be calculated as presented graphically in Fig. 2.

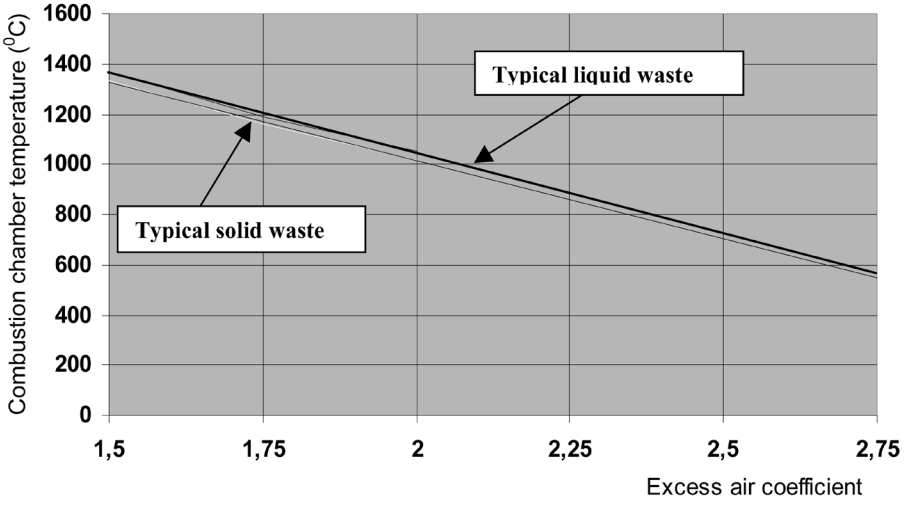

Fig. 2 - Temperature in combustion chamber depending on excess air coefficient

Presented data on diagrams (Fig. 1 and Fig. 2) are derived for the cases of typical ship's solid and liquid waste. They can be used for incinerator designs in defining capacities of the air fan and of the flue gas fan and also of furnace dimensions, depending on the required incinerator capacity.

For example, the case calculation is presented graphically on following diagrams for burning capacity of 80 kg/h of typical solid and liquid waste, where results of total air and flue gas quantity are shown in the range of furnace temperature between 800 and 1200 0C.

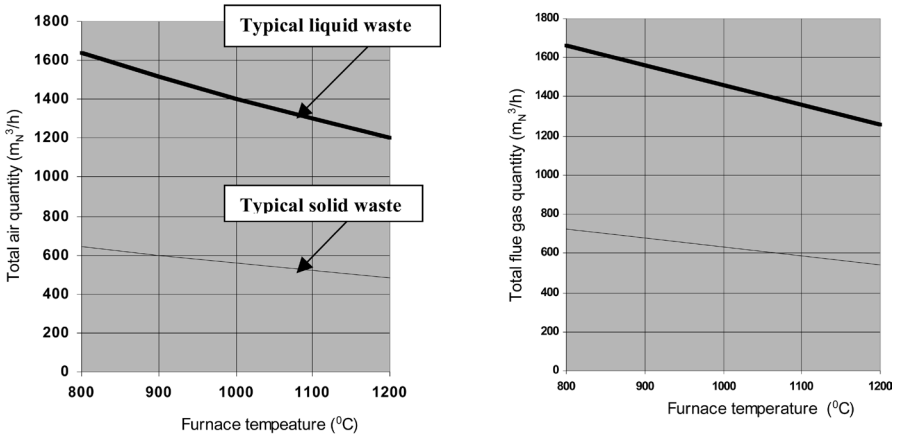

Fig. 3 – Total air and gas quantity for burning capacity 80 kg/h of typical liquid and solid ship's waste

Exhaust flue gas fan

The fan for exhaust flue gas has to be capable to evacuate all gases developed in the combustion chamber creating there a sufficient negative pressure to ensure no gases or smoke leaking out to the surrounding space. In same time, the exhaust fan has to suck into the exhaust duct an adequate quantity of ambient fresh air in order to shock-cool flue gas to maximum 350 0C, avoiding thus building up of dioxins.

For considered data related to the burning capacity of 80 kg/h of typical liquid ship's waste, the air quantity for cooling gas and the total quantity of cooled gas after mixing can be calculated as presented in the following table.

Table 5 – Total gas quantity after mixing and cooling3)

Exhaust flue gas temperature, (0C)	250	300	350
Quantity of air for mixing and cooling, (kg(h)	7070	5390	4225
Total mass of exhaust flue gas, (kg/h)	8960	7280	6115
Total volume of exhaust flue gas, (m3/h)	13620	11815	10780

3) Case for initial furnace temperature 1000 0C

Typical ship's waste installation

The typical scheme is presented on the Fig. 4, where main parts of ship's waste system are shown.

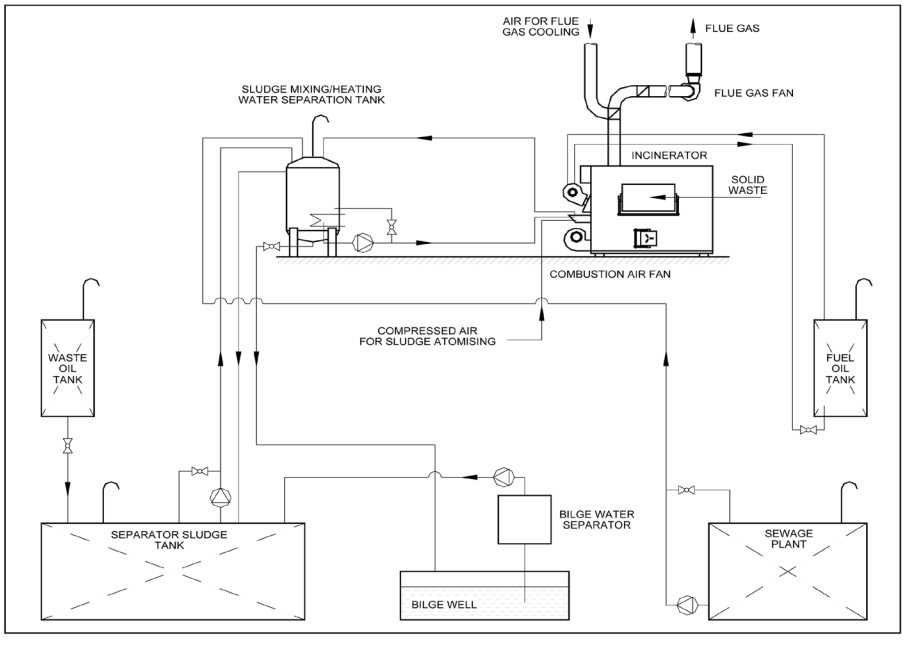

Fig. 4 – Scheme of waste system on ships

CONCLUSIONS

International Convention for the Prevention Pollution from ships (MARPOL 73/78) with Annex V provides the need for shipboard incinerators intended to incinerate garbage and other shipboard wastes generated during the ship's normal service.

International Maritime Organization (IMO) with Resolution of the Marine Environment Protection Committee (MEPC76/40) defines Standard Specification for Shipboard Incinerators which covers the design, manufacture, performance, operation and testing of ship's incinerators.

The incinerator design has to fulfil many safety and environment requirements in conjunction to special ship's services and maritime conditions.

The combustion chamber temperature, exhaust flue gas temperature and retention time in the combustion chamber are major operation conditions that have to be fulfilled by an adequate design of the shipboard incinerator.

O2 content in the combustion zone, CO in flue gas, soot number and amount of unburned components in ashes are main environmental requirements that have to be achieved and approved by the incinerator test.

References:

1) IMO Resolution MEPC 76(40), Annex 8
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Tehnički i ekološki aspekti projektiranja brodskih spaljivača otpada

Sažetak

Glavni je cilj ovoga članka da se razjasne bitni tehnički detalji vezani na brodske spaljivače otpada (incineratore), odnosno da se prikažu načini rješavanja njihovih temeljnih konstrukcijskih zahtjeva. U tome su smislu posebno opisani tehnički i ekološki aspekti projektiranja odnosno izvedbe takvih uređaja. Prikazani su pogonski uvjeti koji moraju biti udovoljeni da bi se postiglo učinkovito termičko zbrinjavanje otpada.
Razmatrani su spaljivači otpada (incineratori) koji su namijenjeni za termičko uklanjanje brodskoga otpada što nastaje tijekom normalnih brodskih aktivnosti, s toplinskim kapacitetom do 1500 kW te u izvedbi bez rekuperacije topline izlaznih dimnih plinova.
Prezentiran je proračun izveden za slučaj obrade tipičnoga brodskog otpada specificiranoga prema IIA (Američki institut za incineratore). Uz to, iznijeti su rezultati proračuna za spaljivač nominalnoga kapaciteta 80 kg/h tekućeg odnosno krutoga brodskog otpada.

Ključne riječi: brodovi, spaljivači, otpadni materijali, sprječavanje onečišćenja mora.

Aspetti tecnici ed ecologici della progettazione di inceneritori di bordo

Sommario

Obiettivo dell'articolo è illustrare le particolarità tecniche degli inceneritori di bordo ed esporre le soluzioni più rispondenti all'esigenze fondamentali di costruzione. A questo scopo vengono specificamente delineati gli aspetti tecnici ed ecologici della progettatione e della costruzione di tali impianti rilevando le condizioni di funzionamento necessarie per effettuare in modo adeguato il trattamento termico dei rifiuti.
Qui vengono esaminati i tipi di inceneritore destinati allo smaltimento dei rifiuti accumulati durante le normali attività di bordo in grado di sviluppare una capacità termica fino a 1500 kW/h nella versione che non prevede il recupero termico dai gas di scappamento.
I calcoli qui presentati si riferiscono allo smaltimento di rifiuti tipici presenti a bordo secondo le specificazioni della IIA (Istituto americano per gli inceneritori) ed i risultati dei calcoli ottenuti si riferiscono ad un inceneritore dalla capacità nominale di 80 kg/h di rifiuti liquidi e solidi.

Parole chiave: navi, inceneritori, materiali di rifiuto, prevenzione dell'inquinamento marino.