TREATMENT OF SHIP SLUDGE OIL USING A PLASMA ARC WASTE DESTRUCTION SYSTEM (PAWDS)

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ABSTRACT

The Plasma Arc Waste Destruction system (PAWDS) uses a plasma torch to quickly gasify solid waste on board ships. Developed under the support of the US Navy, this compact one deck system has been in commercial operation on board a cruise ship for more than three years. With the support of Carnival Cruise Lines and the National Research Council of Canada, the PAWDS was recently modified in order to process, in addition to solid waste, sludge oil, a mixture of heavy fuel oil, lubricating oil, water and grit collected from the ship's hull.

In the PAWDS process, solid waste is pre-treated to render it into a lint-like material which is rapidly gasified in a patented plasma fired eductor. Liquid sludge oils are fed, through a specially designed injector, into the plasma plume for rapid gasification in the same plasma fired eductor. The system can treat mixed solid or sludge oil wastes as well as co-fired mixtures.

Surrogate oil mixtures and actual sludge oil waste were processed using the US Navy PAWDS prototype located at PyroGenesis' facility in Montreal, which is essentially identical to the commercial unit in operation on board a cruise ship. Feed rates of up to 200 litres per hour were successfully processed.

In November 2005, demonstration tests were performed under the supervision of a Lloyd's Register surveyor and with a certified laboratory sampling the emissions from the system. The purpose of these tests was to obtain certified data needed for obtaining a Lloyd's Register Marine Equipment Directive Type Approval Certificate. The emission results were shown to be well within the MARPOL (International Convention for the Prevention of Pollution from Ships, "MARine-POLlution") guidelines with CO emissions being exceptionally low at 3 mg/MJ, which is less than 2% of the MARPOL limit (200 mg/MJ). Although not yet required by MARPOL, the system was shown to be able to obtain SO_x removal efficiencies of 95%. The formal certification was obtained from the Lloyd's Register offices in London on November 2006 for larger and smaller capacity PAWDS for the processing of solid and sludge oil wastes.

PyroGenesis believes that the ability to process sludge oil from ships opens up the possibility of using PAWDS on land-based applications for processing oily wastes and oily muds produced by other industrial sectors.

INTRODUCTION

PyroGenesis has developed, jointly with the US Navy, the Plasma Arc Waste Destruction System (PAWDS). A PAWDS is currently installed on a Carnival Cruise Lines ship, the M/S Fantasy (1, 2, 3, 4). To-date, the system regularly treats combustible solid waste such as cardboard boxes, cabin waste (containing plastics), rags, wood and food. The PAWDS has several advantages over conventional incinerators, including better performance (ie. lower volume of stack gases, lower ash volume and lower unburned components in the ash ash <1%) and much reduced footprint (as much as one fifth the size of a comparable incinerator) due the very rapid reaction kinetics as a result of the high temperature plasma plume combined with the high surface area of the milled waste. This reduced footprint makes the system an ideal solution for retrofitting outdated incinerators or adding new sludge oil processing capabilities on older cruise ships with limited space. The PAWDS has the advantage of requiring only one deck installation, therefore avoiding the need to cut through multiple decks.

Currently, sludge oil, which is a combination of oil, water and solids from the ship's bilges, is offloaded at high costs by cruise lines. The ability to process sludge oil in PAWDS will help the cruise lines reduce their overall waste management costs. Recognizing this advantage, Carnival Cruise Lines provided an advance payment for an upgrade to the existing unit onboard their Fantasy ship. With these funds and with the support of the National Research Council of Canada, PyroGenesis carried out a one year development program to determine the optimum method for processing this type of waste.

Sludge oil is a mixture of oil, water and solids, mainly from the ship bilges. The ship's oil is typically collected in a large steam heated tank. The oils collected in this tank are a mixture of motor oil, fuel oil, lubricating oil, and, possibly cooking oil. Sludge oil is a black, tarry, highly viscous liquid that requires heating to improve its flow characteristics.

The untreated sludge oil on a cruise ship contains a highly variable amount of water with compositions varying from 20-90% water. This sludge oil is typically dewatered by decantation or centrifugation using the ship's oily water separator (OWS) equipment, resulting in dewatered sludge oil with an average water content of between 30% and 50%. PyroGenesis' designed the PAWDS to process this dewatered sludge coming from the OWS equipment, heat it up and then pump it directly into the patented plasma fired eductor. This patented eductor design is a highly efficient reactor which promotes the intimate mixing of the waste stream with PyroGenesis' non-transferred arc air plasma torch which operates at a plume temperature of above 5000 K.

SYSTEM DESCRIPTION

The Plasma Arc Waste Destruction System (PAWDS) was developed with the support of the US Navy for the treatment of waste on board ships. A commercial PAWDS is being used to treat solid waste onboard a cruise vessel while a PAWDS prototype is used as a demonstration unit as part of the ongoing US Navy contract at PyroGenesis' facility in Montreal, Canada. The prototype system consists of three basic sub-systems: waste preparation, thermal destruction and off-gas treatment. A 3-D layout drawing of the PAWDS is shown in Fig. 1.

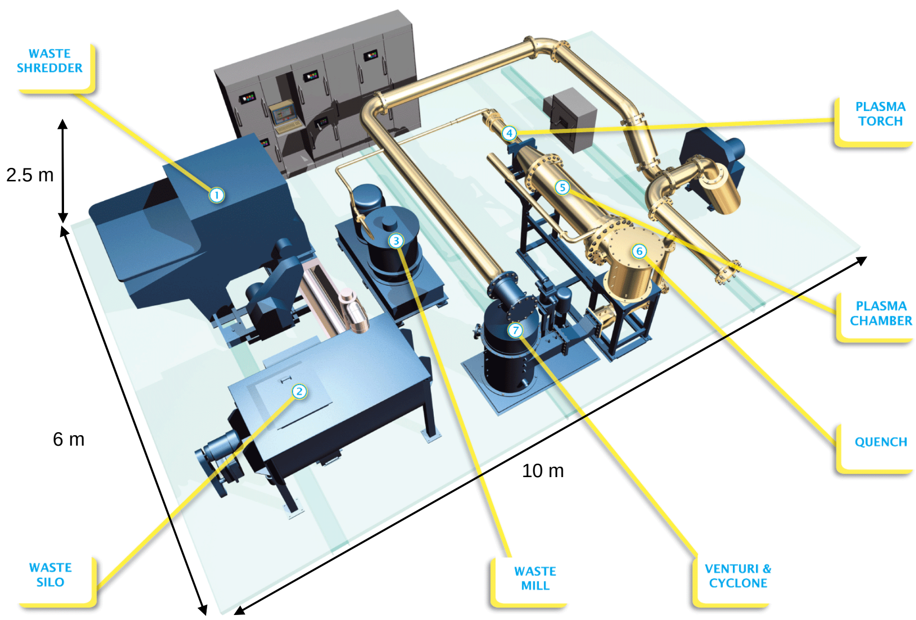

Fig. 1 - 3-D Layout of the PAWDS Prototype in Montreal

Sometimes referred to as the fourth state of matter, plasma is basically an ionized gas comprising of a mixture of electrons, ions and neutral charges. The most well known occurrences of natural plasmas are the lightning strike and the phenomenon known as aurora borealis. Some of the most well known forms of man-made plasma are the plasma gun used for welding and cutting metal and the electric arc seen in a steel melting furnace. In the case of PAWDS, a plasma torch is used to generate plasma. In a plasma torch, in order to generate a plasma plume, an electric arc is struck and sustained between two electrodes (and anode and a cathode) while compressed gas is forced through this arc. This results in an extremely hot gas (typically more than 5000 K).In the case of PAWDS, air is used as the main plasma forming gas. The ionized oxygen molecules, free electrons and UV emissions contribute to accelerating the chemical reactions of gasification in the plasma eductor, ultimately resulting in a compact gasification reactor.

The PAWDS process is schematically illustrated in Fig. 2.

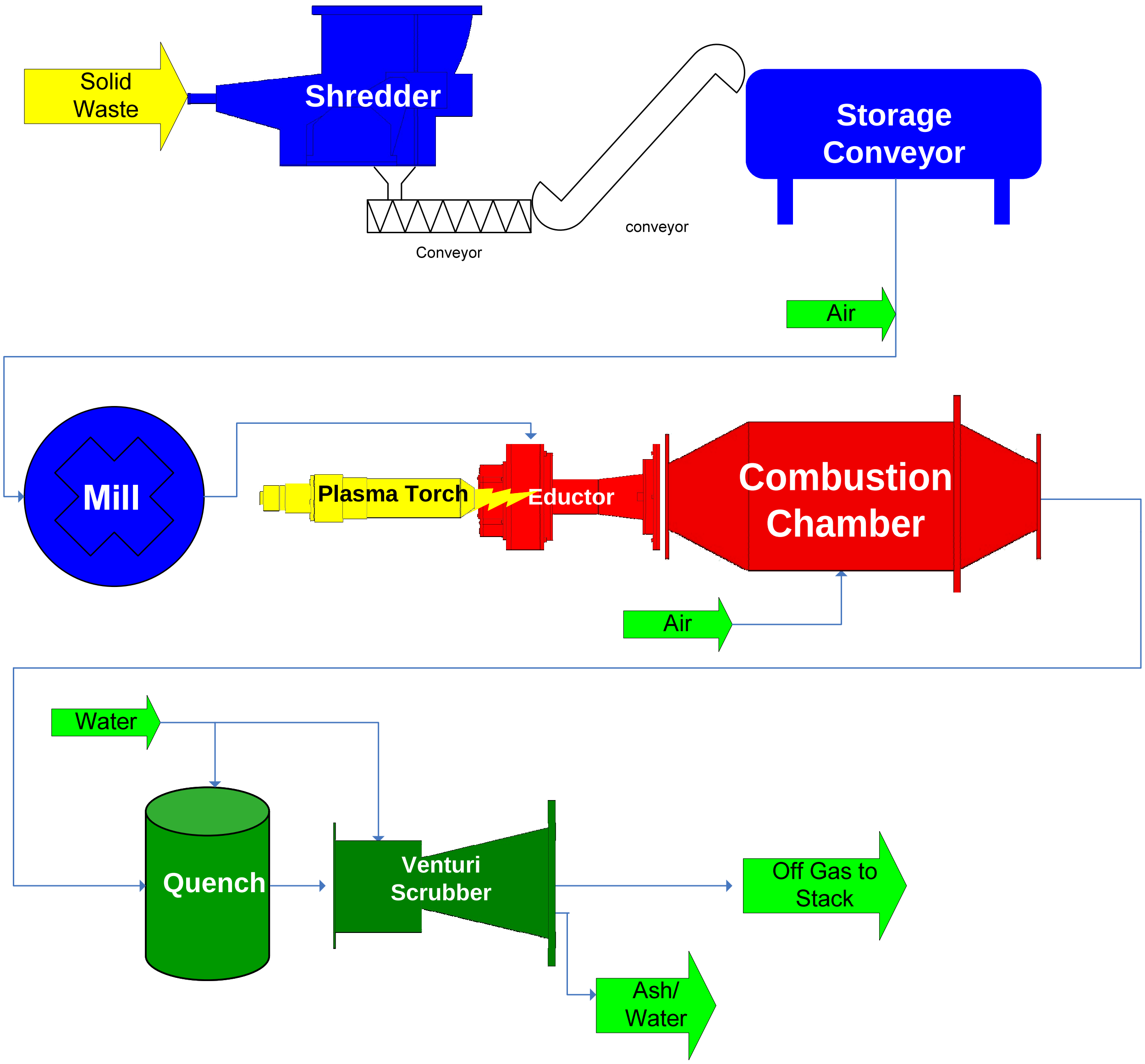

Fig. 2 – Simplified Process Block Diagram

Mixtures of solid wastes are introduced to the system through a shredder. Conveyors are used to transport the shredded waste into a storage mixer. This storage mixer has a dual purpose as it acts as both a buffer for waste storage and at the same time homogenizes the waste mixture using a ribbon-type mixer. The waste feed rate from the storage mixer is metered to the milling section using a screw feeder and a blow-through air lock. The pneumatically conveyed waste is then passed through a mill, where, using a patented process, the waste is pulverized into a uniform and highly combustible fuel which resembles dryer lint. This finely dispersed lint is then introduced pneumatically into the central element of PAWDS, the patented plasma-fired eductor (Fig. 3.)

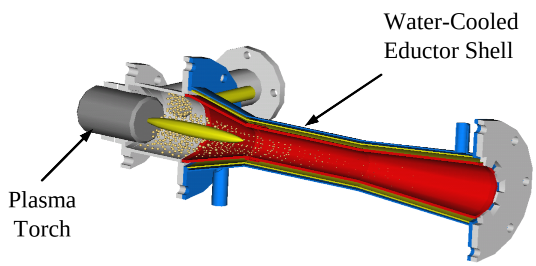

Fig. 3 – Schematic of Plasma-Fired Eductor

In contrast to the manner in which solid waste is introduced into the PAWDS, pre-heated sludge oil is introduced directly into the eductor in a an injector, designed by PyroGenesis, which results in the sludge oil coming into direct contact with the plasma plume. Some of the challenges included finding the right location for sludge oil injection relative to the plasma plume. If the sludge oil injector was too close to the plasma flame, this would result into the melting of the injector. If the injection was too far away from the intense, localized heat of the flame, gasification would not be as efficient as required.

In the eductor, the organic portion of the waste (solid or sludge oil) is gasified and converted to a synthesis gas (syngas), comprised of mainly carbon monoxide (CO) and hydrogen (H_2), as well as carbon dioxide (CO_2) and nitrogen (N_2). This syngas is then combusted in a closely coupled combustion chamber with additional combustion air. The gas is then quenched to reduce the temperature to below 100 ^{o}C, in order to prevent the reformation of dioxins and furans (in the instance where incidental plastic waste might contain some chlorinated compounds) and cleaned of entrained particulates in a Venturi scrubber. Since sludge oil can contain up to 4% sulfur, relatively large concentration of SO2 are present in the system's off-gas when processing sludge oil. In order to prevent corrosion of the downstream equipment, it is necessary to neutralize the SO_2 present in the offgas. A compact and low-cost sulphur neutralization step was integrated into the existing off-gas treatment section for that purpose.

RESULTS AND DISCUSSION

The scope of this project was to develop an efficient and low cost addition to the PAWDS technology for processing sludge oil produced aboard ships and to ensure that this system would meet all of the Lloyds Register requirements. To accomplish this goal, it was necessary to investigate the effect of several variables on the efficiency of the sludge oil gasification and combustion such as air to oil ratio, torch power, injector/eductor type, oil flow rate and composition (water and solids content). The performance of the system was assessed by determining the impact on combustion efficiency, atmospheric emissions (such as acid gases, particulate matter and metals) and combustion temperatures.

Sludge Oil Preparation

Since sludge oil produced from ships contains particulates (salts and dirt), it is necessary to filter this oil prior to its injection. Although it is well understood that finer atomization can be achieved by choosing nozzles with a finer orifice, the required filtration equipment needed to prevent clogging of the finer nozzles was found to be too complicated, expensive, and also prone to clogging. As such a compromise had to be made between the choice of atomizing nozzles with a small orifice (better atomization) and the size of filtration mesh. For the first series of tests, simple cotton cartridge filters, having a mesh size of 100 microns, were used. A basket strainer, having a mesh size of 250 microns, was also installed at the inlet of an oil counter to protect its internal parts as per the manufacturers' recommendation. The cotton cartridge filter was later replaced by a metallic mesh strainer as the cotton fibres were often clogging the fine basket strainer in front of the oil counter.

The first step in preparing the sludge oil for processing is to heat it up to 85^{o}C-90^{o}C to decrease its viscosity so that it can be injected into the eductor. A sludge oil feed preparation tank was fabricated, fitted with an electric heater and the desired temperature was maintained using a programmable logic controller (PLC). A gear pump was used to circulate the oil to the tank to achieve a homogeneous mixture and temperature at the start of each test. This pump was also used to transports the sludge oil to the injector. In order to avoid the sludge oil from cooling down in the pipes, trace heaters connected to thermocouples were installed along the length of the pipe to maintain the temperature of the sludge oil at its desired range of 85^{o}C-90^{o}C. Fig. 4 shows the experimental sludge oil tank set up from two different views.

Fig. 4 – Experimental Sludge Oil Preparation Set-up

Sludge Oil Gasification

For the PAWDS process, air is required so that the chemical reaction of gasification (production of carbon monoxide and hydrogen) can take place. Theoretical calculations demonstrate that in order to complete the gasification of 0.4 gpm (80% of 0.5 gpm of MARPOL recipe) of sludge oil 225 SCFM of gasification air are required to provide the oxygen to transform all the carbon into CO and the hydrogen into H_2. Part of the oxygen required for gasification is provided by partial molecular dissociation of the water in the sludge oil due to the high plasma temperatures. Tests showed that sludge oil mixtures with as much as 50% water could be successfully processed.

Gasification is a combination of complex reactions. Some of the main simplified gasification reactions are as follows:

$C + O_2 \leftrightarrow CO_2$ (exothermic)

$C + H_2O \leftrightarrow CO + H_2$ (endothermic)

$C + CO_2 \leftrightarrow 2\,CO$ (endothermic)

$CO + H_2O \leftrightarrow CO_2 + H_2$ (exothermic)

$H_2O \leftrightarrow H_2 + \frac{1}{2} O_2$ (endothermic)

Nitrogen Oxides Reduction

Tests were done to decrease the amount of total nitrogen oxides (NO_x) in the PAWDS off gas. The main parameter studied was the plasma torch power.

As shown in Figure 4, when the torch power was reduced by 25% the NOx dropped by 30% from 700 to 500 mg/Rm^3 (Rm^3 = reference cubic meter at 11% oxygen, 25°C, 101.3 kPa, dry gas). When the torch power was further reduced by an additional 28% the NOx dropped to 350 mg/Rm^3, resulting in a 50% reduction from its initial value. Although low NOx values are currently not a MARPOL requirement, it is believed that these environmental regulations will eventually include a limitation in NOx emissions. In addition, in the case of using PAWDS on land, the ability to meet the most stringent environmental regulations will be an important requirement.

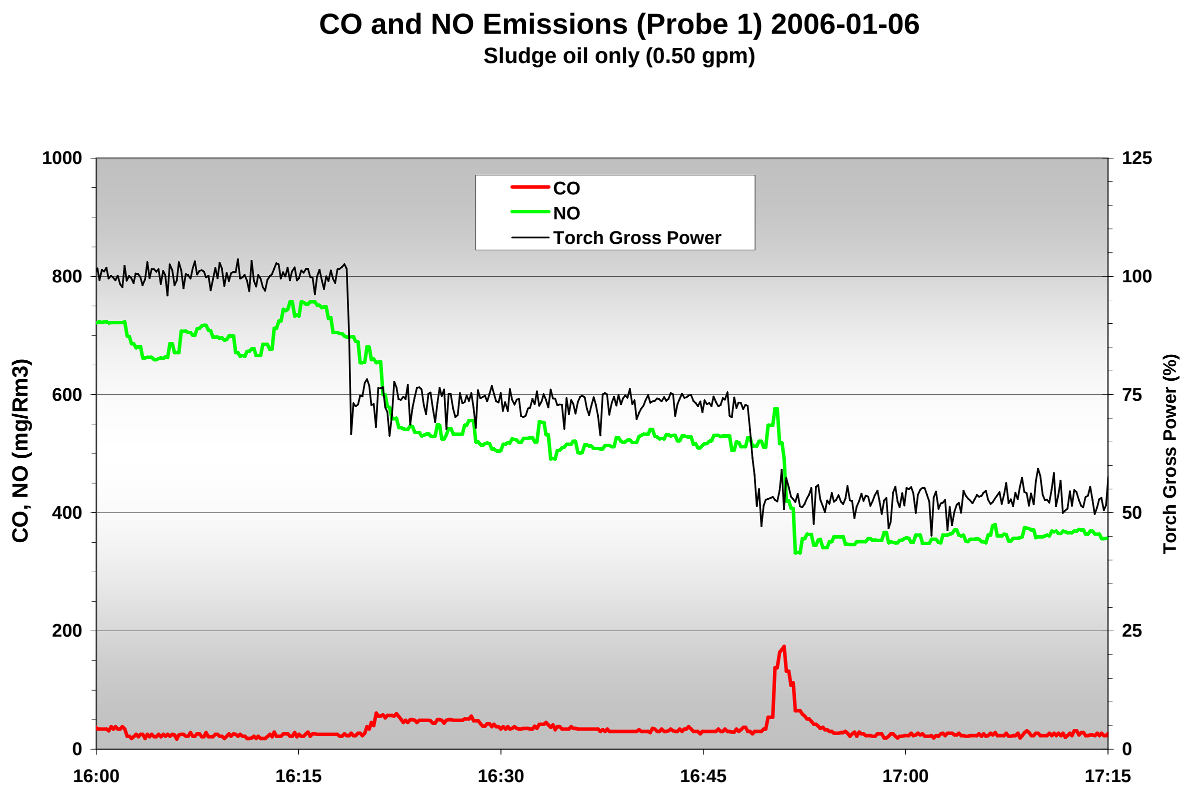

Fig. 5 - Effect of Torch Power on NOx Emission – Sludge oil Processing

Sulfur Oxides Neutralization

As the sludge oil generated aboard ships typically contains a fairly high level of sulphur (around 4 %), the off-gases from the PAWDS system needed to be treated to limit the potential SO_2 emissions and to neutralize the pH of the wash waters which would cause corrosion of the equipment.

Because the existing PAWDS off-gas cleaning design uses a rapid quench, it was decided to take advantage of this configuration and inject a solution of 50% caustic soda (NaOH) directly into the wet gas cleaning system. A dosing pump was used for this purpose and a pH probe was installed on the Venturi water discharge line to measure the discharge water pH (see Fig. 6). This pH measurement was used by the regulatory controller to automatically adjust the speed of the dosing pump to maintain the desired pH.

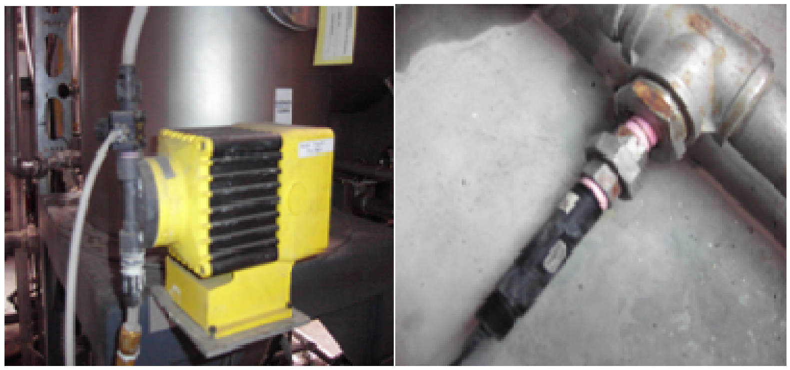

Fig. 6 – Caustic Injection Pump and pH Probe

The efficiency of this pH control system was evaluated based on the SO_2 concentration in the system's off-gas, as measured by the Continuous Emission Monitoring System (CEMAS). This emission monitoring system has two probes with one installed at the exit of the combustion chamber, before the quench, and the other after the Venturi in the off-gas discharge line. The efficiency of the neutralization system was estimated based on the amount of SO_2 detected by the CEMAS after the combustion chamber (CC) (Probe 2 - before the quench) and the residual amount detected in the off gas (Probe 1 – after Venturi neutralization) after the injection of the sodium hydroxide (NaOH).

It was establish that this pH neutralization control system was very effective as it resulted in a very stable operation from the onset of the project. The following examples clearly demonstrate this efficiency:

- Test EDM186-C, maximum of 480 mg/Rm3 SO2 exit CC and less than 20 mg/Rm3 after neutralization with an efficiency of over 95%.
- Test EDM191-B, maximum of 500 mg/Rm3 SO2 exit CC and less than 20 mg/Rm3 after neutralization with an efficiency of over 96%.

MARPOL Certification Testing

Following a mandate received from PyroGenesis, an external laboratory was hired to characterize the off gas emissions of the PAWDS while processing sludge oil on November 2005. The testing for the sludge oil waste Type Approval was witnessed by a senior surveyor for Lloyd's Register. Table I indicates the testing methods used.

Table I – Testing Methods Used

Location	PyroGenesis Inc. – Montreal Canada
Equipment used:	Montreal PAWDS Prototype
Number of tests	3
Duration of each test	2 to 2.5 hours (total 6 to 7.5 hours)
Feed Rate	Test 1, 2 and 3: 110 - 120 liters per hour (675 KW equivalent)
Feed Composition	Sludge oil Waste as per MARPOL 73/78 Annex VI (Regulation 16 (2) (a)), Appendix IV (1)
Operations & Data:	As per PyroGenesis PAWDS Operating Procedures
Sampling of Emissions	Performed by Bodycote Material Testing Canada
Air:	As per Environment Canada's standard: SPE 1/RM/8 "Reference Method for Source Testing: Measurement of Release of Particulate from Stationary

	Source."
Ash:	Performed by Bodycote Material Testing Canada,
Analysis:	Performed by Bodycote Material Testing Canada, a laboratory certified by the Environmental Ministry of Quebec.
Target Emission	As per MARPOL 73/78 Annex VI (Regulation 16 (2)(a)), Appendix IV (2)

In summary, all the measured parameters easily respect pertinent MARPOL air regulation limit values as demonstrated in Table II.

Table II - Summary of Emission Testing Results

GASEOUS COMPONENTS (ppm & %)		
Parameter	Measured value	MARPOL guidelines
O_2 (%)	11.2	6 to 12
CO (ppm)	5	-
CO (mg/Rm^3)	6	-
CO (mg/MJ corrected at 11% O_2)	3.1	200
Off-gas – Opacity (%)*	< 5	< 20
Ash – UNBURNED COMPONENTS (550 ^oC) (%)	NA**	< 10

** MICRO-RINGELMANN SCALE – Règlement sur la qualité de l'atmosphère Q-2, r.20*

*** Not enough ash produced during sludge oil testing to be able to carry out loss on ignition test*.

CONCLUSIONS

As a result of this work, the following conclusions can be drawn:

1. The sludge oil waste can be effectively treated using the plasma arc waste destruction system.
2. Very low CO emissions were measured while treating sludge oils.
3. The temperature inside the combustion chamber was maintained between 850^{o}C and 1150^{o}C.
4. The SO_x neutralization system using direct injection of NaOH into the existing gas cleaning system gives an SO_2 removal efficiency of greater than 95%.
5. The PAWDS has passed the required MARPOL certifications while processing typical marine sludge oil waste.
6. The efficiency of the PAWDS at processing sludge oil has opened up the possibility of using this same design to treat other oil waste and oily mud streams produced by other industries.

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