

Sixty Day Endurance Testing of the Plasma Arc Waste Destruction System (PAWDS)

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ABSTRACT

The Plasma Arc Waste Destruction System (PAWDS) has been developed under support of the US Navy to quickly gasify solid waste generated on board aircraft carriers. The Navy's PAWDS prototype in PyroGenesis Canada's facility in Montreal has undergone a sixty (60) day endurance test, being operated and maintained by US Navy sailors under the oversight of US Navy civilians and PyroGenesis Canada personnel. This test was required to evaluate the PAWDS for installation aboard the Navy's next generation aircraft carrier.

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. The process is highly automated, requiring only minimal skills to operate and can be started up and shut down with the push of a single button. The programmable logic controller advises the operator when and where problems arise.

The sixty day endurance test was successfully completed and demonstrated that the PAWDS is capable of treating the required 6800 lbs/day of representative solid waste containing paper, cardboard, various types of plastics, textiles and wood. The goal of these tests was to assess the overall maintainability and availability of the PAWDS and more importantly identify specific components which, if improved, would increase the PAWDS performance and reduce downtime.

Atmospheric emissions from the system were measured by a certified independent laboratory during July 2007. These tests confirmed that the design of the PAWDS off-gas cleaning system minimizes the formation of dioxins and furans and as such these compounds were well below the most stringent worldwide emission criteria.

INTRODUCTION

Management of waste on board ships is a matter that is being urgently addressed by the various Navies of the world and the cruise industry. Almost every activity performed on a ship generates solid waste, which represents the most visible and largest volume of the shipboard waste streams. The solid waste generated is similar in composition to that created in cities, but unlike municipal rubbish, which is typically sent to landfill sites, there is limited space for storing and processing it on board the ship. In the past, much of the shipboard solid waste was discharged overboard as the principal method of waste

management. However, plastic discharge is strictly prohibited and international interest in preserving the quality of the world's waters has made the practice of at-sea discharge of other solid waste undesirable.

On Navy ships, solid waste is typically managed by using a variety of equipment, including pulpers for food, paper and cardboard, shredders for metal and glass and plastics waste processors for waste plastic. Incinerators are also found on Navy aircraft carriers. However, the current incinerators have low process rates and some operational issues.

Many of the newer large cruise ships have installed the latest incineration technology. These incinerators, however, are large, and sometimes occupy up to four decks of a ship, and are heavy due to their refractory lining. The use of refractory-lined incinerators necessitates gradual start-up and shutdown of the equipment (several hours). This results in some inflexibility for the operation, particularly for the cruise ship industry, as the incinerators need to be kept hot (using fossil fuel) while in port, since waste processing in port is not permitted and thus the operating costs of this equipment increases.

PyroGenesis Canada developed, under contract with the US Navy¹, a compact marine Plasma Arc Waste Destruction System (PAWDS) for the treatment of shipboard combustible solid waste². This marine technology is based on the conversion of waste into a highly combustible lint-type material and the rapid gasification and combustion of this material in a plasma-assisted combustor. A plasma torch is used in this process. The plasma arc-assisted thermal treatment system developed by PyroGenesis Canada for shipboard waste has many advantages over conventional incinerators. All waste, including food and plastics, can be treated with minimum segregation. The all-electric 300 kW system is designed for rapid start-up and shutdown since it contains no refractory lining in its construction. The PAWDS has been proven for the treatment of sludge oil³ through an Industrial Research Assistance Program (IRAP) sponsored program during 2005/2006. The system meets the International standards, in particular MARPOL standards, for emission. As such, the system received its Marine Equipment Directive certification via Lloyds of London in 2006 for both smaller and larger PAWDS units.

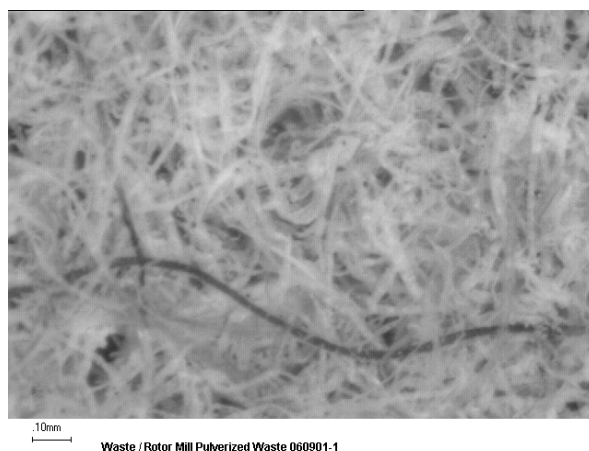
PyroGenesis Canada has also a waste-to-energy technology that can be used for application that could benefit from the energy produced from the waste. However, on nuclear powered aircraft carriers, there is no real need for energy recovery from the waste. The emphasis for this particular application is waste destruction for space saving on the ship.

A commercial PAWDS has been in operation aboard a Carnival Cruise Lines ship since 2003⁴. PyroGenesis Canada, with continued support from the US Navy, has continued to further refine the PAWDS process in particular with respect to improving reliability, maintainability and automation of the system to make it more sailor-friendly for Navy ship operation. The improved PAWDS at PyroGenesis Canada's facility in Montreal has undergone a sixty day endurance test during the summer of 2007, operated and maintained by US Navy sailors. This paper describes the experience gathered during this endurance testing period and provides additional emission data collected by a third party during this operating period.

SYSTEM DESCRIPTION

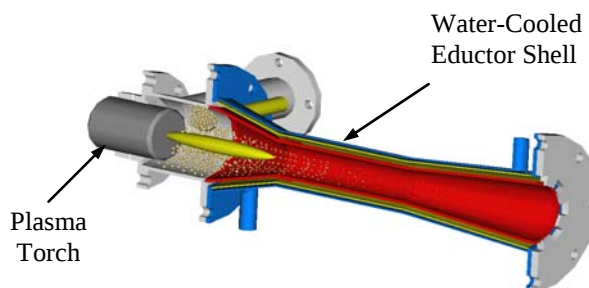
In the PAWDS, the waste is introduced to the system through a side-feeding shredder. The shredded waste drops through an automatically-cleaned magnetic separator to remove incidental ferrous materials. Two conveyors (one horizontal and one inclined) transport the shredded waste to a storage mixer. The storage mixer has a screw feeder attached to its bottom to meter the waste into the thermal destruction system. A blow-through airlock provides a seal between the atmospheric feed section of the system and the mill inlet piping allowing the waste to be pneumatically conveyed into a mill. This patented process converts the waste into finely divided lint (Figure 1) to facilitate its gasification⁵. The finely milled waste, exiting the mill, is introduced into the waste injector in front of the patented plasma-fired eductor⁶.

Figure 1 – Micrograph of the Finely Divided Lint



In the eductor (Figure 2), the organics portion of the waste is gasified into a synthesis gas (CO and H_2). The combustion is further completed in the combustion chamber (CC) where additional air is added to convert virtually all of the CO and H_2 gases into CO_2 and H_2O .

Figure 2 – Plasma-Fired Eductor



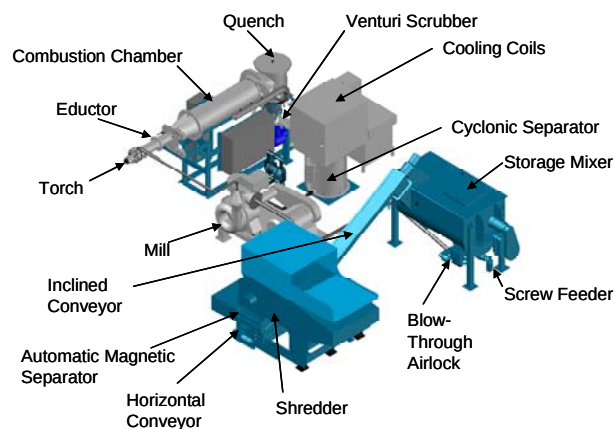
The gases from the CC are immediately quenched with water in a quench to reduce the temperature to below 100°C . This rapid quenching of the combustion gases is essential to prevent the formation of undesirable toxic dioxins and furans. A Venturi scrubber is used after the quench to trap the ash (inorganic portion of the waste) in the water. A cyclonic separator separates the off-gases from the ash-laden wash-water. A negative

pressure is maintained through the thermal processing unit using an Induced Draft Fan (ID Fan), pulling and directing the off-gases from the system towards the system exhaust stack.

The off-gases from the PAWDS are cooled using a combination of fresh water and re-circulated water after passing through a strainer to remove the large particulates. The gases are further passed through a cooling coil above the cyclonic separator to condense most of the water in these gases before exiting the system stack; thus minimizing the creation of a visible plume from the system.

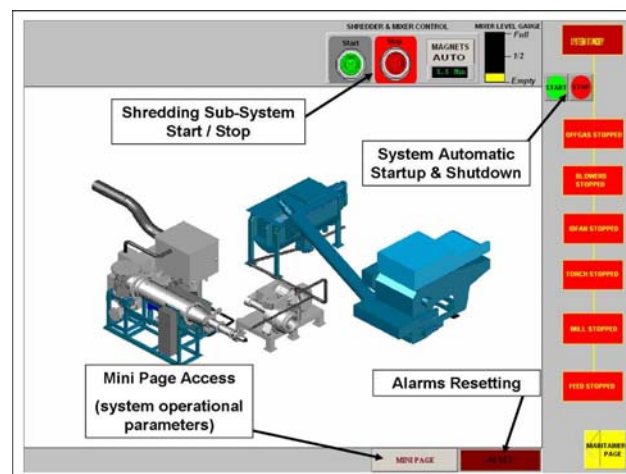
A schematic of the PAWDS set-up is provided in Figure 3.

Figure 3 – PAWDS Schematic



The PAWDS has been automated⁷ so that the operator needs only to push start and stop buttons on the operator interface display to perform equipment startup and shutdown (Figure 4).

Figure 4 – Operator Screen



The feed sub-system (shredder-conveyors-storage mixer) can be operated independently from the rest of the system, if, for example, the operator wants to shred waste and fill the mixer while other routine maintenance is being performed.

ENDURANCE TESTING

Because an aircraft carrier may be out at sea for up to six months at a time, it is of paramount importance that the US Navy understands the reliability and spare parts requirements of all equipment to be used on board this vessel. As such, and as part of the approval process to integrate the PAWDS on the *USS Gerald Ford* (CVN-78), the US Navy's next generation aircraft carrier, the Naval Surface Warfare Center Carderock Division (NSWCCD) scheduled a test at PyroGenesis Canada's facility in Montreal from June 17th to August 19th, 2007. During this period, the PAWDS was operated and maintained by a group of US Navy sailors, simulating operation aboard an aircraft carrier. Oversight of equipment operation and maintenance was provided by NSWCCD personnel with only as needed support from PyroGenesis Canada's personnel. This PAWDS endurance testing was preceded by a training period provided by PyroGenesis Canada to the NSWCCD personnel and US Navy sailors in June 2007. The actual PAWDS operation followed immediately after the training.

US Navy's Personnel Training

During the week of June 11th, 2007, PyroGenesis Canada provided training for thirteen (13) sailors from the *USS Carl Vinson* (CVN-70) aircraft carrier and seven (7) NSWCCD civilian personnel.

The training was provided over a period of four (4) days and consisted of a classroom training period followed by rotational hands-on training periods using the prototype PAWDS.

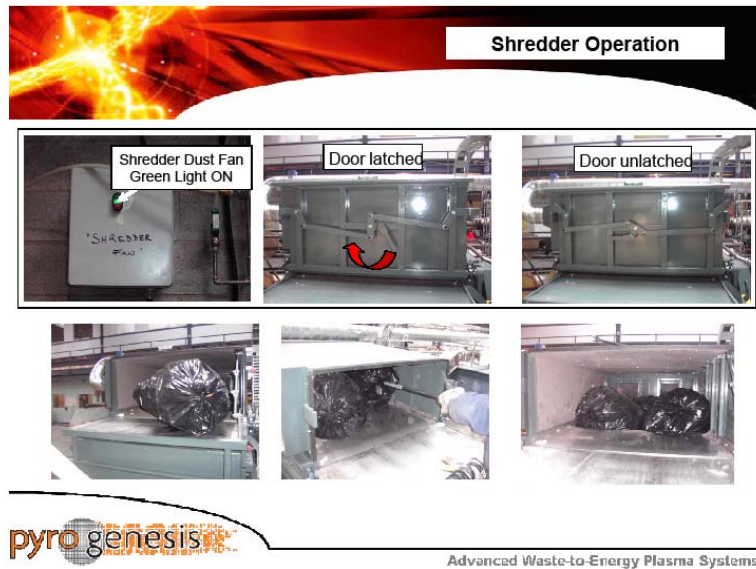
Classroom Training

The first part of the training was provided in a classroom setting. A general company overview was provided followed by a series of presentations with particular emphasis on the following:

- PAWDS System Description
- Safety
- PAWDS Operation
- Preventative Maintenance

The presentations were prepared providing visual on-screen demonstrations of the equipment as shown in Figure 5.

Figure 5 – Example Visual Presentation



The classroom training session was completed in four (4) hours. It was followed by hands-on training.

Hands-on Training

During the hands-on training, five (5) groups were formed and rotated through the various training stations in which one individual from PyroGenesis Canada was positioned at each station and was tasked to provide details on the various operation and maintenance aspects of that specific component or subsystem of the PAWDS equipment. This training format (Table 1 and Figure 6) was necessary to not only ensure a consistent “message” from each instructor at each station, but also help to optimize the efficiency of the training given the large numbers of individuals to be trained in a short period of time.

Table 1 – Hands-On Training Groups

	Jocelyn	Kosta	Bernad	François	Philippe
6/13/2007					
8:30-10:30	G1	G2	G3	G4	G5
10:30-10:45	Break				
10:45-12:45	G2	G3	G4	G5	G1
12:45-1:30	Lunch				
1:30-3:30	G3	G4	G5	G1	G2
3:30- 5:00	Questions & Answers				

6/14/2007					
8:30-10:30	G4	G5	G1	G2	G3
10:30-10:45	Break				
10:45-12:45	G5	G1	G2	G3	G4
12:45-1:30	Lunch				

Figure 6 – Hands-On Training



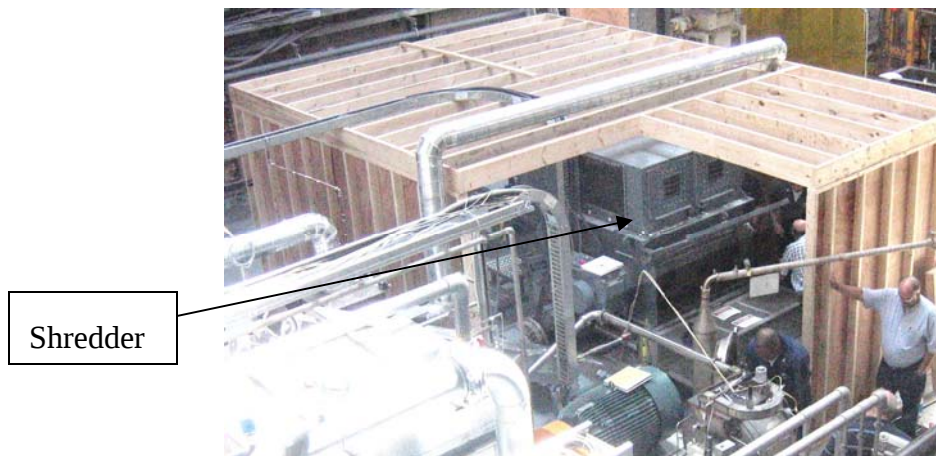
The final part of the training involved the visualization of the trainees of the PAWDS in operation. In this instance the system processed simulated Navy waste for a period of five (5) hours and was operated by PyroGenesis Canada's personnel. The trainees were encouraged to ask questions during this period so that they felt comfortable to operate the unit themselves.

Each trainee was provided with a tracking sheet to use during the training. This sheet was initialed by the individual trainers and trainees to formally document the completion of the different training sessions. The tracking sheets were collected at the end of the training week as a record of completing the training. This format of training was well appreciated by the trainee.

Shipboard Mock-ups

To simulate operation on board an Navy aircraft carrier, and in particular to evaluate the limited space that will be available around individual pieces of equipment, plywood mock-up bulkheads (Figure 7) were constructed to effectively verify that the space available will be sufficient to operate and maintain the equipment.

Figure 7 – Mock-up Bulkheads around Shredder to Simulate a Ship Compartment



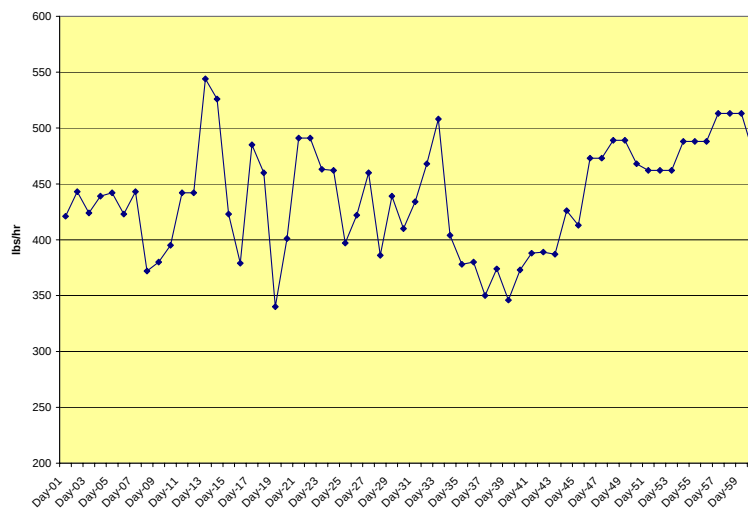
The Navy sailors performed several maintenance demonstrations on various equipments during this testing period. In general, the demonstrations have indicated sufficient space availability for the various tasks required.

The Sixty Days of Operation

The PAWDS endurance testing started on June 17th, 2007 and was completed on August 19th, 2007. During this period, the PAWDS was operated or maintained 24/7 by a rotating crew consisting of two (2) sailors and one (1) NSWCCD personnel. PyroGenesis Canada's personnel provided around-the-clock support and assistance, as required.

The system successfully processed 6,800 lbs per day of surrogate Navy waste mixtures at an average processing rate of 430 lbs/hr for a total of 408,000 lbs over the 60 processing days (Figure 8). Processing days exclude events not accountable to the test, such as power outages or logistics delays. Cleaning and maintenance of the system were performed by the Navy sailors as required during a day's operation or at the end of a processing day.

Figure 8 – Summary of Waste Processing Rates



The typical Navy waste mixture was prepared from recycled components in 25 pound garbage bags and fed to the system shredder. The recipe processed is shown in Table 2. It should be noted that PAWDS is capable of treating food and sludge oils waste in addition to the types of waste listed and used during this test period. However, for this particular application the intent was to treat only non-food solid waste.

Table 2 – Typical Navy Waste Recipe

Paper	46.0%
Cardboard	30.0%
Styrofoam	0.5%
Plastic film	7.5%
Plastic utensiles	1.5%
Milk jugs (HDPE)	3.0%
Soda bottles (PET)	1.5%
Wood	3.0%
Textiles	7.0%

During the testing period, several issues caused some downtime. The most important issues and the resolutions implemented, if applicable, were:

- A design deficiency in the mill leading to some waste by-passing the milling and causing repeated downtime due to the off-gas system having to handle untreated waste. A mechanical modification at the mill exit was made to prevent further occurrence of this by-pass.
- Excessive ash build-up in the Venturi/quench resulting from inadequate maintenance of this part of the system. A routine daily maintenance was integrated during the later part of the testing period to minimize this occurrence.
- The ID fan body cracked resulting from an impeller imbalance due to excessive ash build-up resulting from inadequate maintenance of this part of the system. To resolve this issue, a weekly visual inspection of the fan blades was added to the routine maintenance schedule followed by cleaning, if required.
- The off-gas pump mechanical seal and motor failed due to improper mechanical seal flushing. A water flush line was added to the pump seal to resolve this issue.
- Periods of downtime also resulted due to external factors such as power failure and city water shutdown for maintenance reasons.

These issues caused delays in the operation and led to a certain amount of waste back log. However, excluding these events not accountable to the test, the PAWDS processed all waste (408,000 lbs) in sixty (60) days.

EMISSION TESTING RESULTS

During the PAWDS endurance evaluation period, emission testing was conducted on the 24th and 25th of July 2007 by an independent certified laboratory. The main purpose of this emission sampling campaign was to confirm that the system design would not

produce any dioxins and furans in the off-gas emissions. As mentioned previously, this is an important feature of the PAWDS off-gas design. The results confirmed that the dioxins and furans are orders of magnitude below the most stringent urban regulations. In addition, all other emission parameters easily meet the Marine Pollution (MARPOL) guidelines and are well below EPA guidelines with the exception of particulate emissions. These particulate emissions, however, can be reduced by adding an appropriate dust filter on the system exhaust if in-port operation is desired. The measured PAWDS emission results and the MARPOL and EPA guidelines are presented in Table 3.

Table 3 – Summary of Emission Testing

	Average Measured PAWDS	MARPOL guidelines	EPA guidelines 40 CFR 60 (CCCC)
Dioxins & Furans	< 0.0041 ng TEQ/dscm	None	0.41 ng TEQ/dscm
Particulates	300 mg/dscm	None	70 mg/dscm
CO	102 ppmv (~ 34 mg/MJ)	200 mg/MJ	157 ppmv
HCL	0.28 ppmv	None	62 ppmv
NO _x	163 ppmv	None	388 ppmv
SO _x	11 ppmv	None	20 ppmv
CO ₂	7.9 %	None	None

All values corrected to 7% O₂, dry at 20 °C – dscm = dry standard cubic meter - EPA guidelines 40 CFR 60 (CCCC) is for Commercial & Industrial solid waste incineration units built after Nov. 30, 1999

CONCLUSIONS

PyroGenesis Canada's Plasma Arc Waste Destruction System has successfully undergone a sixty day endurance evaluation, operated and maintained by US Navy sailors. Several mechanical and process maintenance improvements were identified during this evaluation and will be integrated in all future production systems.

The PAWDS emissions were measured by an independent certified laboratory during the endurance evaluation period. Dioxins and furans emissions were confirmed to be orders of magnitude below the most stringent urban regulations. All other emission parameters were below MARPOL guidelines for ships.

ACKNOWLEDGEMENT

The authors would like to acknowledge the participation of all members of the following organizations during the planning and execution the sixty day endurance testing of the PAWDS:

- The *USS Carl Vinson* (CVN-70) crew involved in this training and operation
- The NSWCCD Environmental Quality Division Team
- All of PyroGenesis Canada personnel

The following excerpt was published in the Defense Daily Magazine on September 17th 2007:

A Dirty Business. Fourteen USS Carl Vinson (CVN-70) sailors returned from a trip to Montreal, Canada, where they tested, operated, maintained, and evaluated the Plasma Arc Waste Destruction System (PAWDS), a waste disposal tool currently being evaluated by NAVSEA for use on the next generation of aircraft carriers, the Navy says. PAWDS, developed by PyroGenesis, is designed to shred, mix and incinerate trash by using an 800A, direct current plasma arc system producing only a very small amount of ash. The system has been under design and funded by the Navy for about 12 years. The testing in Montreal was designed to demonstrate the system's performance for a period of 60 days to simulate a ship's partial deployment cycle. The system can process approximately 6,800 pounds of typical Navy solid waste per day, the Navy adds.

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