

Plasma Arc Waste Destruction System Off-Gas Refinement

Paper # 10

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ABSTRACT

The Plasma Arc Waste Destruction system (PAWDS) uses a plasma torch to quickly, safely and efficiently gasify solid waste. This compact, single deck, waste destruction system is designed to be used on board ships but can also be employed as a mobile land-based unit. This novel system has been developed by PyroGenesis Canada Inc (PGC) with the support of the US Navy and is MARPOL certified for both Type II Solid waste and Sludge oil. The first commercial unit was installed aboard a cruise ship in 2003 and the first military unit is currently under construction at PyroGenesis Canada Inc's (PGC) facility for the US Navy's next generation aircraft carrier.

PAWDS is capable of treating 6800 lbs/day of solid waste containing paper, cardboard, various types of plastics, textiles and wood. A sixty-day (60-day) endurance test was successfully completed in 2007, where the system was operated and maintained by US Navy sailors. Specific areas of improvements were identified during this testing period to further improve the system operational availability with a particular focus on upgrading the off-gas treatment system.

To assess the impact of the various modifications made to the off-gas treatment sub-system a thirty-day (30-day) non-continuous test was conducted using the US Navy PAWDS prototype located at PGC's facility in Montreal in the fall of 2009. This testing has demonstrated that the changes made to PAWDS off-gas sub-system had an important impact on the overall system's performance, reliability and operational availability.

INTRODUCTION

The development of the Plasma Arc Waste Destruction System (PAWDS) started in 1999. The technology was initially demonstrated in 1999-2001, as part of an Advanced Technology Demonstration (ATD) program funded by the Office of Naval Research (ONR). In 2003, Carnival Cruise Lines, recognizing the benefits of PAWDS, selected the technology for implementation on one of their cruise ships, the M/S Fantasy. The system was installed in September 2003 and has been in operated by the cruise ship personnel since June 2004. During the same period, the US Navy contracted PyroGenesis to build a new system at PyroGenesis' Montreal facility similar to the commercial or "industrial" design. This system, referred to as PAWDS - Engineering Development Model (PAWDS-EDM), is virtually identical to the system aboard Carnival's M/S Fantasy. It was built and installed at PyroGenesis Canada's facility in Montreal.

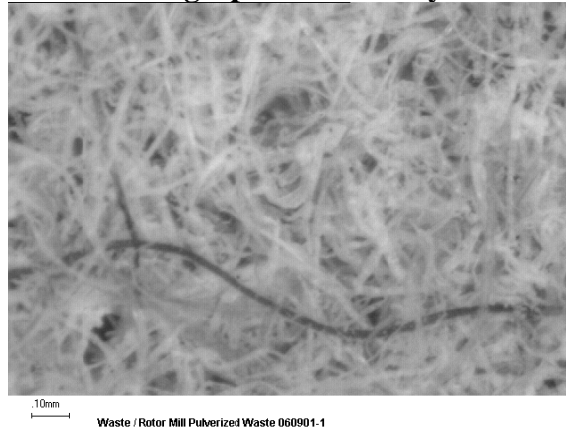
PyroGenesis Canada continued to refine the PAWDS technology over the last 6 years^{1,2} particularly making it "sailor-friendly". The PAWDS-EDM was successfully operated by US Navy sailors in 2007 for a continuous 60 days period³. During this land-based testing

period, several areas of improvements were identified to further increase the PAWDS reliability, maintainability and operational availability. During 2008-2009, PAWDS-EDM process refinements were undertaken particularly focusing on improving the operational availability of the off-gas system. Several system upgrades were completed. These system upgrades were followed by separate commissioning tests before ending the evaluation of the refinements through a series of final long duration tests. This was to allow the assessment of the impact of the upgrades on the PAWDS-EDM performance.

SYSTEM DESCRIPTION

The key to the PAWDS process is that combustible waste such as food, paper, textiles, wood, cardboard and plastics is transformed through a patented process into a highly efficient fuel (see Figure 1) prior to being gasified and combusted.

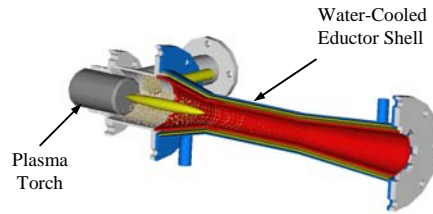
Figure 1 – Micrograph of the Finely Divided Lint



The PAWDS is a continuous process in which the waste is fed 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 conveyor) 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 the mill. The finely milled waste, exiting the mill, is introduced into the waste injector in front of the patented plasma-fired eductor⁴.

The eductor is composed of two water-cooled sections: a throat-diffuser section and a cylindrical extension (see Figure 2). In the eductor, the organics portion of the waste is gasified into a synthesis gas (CO and H₂). The synthesis gas is combusted in a patented combustion chamber (CC) where excess air is added and most of the CO and H₂ gases are converted into CO₂ and H₂O.

Figure 2 – Plasma-Fired Eductor

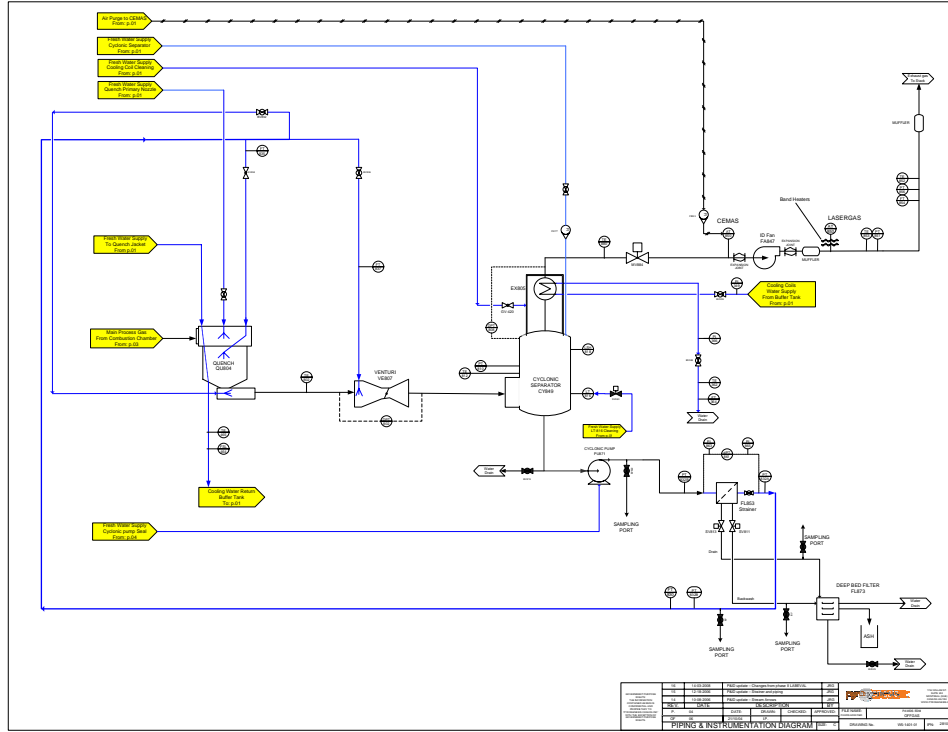


The gases from the CC are immediately quenched with water in a vertically oriented quench to reduce the temperature to below 100 °C. Rapid cooling of the gas prevents any dioxin and furan formation, which typically occurs at temperatures between 200 and 500 °C^{5,6}. A Venturi scrubber is used after the quench to trap the ash (inorganic portion of the waste) in the water. A cyclonic vessel follows to separate 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.

Fresh water is introduced into the off-gas system at the quench and into the cyclonic separator through several nozzles. Water, accumulated at the base of the cyclonic separator, is pumped, using an off-gas pump, to a self-cleaning strainer before being recycled back into the off-gas system through another set of nozzles. The dirty water flushed from the self-cleaning strainer is sent to a deep bed filter where large particles (larger than 40 microns) are collected on a filter media. The filtered water is then discharged to the drain. This deep filter installation is only used on the PAWDs prototype system in Montreal to limit the amount of discharged particles into the city drain. On a ship production system, the discharge of the self-cleaning strainer will be directed to the sea since it will only contain inorganic particles that do not cause a risk to the sea environment.

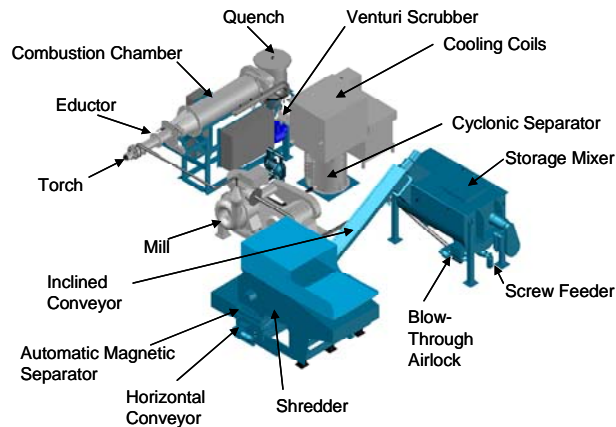
A schematic of the Off-gas system before any modifications is presented in Figure 3.

Figure 3 – Off-Gas Schematic Before modifications



The off-gases from the system pass 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. An automated exhaust line damper is located at the exit of the cooling coil and before the system's Induced Draft Fan (ID Fan) to control the negative pressure at the exit of the combustion chamber. A schematic of the PAWDS-EDM set-up is provided in Figure 4.

Figure 4 – PAWDS-EDM Schematic



An Allen Bradley Contrologix Programmable Logic Controller (PLC) with Rockwell automation RSView software is used to operate the PAWDS-EDM. The PAWDS-EDM is fully automated so that the operator needs only to push start and stop buttons on the operator panel to start and stop the system. The feed sub-system (shredder-conveyors-storage mixer) can be operated independently from the rest of the system, if the operator wanted to shred waste and fill the mixer, for example, while doing other maintenance on the system.

PAWDS-EDM OFF-GAS UPGRADES

Based on the experience with the operation and maintenance of the PAWDS-EDM during the land-based testing conducted in 2007, the off-gas sub-system was identified as a source of system downtime. The focus during this project was aimed at identifying alternative equipment or reconfiguration arrangement to positively impact the PAWDS operational availability.

A survey was undertaken at the on-set of this refinement program to identify alternative equipment with the potential of providing improvements to the system operation, maintainability and to reduce downtime.

The following modifications / upgrades were undertaken on the off-gas sub-system during 2009:

1. A new off-gas pump, replacing the existing pump which was a source of downtime during the earlier testing in 2007.
2. The integration of a duplex suction strainer in front of the off-gas pump, intended to remove larger particles from the water before it is processed by the pump.
3. A new self-cleaning strainer to replace the original strainer which required daily maintenance and was responsible for a large part of the system downtime during the 2007 testing.
4. Several other piping modifications to improve the operability of the off-gas sub-system.

A schematic of the PAWDS off-gas system following the modifications is presented in Figure 5.

Figure 6 – New Pump & Suction Strainer Installation



Commissioning tests were performed under normal operating condition. During these tests, priming of the suction strainer following the cleaning of either side of the duplex baskets was problematic. This caused air ingress into the pump suction. This resulted in a pump outlet no-flow condition which finally caused system shutdowns.

Several modifications were necessary to resolve these priming issues. The addition of a fresh water line, to fill the standby basket following a cleaning, was found to be somewhat effective (Figure 7).

Figure 7 - Fresh Water Fill Line to Suction Strainer



Phase 2: New Self-Cleaning Strainer Commissioning Tests

The new self-cleaning strainer (Figure 8) has a rotating cleaning mechanism to self clean the internal basket and expose clean pore surfaces to the water flow without interrupting the flow to the off-gas system nozzles.

Figure 8 – New Self Cleaning Strainer



The strainer self-cleaning sequence was integrated in the PAWDS-EDM PLC to initiate a cleaning if a differential pressure set point through the strainer was reached or if a timer has elapsed.

Three different basket pore size screens (small, medium and large) were tested during the commissioning phase.

Small screen size (100 micron)

The smallest pore size screen was tested in the self-cleaning strainer to determine if it would be effective at reducing the residual ash in the re-circulated water and if it would have a beneficial impact on ash deposits in the system. The use of this very fine screen resulted in starving the system from water after a very short operating time. The use of the suction strainer in front of the off-gas pump did not have a positive impact on the operation with this finer screen. It was therefore concluded that this size screen is not suitable for the PAWDS operation.

Large screen size (1000 micron)

The largest screen size was used successful in the new strainer and the cleaning cycle was only activated after the timer expired and not due to a rising pressure across the strainer. It was therefore concluded that this larger screen size was oversized for the PAWDS and did not offer much particles' retention.

Medium screen size (500 micron)

The medium pore size basket in the self-cleaning strainer was successfully tested. The cleaning cycle was found to be fairly effective at recovering system operation without causing any system upsets or shutdowns. The self-cleaning sequence was initiated by the

differential pressure across the strainer rather than by the timer as with the larger basket size, meaning the screen was efficiently capturing particles and reducing residual ash in the re-circulated water as desired. The medium self-cleaning strainer was also tested with and without the duplex suction strainer, in both cases, no noticeable difference was observed on the self-cleaning operation or the PAWDS-EDM in general. This screen size was deemed more suitable for the PAWDS-EDM application and was used for the long duration testing as discussed later in this paper.

Phase 3: Overall Off-Gas Sub-System Final Commissioning Tests

The conditions of the final commissioning of the overall off-gas sub-system modifications were as follows:

- New off-gas pump
- Duplex suction strainer
- New in-line self-cleaning strainer with the medium basket
- All other piping modifications

The final overall commissioning test was successfully completed with no problems encountered. The system seemed to perform fairly well, which means: no system upsets, no irrelevant error messages or premature system shutdowns.

LONG DURATION TESTING

Once all the off-gas sub-system upgrades were integrated into the PAWDS-EDM and successfully commissioned, the system was ready to be tested for longer periods to establish the real impact of these upgrades on the system's operability, maintenance and downtime durations. The system was operated in automatic mode processing simulated typical Nominal Navy Waste Mixtures for a total of thirty (30) operating testing days. The testing occurred over 10 consecutive calendar weeks. In general, testing for 8 hours for 3 consecutive days of operations was targeted.

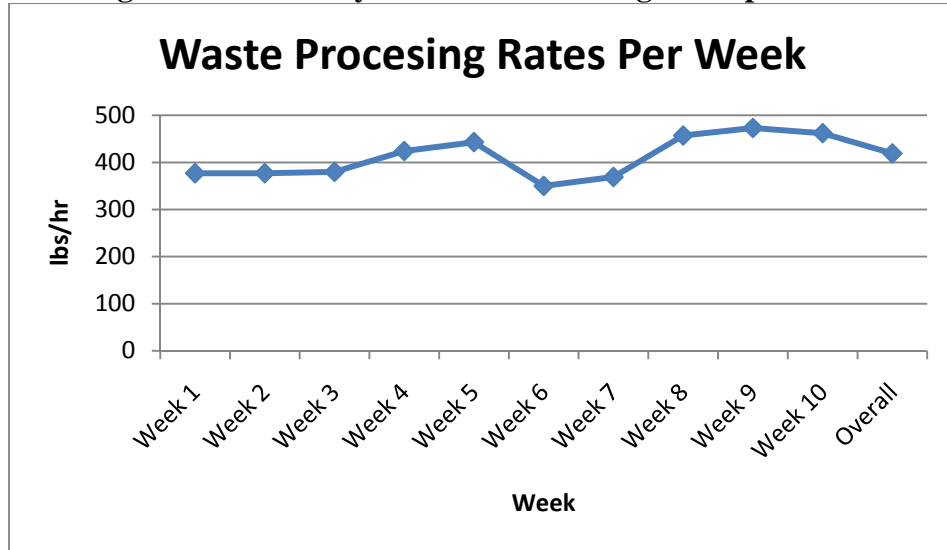
The typical Nominal Navy Waste Mixture (NNWM), as shown in Table 1, was used during these long duration tests. The prepared waste recipe was pre-mixed and pre-weighted in advance of testing in trash containers or plastic bags, ready to feed the shredder on-demand.

Table 1 - Nominal Navy Waste Mixture Recipe

Material	Paper	Cardboard	Plastics	Wood	Textiles
Weight %	46	30	14	3	7

The system processed a total of 80 000 lbs of waste at an average feed rate of 419 lbs/hr, over the 30 testing days. Figure 9 provides a graphical representation of the average processing rates during the long duration tests.

Figure 9 – Summary of Waste Processing Rates per Week



The new off-gas pump performed very well without requiring any maintenance during the 30 days testing. The pump was opened at the end of the test for further inspection. Figure 10 shows a picture of the impeller taken at the end of the long duration test confirming that no damage was noted on the impeller or casing and that no particles accumulation was noted in the pump. It is believed that this pump provides an important improvement over the previous off-gas pump.

Figure 10 - New Improved Off-Gas Pump Impeller at the End of the Long Duration



The Duplex Suction Strainer was used during the first 5 weeks of testing. Several problems were encountered due to the use of this strainer. The main problem encountered has not being able to consistently maintain the priming of the off-gas pump following a basket switch as discussed previously during the commissioning phase. In addition, fine ash accumulated in the suction strainer mechanism causing difficulties in switching the

basket's handle. These mechanical difficulties increased gradually over the 5 weeks of testing until it reached a point where additional leverage was required to move the handle. At the end of the tests, the suction strainer was dismantled inspection. Excessive amounts of ash were evident on the strainer internal surfaces as shown in Figure 11.

Figure 11 – Suction Strainer Internal Mechanism at the End of the Long Duration



The cleaning frequency of the suction strainer has also increased from once a day during the first week of testing to once or twice every hour or even more frequent near the fifth week of testing (Table 2). This suction strainer switching frequency is fairly high and would not be operable on board a ship.

Table 2 – Suction Strainer Switching Frequency

<i>Test Day</i>	<i>Operating Hours</i>	<i>Cumul. Operating hours</i>	<i>SS switches</i>
1	6.4	6.4	0
2	2.4	8.8	0
3	2.0	10.8	3
4	5.2	16.0	1
5	7.7	23.6	0
6	4.2	27.8	2
7	8.1	35.9	2
8	7.5	43.4	2
9	7.1	50.5	4
10	8.0	58.5	1
11	8.1	66.6	3
12	8.4	75.0	7
13	6.9	81.9	6
14	8.2	90.1	8
15	7.5	97.6	3
Total	97.6		42

After the first 5 weeks of testing using a suction strainer, the PAWDS-EDM was operated with all the off-gas system upgrades while by-passing the suction strainer to compare the performance of the system . A complete cleaning of the off-gas system was performed between to two periods of testing to provide a fair comparison.

The system was visually inspected for particles and ash accumulation after the first 5 weeks of testing (with the suction strainer) and at the end after the last 5 weeks of testing (without the suction strainer). As seen in Table 3, the duplex suction strainer did not have a significant impact on the ash accumulation in the system.

Table 3 - Particles Accumulation With or Without the Suction Strainer

Accumulation Evaluation	First 5 weeks (With Suction Strainer)	Last 5 weeks (Without Suction Strainer)
Off-Gas Equipment A	Medium	Low
Off-Gas Equipment B	Medium	Low
Off-Gas Equipment C	Medium	High
Off-Gas equipment D	Low	Low
Off-Gas equipment E	n/a	Medium

The long duration tests demonstrated that the PAWDS can operate with a suction strainer. However, it is not believed that the suction strainer is required or even significantly beneficial for PAWDS operation. It will, thus, not be recommended for all future designs.

The new self-cleaning strainer, fitted with a medium screen, operated without the need for any major maintenance/cleaning or operator intervention during the 30 days testing period. This is due to its more efficient self cleaning mechanism compared to the original in-line strainer used on the PAWDs previously. During the previous 60 days test Land-Based tests conducted in 2007, the previous self-cleaning strainer required much more maintenance intervention and caused excessive system downtime. The newly selected self-cleaning strainer reduced the frequency for operator cleaning intervention of at least 6 times compared to the previous self-cleaning strainer.

The self-cleaning strainer's basket was inspected twice; one after the system operation with the suction strainer and at the end of the testing following the period while the suction strainer was by-passed. No significant ash accumulation was noted on the basket. Under both testing conditions, the new self-cleaning strainer was capable of cleaning itself and returning to operation after each cleaning cycle without causing any off-gas system upsets. Figure 12 shows the basket of the self-cleaning strainer after the testing period.

Figure 12 - Basket Condition at the End of 10 Weeks of Testing



All other piping modifications, which included the addition of new fresh water lines and better instrumentation of the off-gas water duty lines, have demonstrated a more stable system performance and improved process control.

During the long duration tests as well as during all testing conducted on the PAWDS-EDM a Continuous Monitoring and Analysis System (CEMAS) is used to monitor important system emissions to confirm good operation of the PAWDS. During all the testing period, the system emissions were not different than previously noted good system performance. It should be noted that PAWDS-EDM emissions were sampled by an independent certified laboratory in 2007 during the 60 days Land-Based testing while being operated by US Navy Sailors. The main purpose of this emission sampling campaign was to confirm that the process does 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 4³.

Table 4 – 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

The PAWDS-EDM off-gas sub-system upgrades were undertaken in order to reduce the downtime encountered during the land-based testing conducted in 2007. Major improvements to the system operational availability were demonstrated due to the implemented system upgrades, in particular:

Following the off-gas refinement, since the off-gas modification has successfully completed the 30 days long duration test, the off-gas sub-system is no longer a major source of downtime. The major improvements and learning establish during this project are:

1. The new off-gas pump has performed very well with no required maintenance, eliminating the need for operator intervention compared to the original off-gas pump.
2. The new self-cleaning strainer fitted with a medium pore size basket has outperformed the original self-cleaning strainer, particularly requiring at least 6 times less operators' intervention for cleaning or maintenance. It is expected that this improvement will be even higher with additional testing.
3. The additional off-gas piping and fresh water modifications to the system had a positive impact on the system control and overall performance.

It should be noted that the even though the use of a pump suction strainer was workable; its use did not offer any operational improvement to the system. The use of a pump suction strainer for the PAWDS is therefore not recommended.

ACKNOWLEDGEMENT

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