Plasma Arc Waste Destruction System (PAWDS) A Novel Approach to Waste Elimination Aboard Ships

Aïda Kaldas, Isabelle Picard, Christos Chronopoulos, Philippe Chevalier, Pierre Carabin, Gillian Holcroft, Gary Alexander, Joseph Spezio, Jim Mann and Henry Molintas

Abstract

The Plasma Arc Waste Destruction System (PAWDS) uses plasma energy, with temperatures over 5,000oC, to rapidly and efficiently destroy combustible waste aboard ships. PAWDS has proven itself to be a viable alternative to traditional incinerators. **»***In September 2003, Carnival Cruise Lines were the first to install a PAWDS aboard their 2,056 passenger (plus 1,000 crew members) capacity, M/S* Fantasy *cruise ship, to treat ship waste including paper, cardboard, plastics, textiles, wood, and food. As of June 2004, it is being operated and maintained solely by Carnival Cruise Lines personnel and has been permitted to operate in port by the Bahamian port authorities.* **»***The Navy's next generation aircraft carrier, CVN 21, will be equipped with two PAWDS to process all of the non-food combustible solid waste generated with sufficient system redundancy. The US Navy has been jointly developing the PAWDS with PyroGenesis Inc. over the last 6 years. The development efforts in 2004 and 2005 coupled with lessons learned from operation aboard Carnival's cruise ship have resulted in the identification of additional process and design improvements. Source emission testing by an independent laboratory has also demonstrated that the PAWDS easily meets IMO MARPOL requirements for the destruction of solid waste.*

Introduction

For the last 6 years, under contract with the US Navy, PyroGenesis has been developing the Plasma Arc Waste Destruction System

(PAWDS) for the treatment of solid waste to be installed aboard future Navy ships. In 1999, as part of an Advanced Technology Demonstration (ATD) program funded by the Office of Naval Research (ONR), PyroGenesis designed, fabricated and successfully demonstrated, in its Montreal facility, a first prototype PAWDS, for the treatment of waste generated aboard aircraft carriers. The PAWDS ATD prototype was tested over a period of three years and logged over 1,500 hours of operation. The Naval Surface Warfare Center Carderock Division (NSWCCD) and PyroGenesis Inc. (PGI) entered into a Cooperative Research and Development Agreement (CRADA) allowing the two parties to collaborate in the modification, testing and demonstration of PAWDS for installation aboard a non-Navy vessel. PGI benefited from commercializing this technology while the US Navy benefited from the development and early demonstration of a shipboard system. The technology won the 2002 Federal Laboratory Consortium (FLC) Award for Excellence in Technology Transfer. Originally designed for processing rates of 360 lbs/hr, PAWDS has since reliably demonstrated processing rates in excess of 400 lbs/hr (Kaldas et al. (2003), Alexakis et al. (September 2002), Alexakis et al. (May 2002), Nolting et al. (May 2001) and Nolting et al. (April 2001)).

PAWDS is a compact, reliable, safe and efficient alternative to methods currently being used to treat shipboard waste. The high energy density of the plasma flame and the use of a unique wall design for the thermal destruction section has resulted in a system that is both compact (approximately one quarter (¼) the size of a comparable incinerator) and lightweight (approximately one half (½) the weight of a comparable incinera-

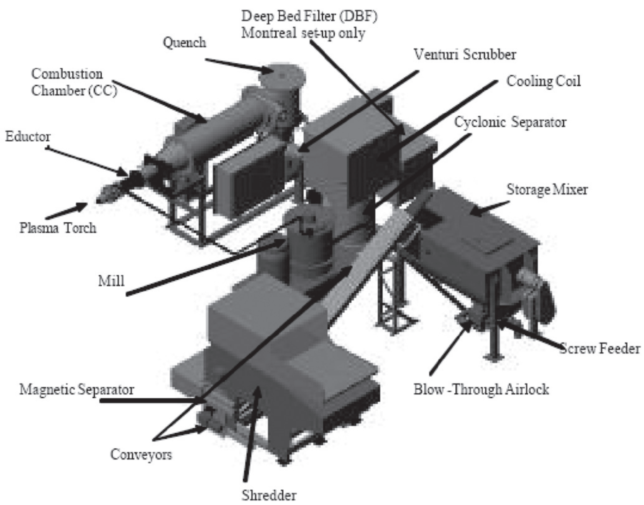

Figure 1: *PAWDS System Overview*

tor). An important feature for ship design is that this compact system is designed to occupy only one-deck compared to conventional incinerators that typically occupy four decks. The system is highly automated, with single-button start-up and shutdown sequences and is designed so that operators with minimal skill-levels find it easy to operate. The PAWDS has no refractory construction and as such has a very short start-up and shutdown periods (minutes rather than hours for incinerators).

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 operation since October 2003. Over the last twenty four (24) months, it has logged more than 3,000 hours of operation.

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 where it has logged over 800 hours of operation since December 2003.

This paper begins by providing a brief technical description of the PAWDS followed by a review of the operating experience aboard the Carnival *Fantasy* ship. Specifically, the paper presents some of the operating and air emissions data from the PAWDS operation. It also describes several process control improvements and unit operation modifications that resulted from the experience gained from the shipboard operation as well as from the continuous process improvements undertaken on the PAWDS-EDM.

System Description

The key to the PAWDS patented process is that it first shreds and then mills waste into a lint-like material so that it is transformed into a highly efficient fuel (Alexakis et al. US Patent no. 6,871,604). This milled waste is then rapidly gasified in a patented plasma-fired eductor (Nolting et al. US Patent no, 5,960,026). The resulting synthesis gas is then combusted with excess air in the patented lightweight combustion chamber (Tsantrizos et al. US Patent no. 6,152,050), resulting in a fully oxidized off-gas, comprised of carbon dioxide and water. This off-gas is then shock-cooled from above 1,000°C to approximately 80°C, using a water-quench, preventing the formation of dioxins and furans. Finally, the gas goes through a Venturi scrubber, used to remove particulates from the gas, before being exhausted to the ship's stack.

The system consists of three basic sub-systems **(Figure 1)**: waste preparation, thermal destruction and off-gas treatment.

In the process, combustible waste such as food, paper, textiles, wood, cardboard and plastics are pre-treated through a series of size reducing equipment and converted to "lint". The waste pre-processing subsystem is composed of a shredder, shredded waste conveyors, a storage mixer and a mill. Waste is fed into the shredder where its size is reduced. An automatic magnetic separator captures the incidental ferrous metals from the shredded waste at the exit of the shredder. The waste is then transported to the storage mixer using shredded waste conveyors. The purpose of the storage mixer is twofold as it mixes and homogenizes the waste and at the same time provides waste storage capacity of one to two hours. A screw feeder is attached to the base of the storage mixer and is used to meter the waste into the blow-through airlock and then onwards to the mill. The blow-through airlock provides a seal between the atmospheric feed section of the system and the oxygen starved gasification section of the process. Air from a gasification blower is used to pneumatically convey the material to the mill. The mill performs the final waste feed preparation step. The mill consists of blades that rotate at high speed thereby pulverizing and drying the waste into fine fibers that resemble lint. This type of pre-treatment dramatically increases the surface to mass ratio of the waste particles, thus, allowing them to gasify rapidly when exposed to extreme heat. The final product, leaving the mill, is a highly combustible and dry material that looks similar to lint from a household dryer. Effectively, the waste preparation sub-system converts a waste stream into a finely divided solid fuel stream.

The milled waste "fuel" is conveyed by air and injected into the plasma-fired eductor **(Figure 2)**. In the eductor, this "fuel" is exposed to the high temperature of the plasma plume that results in rapid gasification of the solid waste into a synthesis gas composed primarily of carbon monoxide (CO) and hydrogen (H_2). This gas flows into the combustion chamber, where more air is added to complete the combustion and convert the synthesis gas into carbon dioxide (CO_2) and water vapor (H_2O). The gas temperature at the exit of the combustion chamber is typically about 1,000°C. Any inorganic substances in the waste are transformed into an inert ash.

A feature of the PAWDS technology is its use of air and/or water-cooled walls instead of heavy refractory for the eductor and combustion chamber. Internal to the water-cooled jacket for the combustion chamber is an air-cooled liner made of a super-alloy. These unique design features result in a reduction of weight of approximately 90% of the thermal section compared to a traditional refractory incinerator with the same processing capacity.

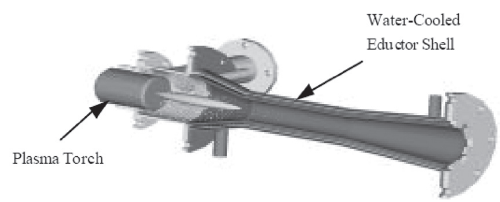

Figure 2: *Schematic of the Plasma-Fired Eductor*

Upon exiting the combustion chamber, the gases enter the quench, where water is sprayed to reduce the temperature of the gas to 80°C typically. Rapid cooling of the gas prevents any dioxin and furan formation, which typically occurs at temperatures between 200 and 500°C (Cernuschi et al. (2000) and Lemieux et al. (2000)). The cooled gases then enter a Venturi scrubber where particulates are removed from the gas stream by trapping and collecting them in the water stream. A cycl onic separator separates the water/ash stream from the gas stream prior to its discharge into the ship's stack. The ash/water stream inside the cyclonic separator is pumped through an in-line strainer (a deep bed filter is used in the Montreal setup) to separate the inert ash fraction from the water. The strained water is re-circulated to the quench spray nozzles to decrease the water consumption of the system aboard the ship. The same operation of an in-line strainer and water recirculation is intended for the systems to be installed aboard CVN 21.

Building The Shipboard System

The detailed design of the commercial PAWDS was initiated in January 2003, following the receipt of the contract from Carnival in December 2002. The goal was to ensure that the PAWDS was designed, built **(Figure 3)**, factory tested and ready for shipment by the end of August 2003 so that it would be ready for installation during the Carnival M/S *Fantasy's* pre-scheduled dry-dock in September 2003. This tight schedule necessitated that all detailed designs be completed within 2.5 months, to allow for 3.5 months of procurement, fabrication and assembly followed by 1.5 months of commissioning and testing and 0.5 months for disassembly, packaging and shipping. The entire system was shipped using two 40 foot container trucks which were then loaded onto a containership to the Carnival M/S *Fan-*

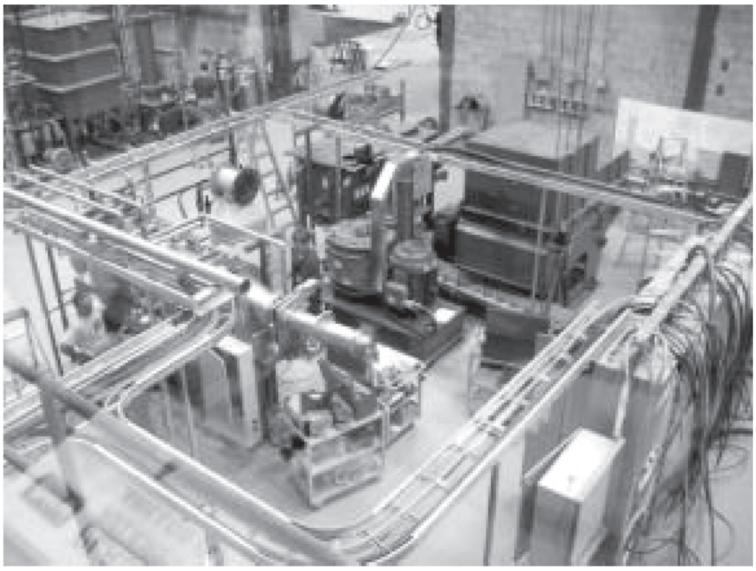

Figure 3: *Assembly at PGI (Summer 2003)*

tasy at the Grand Bahamas Shipyard dry-dock in Freeport, Bahamas.

Installation Aboard M/S Fantasy

The PAWDS system was installed on the Carnival Cruise Lines M/S *Fantasy* ship during its three-week dry-dock in September 2003. To expedite installation, a hole was made in the side of the ship, at the location of the "garbage room", to transfer the PAWDS equipment into the room. Although it is common practice during dry-docks to cut a hole in the side of the ship, the installation can also be accomplished without a dry-dock period on ships like the M/S *Fantasy* where the equipment can be loaded through the marshalling (baggage) area and transported to the garbage processing room. This modular design feature of PAWDS along with the fact that each piece or skid is relatively small is an important advantage in comparison to conventional shipboard incinerators. In addition, because the PAWDS occupies only a single deck and is relatively light-weight, there was no need to cut through the decks. The only areas that required some structural reinforcement as well as vibration shock mounts were under the mill and shredder. The entire installation was carried out in four weeks using two persons from PyroGenesis (electrical and mechanical) plus a 13-person crew of electricians, pipe fitters and millwrights from Carnival's dry-dock team.

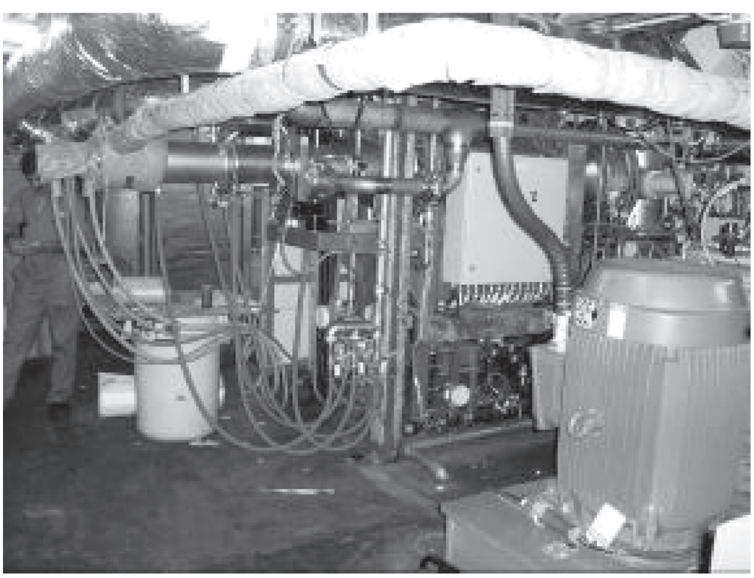

Figure 4: *PAWDS Installation aboard Fantasy*

The system layout was designed to accommodate the existing garbage room space. In this design, the system occupies a footprint of 8 m by 12 m or 1,000 square feet and fits into a room space, which has a ceiling or deck height of only 7ft 8in **(Figure 4)**. It should be noted that the layout of the system is very flexible and can be arranged in various configurations as required.

Following a training period, the PAWDS aboard M/S *Fantasy* is currently operated by one technician. The same environmental crew, that handles all aspects of the waste management aboard the ship, takes care of feeding the garbage into the shredder as well as collecting the garbage from the marshalling area and bringing it to the garbage room for processing.

Operating Experience

The PAWDS has been processing waste aboard the Carnival M/S *Fantasy* for over 24 months since it was installed and commissioned in October 2003. The system currently processes a combination of food, cardboard and cabin waste. Cabin waste is the waste generated in the passenger's cabins and is composed mainly of paper and plastics. Plastic bottles and metal cans are manually removed from the cabin waste prior to processing. The processed waste contains approximately 65% cardboard, 5% food and 30%

cabin waste. The system is designed to process waste at a nominal rate of 400-450 lbs/hr. As seen in **Figure 5**, from October 2003 to February 2004 the system's operating hours were slowly ramped up to about 40 hours per week or 160 hours per month. At the beginning and due to the ship's itinerary, a maximum of only 70 hours were available each week to process the waste since the ship had not yet obtained permission to operate in the ports and waters of the Bahamas. During the period from March to May 2004, several operating problems were encountered which resulted in a drop in operating hours. More specifically, some milling high amperage and overheating problems occurred as a result of inadequate mill blade replacement procedures as well as insufficient spare parts on the ship. PyroGenesis refined these maintenance procedures and then transferred this information to the ship's crew. In addition, the ship has purchased much of the recommended spare parts, which helped to reduce lengthy downtimes. Technicians aboard M/S *Fantasy* are currently doing all the required mill maintenance (including blades and liners change) without encountering any technical difficulties.

Three environmental crew rotations have occurred to-date: the first in May 2004, the second in November 2004 and the third in June 2005. Since the system aboard M/S *Fantasy* is not yet fully automated, a noticeable trend has been that operating hours drop during a new crew's first month until the operators get used to the system. This issue will be resolved with the fully automated control program, currently under development and planned for implementation during the latter part of 2005 on the PAWDS-EDM and intended for all future commercial and the Navy shipboard systems.

The system was originally delivered with only two plasma torches, one in operation and one as a spare. The plasma torch is normally shipped back to Montreal to replace the consumable electrodes. In August 2004, premature failures of the air plasma torch occurred due to a problem with contamination of oil and dirt in the compressed air supply, and resulted in periods of downtime since the ship was operating with only one torch while the second torch was in transit for refurbishing. The ship's problem of variable/poor compressed air quality was rectified by installing an air filter, a dryer and an oil trap. In addition, an additional spare torch was purchased by Carnival. In the future, the Carnival operators will be trained to replace the plasma torch electrodes aboard the ship, which is also the intention aboard Navy vessels.

In June 2004, the ship obtained permission from the Bahamian port authorities to operate in the ports and waters of the Bahamas after providing local authorities with information regarding the emissions from the system. The system emissions are discussed in more details in the following section. At this point, the available operating hours increased from 70 hours per week to 110-140 hours per week (approximately 18 hours per day for 5 days plus 10 hours on the days the ship is sailing to and from the port of Florida. Nevertheless, the PAWDS aboard M/S *Fantasy* is waste generation limited. In addition, its capability to process hard plastics was also constrained up until the end of 2004. This shortfall in the capability of the PAWDS to process hard plastics was the focus of further process improvements, as will be discussed in the process improvement section of this paper. After first evaluating it at the mill manufacturer and on the PAWDS-EDM system, this particular process improvement was implemented on the Carnival M/S *Fantasy* in January 2005 and, as seen in Figure 5, the processing rates have begun to increase since

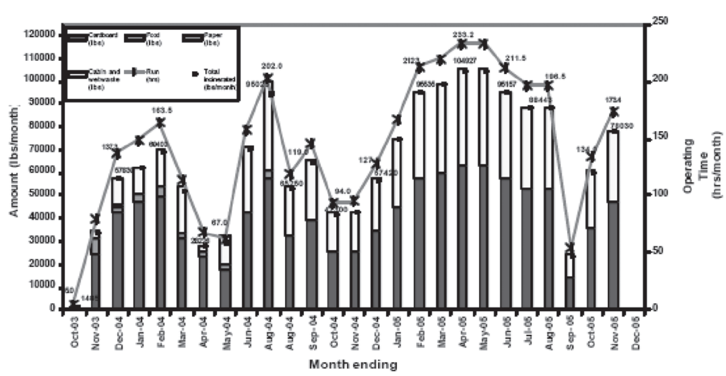

Figure 5: *PAWDS Operating Log for M/S FANTASY*

Table 1: Nominal Navy Waste Mixture

Material	%
Paper	46
Cardboard	30
Styrofoam	0.5
Plastic Utensils	1.5
Plastic Film	7.5
Milk Jugs (HDPE)	3
Soda Bottles (PET)	1.5
Wood	3
Rags	7

that time. Specifically, at the end of February 2005, the weekly rate increased to 53 hours or 212 total hours for that month. In addition, the PAWDS was operated for 15-17 hours in a single day, which is approaching its targeted operation of 18 hours per day. A three (3) weeks shutdown (dry-dock) period occurred during the month of September 2005 during which no waste was processed by the system.

Over the last twenty four (24) months, the system has logged nearly 3,000 hours of operation and processed approximately 1,250,000 pounds of waste.

Performance And Emission Results

A typical nominal Navy waste mixture **(Table 1)** has been processed successfully on the PAWDSEDM and resulted in system emissions compliance with IMO/MARPOL regulations through a series of seven (7) days of Stress Tests during 2004. The tests demonstrated the ability of the PAWDS-EDM to successfully treat the nominal Navy waste mixture at the required processing rate of a minimum of 400 lbs/hr. All routine maintenance and downtime were completed in less than 4 hours **(Figure 6)**. Some unplanned intermediate maintenance was necessary to continue with the testing, but all was completed within the overall 24 hours assigned for each test.

Figure 6: *Summary of Stress Tests*

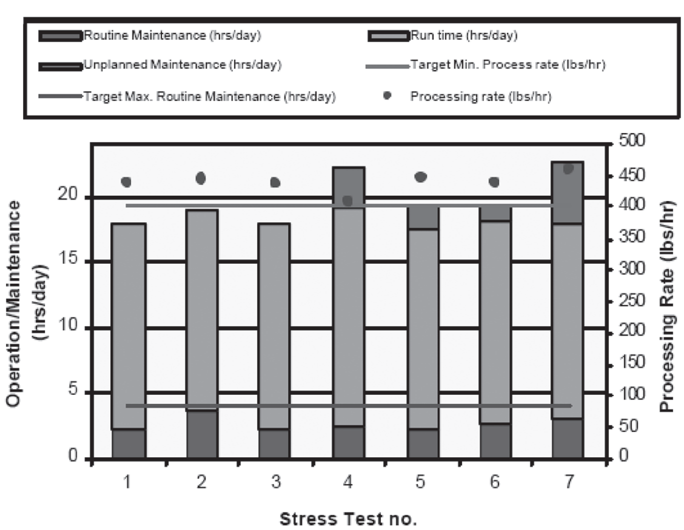

Table 2 provides a summary of the system performance and emission results during the seven (7) days of Stress Tests completed during 2004 and forming the basis for the "Go" decision for a dual PAWDS installation aboard CVN 21.

In order to apply for MARPOL Type Certification, on September 23rd, 2004, a certified external laboratory (Bodycote Material Testing of Sainte-Foy, Quebec) sampled and analyzed the off-gas emissions and ash generated from the PAWDS-EDM system in Montreal while processing MARPOL Type II solid waste. Since this PAWDS-EDM is essentially identical to the system aboard the M/S *Fantasy*, the results obtained can be used to certify both plasma systems.

The IMO/MARPOL regulations require that a six (6) hour test be carried out using a waste feed mixture comprised of 50% food waste and 50% rubbish. Details of the mixture are summarized in **Table 3.** The average feed rate during this test period was 425 lbs/hr.

A series of three (3) two (2) hours runs were sampled and tested. All the results obtained were clearly below IMO/MARPOL requirements as shown in **Table 4.** On the basis of these test results, PyroGenesis plans to request from Lloyds Register the formal IMO MED certificate.

Process Improvements

Since the system was installed on M/S *Fantasy*, several process improvements have been realized through the continued development work carried out in Montreal on the PAWDSEDM

Table 2: Summary of Stress Tests

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Start	Nov. 29th , 2004 @ 7:50 am	Nov. 30th, 2004 @ 2:42 am	Nov. 30th, 2004 @ 10:22 pm	Dec. 1st, 2004 @ 5:01 pm	Dec. 13th, 2004 @ 8:39 am	Dec. 14th, 2004 @ 4:21 am	Dec. 14th, 2004 @11:54 pm
End	Nov. 30th, 2004 @ 1:37 am	Nov. 30th, 2004 @ 9:35 pm	Dec. 1st, 2004 @ 4:09 pm	Dec. 2nd, 2004 @ 3:06 pm	Dec. 14th, 2004 @ 4:00 am	Dec. 14th, 2004 @ 11:32 pm	Dec. 15th, 2004 @ 10:30 pm
Total test time (hrs)	17.8	18.9	17.8	22.1	19.4	19.2	22.6
Total Waste Feed time (hrs)	15.5	15.4	15.6	16.7	15.3	15.5	14.8
Downtime for routine maintenance (hrs)	2.3	3.5	2.1	2.5	2.1	2.6	2.9
Downtime for intermediate maintenance (hrs)	0	0	0	3	2	1.1	4.9
Total amount of waste processed (lbs)	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Average Feed Rate (lbs/hr)	438	442	435	408	445	439	459
Average CO emissions (mg/MJ (MARPOL limit = 200)	99	134	97	123	110	104	195
Average Ash Volatile content - LOI (%) (MARPOL< 10 %)	7.2	7.1	8.3	6.6	6	7.3	7.6

and sponsored by the US Navy. Some of these process and automation improvements have been implemented aboard Carnival's *Fantasy*. The following sub-sections discuss the process improvements implemented to-date.

HARD PLASTICS PROCESSING

The waste mixture aboard a cruise ship or an aircraft carrier typically contains around 14% plastics in which roughly half of these plastics are "hard" (e.g. utensils, HDPE and PET). The original PAWDS mill was unable to properly process these hard plastics **(Figure 7)** and as a result, plastic fragments were frequently recovered in the ash discharged from the system during tests at PyroGenesis facility in Montreal. This situation not only caused fluctuations in carbon monoxide (CO) emissions but also resulted in higher than acceptable organics content (Loss-On-Ignition LOI) in the ash. For this reason, the system aboard M/S *Fantasy* was only processing soft plastics up until January 2005.

Improvements to the milling process were achieved during a development program undertaken in 2004 and sponsored by the US Navy. These improvements have resulted in a more

Table 3: MARPOL TYPE II Solid Waste Composition

50% Food Waste	50% Rubbish containing roughly:
	– 30% paper
	– 40% cardboard
	– 10% rags
	– 20% plastics

Table 4: Emission Results by a Certified Laboratory

	SAMPLING SCHEDULE				
Run Number	1	2	3	Avg.	MARPOL Limit
Date	23/09/04	23/09/04	23/09/04		
Starting Time	9h14	13h22	16h22		
Ending Time	12h40	15h54	18h23		
	GASEOUS COMPONENTS (PPM & %)				
O_2 (%)	10.3	9.3	10.2	9.9	6-12
CO_2 (%)	10.1	10.9	10.2	10.4	N/A
CO (ppm)	145	106	72	108	N/A
	GASEOUS COMPONENTS (M G/RM^3)				
CO (mg/Rm^3)	165	122	82	123	N/A
	Carbon Monoxide (mg/MJ corrected at 11 % O_2)				
CO (mg/MJ corrected at 11%O_2)	81.7	55.8	40.7	59.4	200
	OTHER MEASUREMENTS				
Opacity*	< 20%	< 20%	< 20%	< 20%	< 20%
Unburned Components in the Ash (%)		< 1 %			< 10 %

** Micro -Ringleman Scale*

Figure 7: *Poorly Milled Plastics*

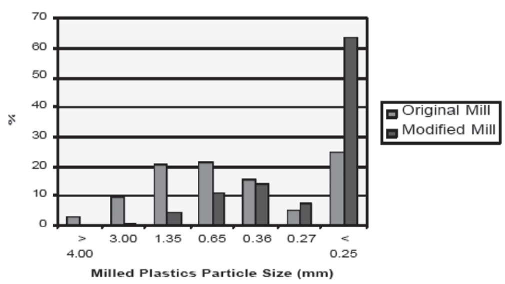

Figure 8: *Improvement Achieved in Milled Particle Size Distribution*

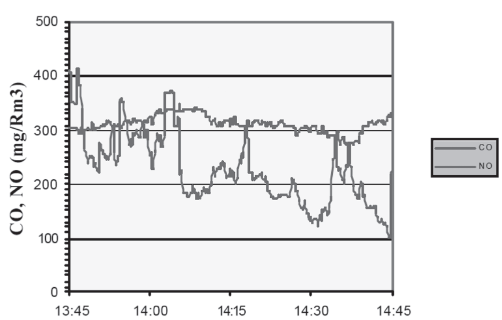

Figure 9: *Typical PAWDS Performance before Mill Improvements*

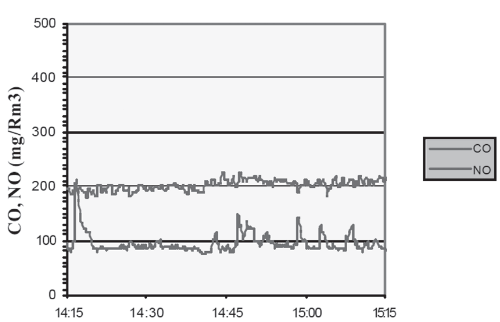

Figure 10: *Typical PAWDS Performance after Mill Improvements*

finely produced particle size (over 60% finer than 250 microns) **(Figure 8)**.

The mill modification allowed successfully processing of hard plastics on the PAWDS with emission results much below MARPOL requirements. **Figure 9** and **Figure 10** provide examples of carbon monoxide CO and nitrogen oxide NO emissions before and after these mill modifications. It is apparent from these graphs that the undesirable emissions are both lower and much more stable. These mill improvements were subsequently implemented on the M/S *Fantasy* in January 2005.

STACK VISIBLE PLUME ELIMINATION

Since the gas is cooled by water evaporation, it contains a large amount of water vapor, typically 40-50% by volume at the exit of the cyclonic separator. Under certain weather conditions, this water vapor condenses as the gases exit the stack into the ambient air, resulting in a visible plume, typical of most combustion systems. As previously described, a water-quench is used to bring down the temperature of the PAWDS off-gas from 1,000°C to 80°C in less than 0.5 seconds to prevent dioxins and furans formation. This process, however, poses a problem for shipboard operation, especially on an aircraft carrier, since the plume produced can present a visual obstruction to the aircrafts during landing.

A system to eliminate the visible plume was developed and demonstrated on the PAWDSEDM set-up in Montreal. The approach was to condense out the water from the quenched off-gas and re-heat it slightly in order to lower its relative humidity. Although others have developed similar systems for this purpose, in the case of PAWDS, the challenge was to design a plume suppression system that was compact and could fit within the limited real estate available on a ship.

A final design was selected from several possible options. The selected design included a cooling coil and an electric re-heater. Tests, carried out in winter conditions have clearly shown **(Figure 11)** that the plume from the PAWDS stack was virtually eliminated, even without having the re-heater on-line. The moisture content of the gas exiting the cooling coil, now installed above the cyclonic separator, has been reduced from

40-50% to less than 13%, bringing down the relative humidity from 100% (saturation) to less than 20%. Additional tests have shown that the use of an additional re-heater only had beneficial effects on the relative humidity of the plume (less than 10%), as again no plume could be visually identified during these tests either.

Figure 11: *PAWDS Visible Plume Elimination*

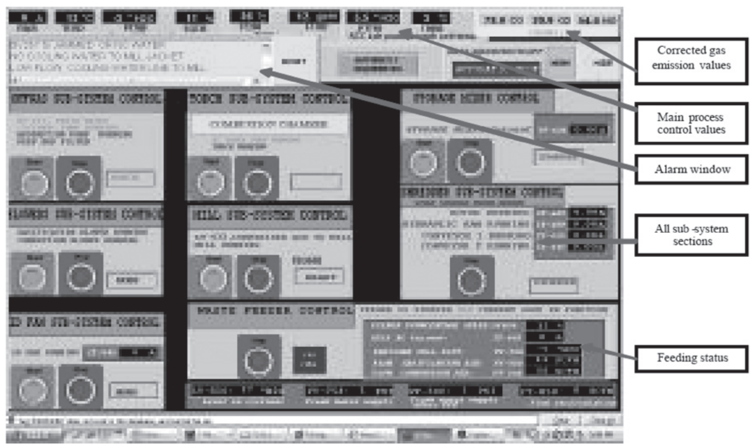

Figure 12: *PAWDS Operator Interface*

FULLY AUTOMATED OPERATION

Several improvements were made to the automation and process control of the PAWDSEDM during 2004 and 2005. These improvements include: implementing automatic startup and shutdown sequences, control of the combustion air blower speed based on the oxygen concentration in the exhaust, feedback control of torch power, temperature control of the mill, feedback control of the screw feeder, and improvement of the operator interface. Several descriptive pop-up screens have been added to the operator interface **(Figure 12)** in an effort to help guide the operator to either rapidly troubleshoot the system or as a reminder that maintenance is required on a specific item. Feedback from *Fantasy* operators has been that these screens have helped reduce system downtime allowing them to achieve a faster diagnostic and troubleshooting of the system.

The system has also been designed with the possibility of remote access over the internet, if required. Further developments are underway to fully automate the operation of the system with the ultimate goal of providing a sailor-friendly operator interface requiring no operator intervention during operation and enabling the operator to determine what action to take to fix the system, if required. The system will create interactions between the independent control loops to intelligently control and optimize system operation compensating for variations in the waste composition by maintaining a specific amount of oxygen content in the off-gas within a specific range of combustion air flowrate.

Conclusion

A commercial PAWDS system has been installed on a cruise ship and has been running since October 2003. The system has logged nearly 3,000 hours of operation and processed roughly 1,250,000 pounds of waste. External laboratory testing has shown that the system meets IMO/MARPOL emissions for operation at sea when processing Type II solid waste compositions. In addition, the system is authorized to operate in the ports and waters of the Bahamas.

Several process improvements have been implemented on the system with the goal of improving the system reliability, reducing maintenance effort and cost, and achieving full system automation. These improvements focused on increasing the ability of PAWDS to process all types of plastics as well as refining the process control system to ensure a more stable waste feed rate into the thermal section. Automatic “pop-up” screens were added to the operator interface as a means of assisting the operator in rapid troubleshooting and as a reminder for the required maintenance. The system’s exhaust visible plume also has been virtually eliminated.

Continued developments are underway with the aim of reducing the system’s operating costs, as well as increasing PAWDS capability by being able to treat wastes such as sludge oil (commercial only), as well as to consider the incorporation of energy recovery into the system (commercial only).

Acknowledgement

The authors would like to acknowledge the hard work and dedication of Platon Manoliadis who was PyroGenesis' M/S Fantasy project manager along with the PyroGenesis' design and fabrication teams which included: Bill Kreklewetz, Jocelyn Remillard, François Deprez, Bernard Allard and Nick Tsantrizos as well as the PyroGenesis installation, commissioning and training teams which included: Luigi Sperduti, Serge Grenier, Daniel Lafrenière, Andre Béland, Kosta Bacogiannis and Mathieu Côté.

Acknowledgements are also extended to members of the NSWCCD support team during the PAWDS-EDM continuous development program, in particular: Jack Pitchford, Carlton Jones and Thomas Walters.

We would also like to thank the CVN 21 Program Office for funding the development of the shipboard PAWDS and providing technical guidance for shipboard integration, in particular:

Doug Vaughters, Hank Berry, David Shen, and Eric Pitt. Acknowledgements are also extended to Northrop Grumman Newport News (CVN 21 Lead Design Yard) employees Kyle Bullard and Benjamin Raper for their contributions towards improving the PAWDS for shipboard integration.

In addition, the authors would like to acknowledge the support provided from Brian Swensen, Vice President of Technical Operations, Carnival Cruise Lines, Markku Hokkanen, of Kvaener-Masa Yards, during the planning and installation of the system aboard Fantasy, the Fantasy Chief and Staff Engineers, the Captain and Staff Captain and Paul D'Annunzio, Carnival's Environmental Officer, along with the Fantasy's Environmental Teams.

References

Alexakis, T., P.G. Tsantrizos, A. Kaldas, S. Pelletier and P. Manoliadis, "Compact Plasma Waste Elimination System for Ships", *Proceeding of the International Conference on Ship Design and Operation for Environmental Sustainability*, September 2002, London, U.K.

Alexakis, T., P.G. Tsantrizos, P. Manoliadis, D. Beverly and S. Pelletier, "A Plasma-Arc-Assisted Thermal Treatment System For Shipboard Waste", *Proceedings of the 21st Conference on Incineration and Thermal MEETS06* - Crystal City (Arlington), Virginia - January 23rd to 25th, 2006

Treatment Technologies, May 13-17, 2002, New Orleans, Louisiana.

Alexakis, T., J.W. Cofield, P. Manoliadis, E.E. Nolting, P.G. Tsantrizos and R.V. Richard, "Conversion of waste into highly efficient fuel", *Patent no. 6, 871, 604.*

Cernuschi, S., M. Giugliano, M. Grosso, E. Aloigi and R. Miglio, "PCDD/F and Trace Metals Mass Balance in a MSW Incineration Full Scale Plant", *Proceedings of the 19th International Conference on Incineration and Thermal Treatment Technologies,* May 8-12, 2000, Portland, Oregon.

Kaldas, A., T. Alexakis, P.G. Tsantrizos and S. Pelletier, "Optimization of the Marine Plasma Waste Destruction Technology", *Proceedings of the 22nd International Conference on Incineration and Thermal Treatment Technologies*, May 12-16, 2003, Orlando, Florida.

Lemieux, P.M., C.W. Lee, J.V. Ryan and C.C. Lutes, "Bench-Scale Studies on the Simultaneous Formation of PCBs and PCDDs/F from Combustion Systems", *Proceedings of 19th International Conference on Incineration and Thermal Treatment Technologies*, May 8-12, 2000, Portland, Oregon.

Nolting, E.E., J.W. Cofield, T. Alexakis, P.G. Tsantrizos and P. Manoliadis, "Plasma Arc Thermal Destruction Technology for Shipboard Solid Waste", *Proceedings of 20th International Conference on Incineration and Thermal Treatment Technologies,* May 14-18, 2001, Philadelphia, Pennsylvania .

Nolting, E.E., J.W. Cofield, P.G. Tsantrizos, P. Manoliadis and T. Alexakis, "A Compact Solid Waste Destruction Device Using a Plasma Arc Discharge", *American Society of Naval Engineers Conference*, April 2001.

Nolting; E.E., J. Cofield, R. Richard and S. Peterson, "Organic Waste Disposal System", *US Patent no. 5, 960, 026.*

Tsantrizos, P.G., T. Alexakis, M.G. Drouet; P. Manoliadis, E.L. Rademacher Jr. and T.J. Rivers, "Lightweight Compact Waste Treatment Furnace", *US Patent no. 6,152,050.*

Author Biographies

AÏDA KALDAS, *Eng. is the principal author and Technical Manager at PyroGenesis Inc. She is currently leading the process development team of the Plasma Arc Waste Destruction System for applications on board ships. She holds a Bachelor in Chemical Engineering from Cairo University and a Masters in Engineering Science from the University of Western Ontario. She is a member of "l'Ordre des Ingénieurs du Québec" since 1981. Prior to joining PyroGenesis Inc., Mrs. Kaldas has led several development programs working for Orica (formally ICI Explosives) for over 20 years. Her areas of expertise include process optimization and debottlenecking, process modeling and particles processing.*

GARY ALEXANDER *is the program manager for PAWDS for the U.S. Navy at the Naval Sea Systems Command, Carderock Division. He is responsible for all aspects of the PAWDS development for installation aboard CVN 78, including equipment design, testing, evaluation and ship integration. He has been managing the PAWDS program since 2002. During this period, he has participated in the design, development and construction of the Navy's PAWDS EDM, overseen testing of the EDM, and observed the installation and operation of the Carnival Cruise Lines PAWDS system. He holds a Bachelor of Science in Mechanical Engineering from the University of Maryland He has worked in the environmental field for over ten (10) years. His areas of expertise are solid waste processing and thermal destruction systems.*

PIERRE CARABIN, *Eng. is presently the Chief Engineer and Technical Manager for PyroGenesis Inc's Plasma Resource Recovery technology. Mr. Carabin has been employed by PyroGenesis Inc. for the past seven years, during which time he worked in the design and development of gasification and vitrification of ash using graphite arc, lightweight combustor walls and plasma resource recovery from MSW and other waste types. Prior to joining PyroGenesis Inc., Mr. Carabin has been working on process engineering and process development in the pulp and paper industry for a period of eight years. He holds a Master's degree in Chemical Engineering from McGill University. He is a member of "l'Ordre des Ingénieurs du Québec".*

Philippe Chevalier, Eng. is the Automation Department Leader at PyroGenesis Inc. Mr. Chevalier earned his Bachelor's Degree from "L'École de Technologies Supérieures" in 2000. He immediately joined PyroGenesis as an automation engineer. Mr. Chevalier was an integral member of the installation and commissioning team with respect to the Compact Plasma Waste Elimination System project on board Carnival's M/S Fantasy *cruise ship. He is also a key member of the Plasma Resources Recovery team. He is a member of "l'Ordre des Ingénieurs du Québec".*

CHRISTOS CHRONOPOULOS, *Eng. is presently a Product Development Engineer at PyroGenesis Inc. Over the last two years, Mr. Chronopoulos has worked on the design and development processes for the treatment of all types of wastes. Prior to joining PyroGenesis Inc., Mr. Chronopoulos worked on process engineering and process development in the Fuel Cell industry for a period of two years and also in the Electronic Plating industry for 4 years. He holds a Bachelor's degree in Chemical Engineering from Sherbrooke University. He is a member of "l'Ordre des Ingénieurs du Québec".*

GILLIAN HOLCROFT, *Eng. is presently PyroGenesis Inc. Director of the Waste Treatment division. Prior to joining PyroGenesis Inc., as the manager of CIMA+ advanced control and optimization group, she was both the business development and technical lead for this group. During her twelve years at Noranda she had many roles and responsibilities. As team leader of the process control and optimization group, she led a team of engineers and technologist who provided technical support to all Noranda operations. Mrs. Holcroft's areas of expertise include process control, process simulation and business modeling. She earned her Bachelor's Degree in Chemical Engineering from McGill University in 1989 and then went on to re-*

ceive her Master's Degree in 1994 in Chemical Engineering while working at Noranda. She is a member of "l'Ordre des Ingénieurs du Québec".

JAMES MANN, P.E. *is the Systems Engineer for PAWDS for the U. S. Navy at the Naval Sea Systems Command, Carderock Division. He is responsible for the ship integration of the PAWDS system into the Northrop Grumman Newport News (NGNN) ship design for CVN 78. He has been part of the PAWDS program since 2001. He has a Bachelor of Science in Mechanical Engineering from the Virginia Polytechnic Institute and State University. He has been a licensed Professional Engineer in Maryland since 1987. He previously worked as the Chief Engineer for International Waste Industries, a manufacturer of incinerator systems; as a marine engineer for MAR Incorporated, and an engineer for Newport News Shipbuilding and DryDock Company (now NGNN). His areas of expertise are in waste combustion equipment, marine shipboard equipment, and automatic control systems.*

HENRY MOLINTAS *is a Mechanical Engineer at the Naval Surface Warfare Center, Carderock Division (Code 634). He is the Technical Point of Contact (TPOC) of the Plasma Arc Waste Destruction System (PAWDS) ongoing improvement program. He holds a Bachelor's Degree in Mechanical Engineering from Saint Louis University (Baguio, Philippines) and a Masters in Mechanical Engineering from Old Dominion University. Mr. Molintas served as the lead environmental pollution control engineer for CVN 21 at NAVSEA and a holder of US Patent No. 6740205-Processing of Shipboard Wastewater. Mr. Molintas is currently pursuing a PhD in Mechanical Engineering at the University of Maryland. His areas of expertise include oily wastewater ultrafiltration processing and operations of Navy shipboard HVAC and associated auxiliary machinery systems.*

ISABELLE PICARD, *Eng. is a Product Development Engineer at PyroGenesis Inc. She is currently part of the process development team of the Plasma Arc Waste Destruction System for applications on board ships. She holds a Bachelor in Chemical Engineering from "École Polytechnique de Montréal". She is a member of "l'Ordre des Ingénieurs du Québec" since 1995. Prior to joining PyroGenesis Inc., Mrs. Picard has worked as project leader for several development project related to natural gas applications working for The Natural Gas Technologies Center and as Product Development Engineer for the fuel cell industry working for H Power Canada inc. Her areas of expertise include process development and optimization, system integration and equipment sizing.*

JOSEPH SPEZIO, ENG. *is a Mechanical Engineer at the Naval Surface Warfare Center, Carderock Division. He is currently providing technical and programmatic support for the Plasma Arc Waste Destruction System development team. He holds a Bachelor's degree in Mechanical Engineering from the University of Maryland Baltimore Co. Mr. Spezio has worked in other environmental areas for the U.S. Navy including developing oily waste disposal systems and environmental compliance procedures.*