OPTIMIZATION OF THE MARINE PLASMA WASTE DESTRUCTION TECHNOLOGY

Aïda Kaldas, Theodora Alexakis and Peter Tsantrizos
PyroGenesis Inc.

ABSTRACT

A novel technology has been developed by PyroGenesis for the thermal treatment of shipboard combustible solid waste. The technology is based on the conversion of waste into a lint-type material, which is then rapidly gasified and combusted in a plasma-assisted combustor. Maintaining a consistent waste feed rate and lint quality is essential for optimal performance in terms of combustion efficiency and overall emissions. Optimization of emissions is also achieved through proper control of the chemistry in the plasma-assisted combustor.

This paper describes the results from the optimization study that was aimed at improving the operating performance of the Marine Plasma Arc Waste Destruction System (PAWDS) in terms of combustion efficiency and gas emissions.

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. Historically, much of the shipboard solid waste has been discharged overboard as the principal method of waste management. However, international interest in preserving the quality of the world's waters has made the practice of at-sea discharge unacceptable.

On Navy ships, solid waste is typically managed by using a variety of equipment. Shredders and pulpers are used for food, paper and cardboard, while melters are used for plastics. Low-tech incinerators are also found on Navy ships; however, these are plagued with high maintenance requirements and poor performance issues. Many of the newer large cruise ships have installed the latest incineration technology. These incinerators, however, are large, occupying four decks of a ship, and heavy due to their refractory lining. They are also problematic when operated with high concentrations of food or plastics. The high moisture content in food waste quenches the reaction in the incinerator and can result in potentially hazardous gas emissions. High plastic concentrations result in excessive temperatures that can cause damage to the refractory lining. The use of refractory liners in incinerators necessitates gradual start-up and shutdown of the equipment resulting in some inflexibility for shipboard operation.

As part of the US Navy's Advanced Technology Demonstration (ATD) program, PyroGenesis developed a compact, plasma-based combustion technology for the treatment of shipboard combustible solid waste (1,2). The 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. The plasma arc-assisted thermal treatment system developed by PyroGenesis for shipboard waste has many advantages over conventional incinerators. All waste, including food and plastics, can be treated with minimum segregation. The system is designed for rapid start-up and shutdown since it contains no refractory lining in its construction. The system also meets the International standards, in particular MARPOL standards for emission. Recent optimization of the technology has resulted in continued improvements to off-gas system emissions. This work has also resulted in further reduction of the size of the system making it even more compact and suitable for commercial cruise ship applications.

SYSTEM DESCRIPTION

The Plasma Arc Waste Destruction System (PAWDS), developed for the treatment of waste on board ships, has been demonstrated 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 prototype is shown in Fig. 1.

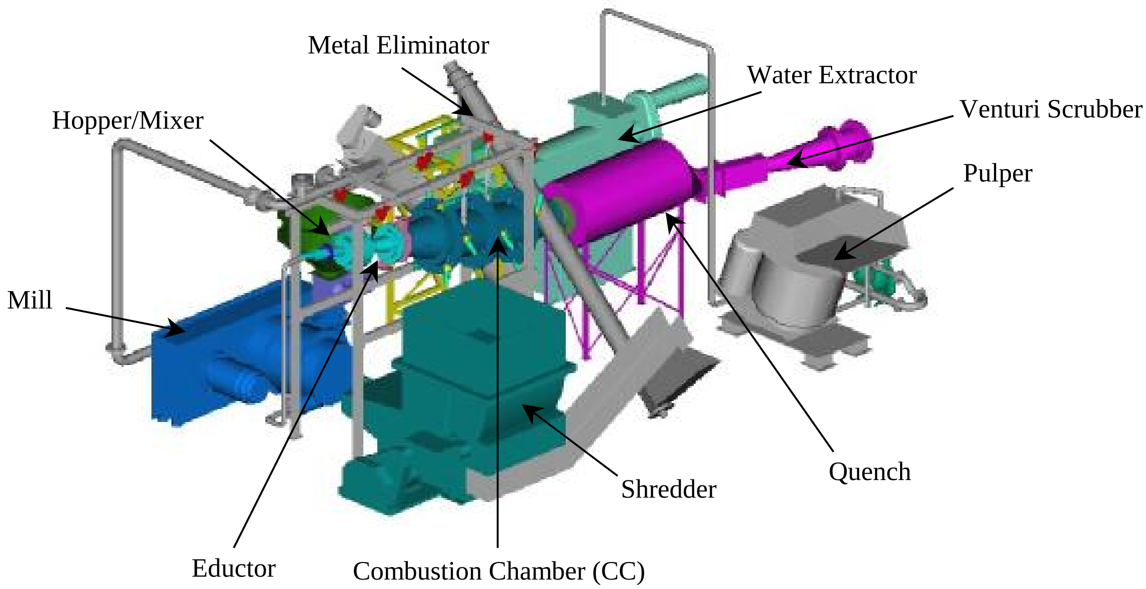

Fig. 1. Overall Layout Drawing of PAWDS

The waste is introduced to the system either through a shredder (dry waste) or a pulper (food waste). A combination of conveyors, pumps and a water extractor convey the shredded and/or pulped waste into the mill, where it is pulverized and, thus converted into a uniform and highly combustible fuel, resembling lint.

This finely dispersed lint is introduced pneumatically into the central element of PAWDS, the plasma-fired eductor shown in Fig. 2, where the organic portion of the waste is gasified. The combustion is further completed in the combustion chamber where excess air is added.

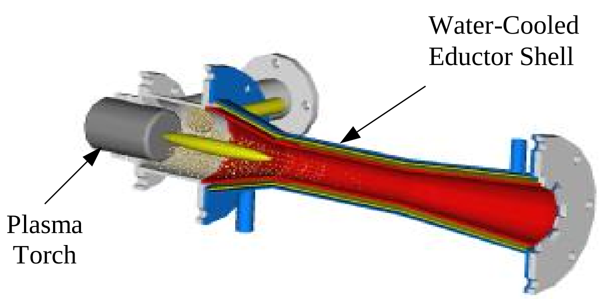

Fig. 2. Schematic of Plasma-Fired Eductor

The gases from the combustion chamber are immediately quenched with water to reduce the temperature below 100 ^{o}C. A Venturi scrubber is used after the quench to remove the ash (inorganic portion of the waste) from the off-gases of the system.

A Continuous Emission Monitoring Acquisition System (CEMAS) is used to monitor the composition of the combustion gases exiting both the combustion chamber (CC) and the system stack.

OPTIMIZATION STUDY SCOPE

The scope of the present study was to identify factors that influence the system performance. An optimization of these factors was carried out and resulted in improved system combustion efficiency and an overall reduction in gas emissions.

RESULTS AND DISCUSSION

In the eductor, combustible material is forced into intimate interaction with a high temperature plasma flame, resulting in the rapid gasification of waste to produce a synthesis gas containing CO and H_2. The focus of this study was aimed at optimizing the waste gasification efficiency in the eductor, which would invariably improve the overall system performance and emissions. The study covers three main areas: waste feed preparation, stability of the waste feed and eductor operating conditions.

Waste Feed Preparation

The conversion of waste into lint-type material is a critical step in the PAWDS process. Waste is pulverized in a mill, which consists of a series of blades rotating at high speed (>3000 rpm). In the process, waste is pulverized resulting in a uniform and highly combustible material. A micrograph of the milled waste can be seen in Fig. 3.

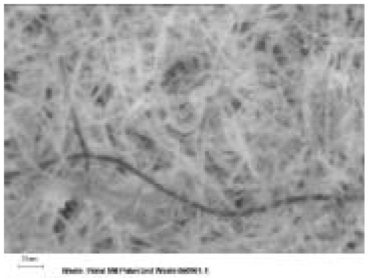

Fig. 3. Micrograph of Milled Waste Resembling Lint

Due to the rapid gasification that occurs in the eductor, which is characterized by high temperatures and low residence time, the quality of the milled waste is essential for good gasification. For ideal operation of the eductor, it is expected that all solid particles be gasified and converted to a gaseous mixture containing CO, CO_2, CH_4 and H_2. The gaseous mixture, which is easily combusted, can then be converted to CO_2 and H_2O in the combustion chamber. If the gasification process is inefficient, thereby allowing a large amount of unburned particles to enter the combustion chamber, overall combustion efficiency is compromised. Although the combustion chamber offers enough residence time for the combustion of CO, CH_4 and H_2, the residence time may not be long enough to fully combust solid particles. As such, it is important that the gasification process in the eductor be optimized.

When the mill is fitted with new blades, the lint produced is quite fine and is uniform in terms of its particles size. However, as the mill blades wear the uniformity and particles size of the lint is affected. As can be seen in Fig. 4, large particles have been collected at the mill exit when the mill blades were significantly worn.

Fig. 4. Milled Particles Produced When Blades Are Worn Out

It was confirmed experimentally that when the lint quality deteriorates (i.e. non-uniform and coarser particle size) the overall combustion efficiency[a] is reduced. When uniform and finely pulverized lint is fed to the system, the overall combustion efficiency was found to be greater than 99%. However, when non-uniform and coarser lint is produced, the overall efficiency drops to about 97%.

The causes for mill blade wear have been investigated. Blades of different materials having high wear resistance have been tested. Results to date have shown that some materials offer double the wear resistance as the original mild steel blades.

Stability of the Waste Feed

A consistent waste feed to the plasma-fired eductor is essential to maintain steady operation, which in turn, has a direct effect on the system efficiency and emissions. To date a reliable method for directly measuring the feed rate of shredded waste material has not been found. The mill amperage, however, has been a useful indicator of waste feed rate. The mill amperage is plotted in Fig. 5, along with the carbon monoxide (CO) concentration in the off-gas and the combustion gas temperature. Figure 5 demonstrates that inconsistent feed to the thermal processing chambers leads to a sharp drop in the system temperature along with a rapid increase in CO concentration. Since maintaining consistent temperatures in the eductor and combustion chamber is key to achieving high system combustion efficiency, stability in the waste feed is therefore essential.

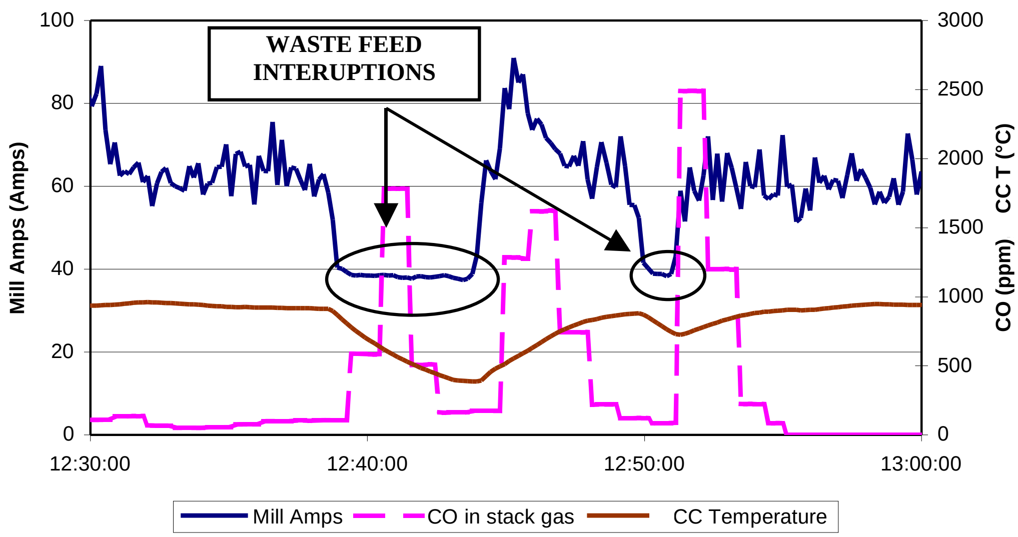

Fig. 5. Example of Data Acquisition During Inconsistent Feed Periods

Feed interruptions were typically caused by "dead-spots" in the feed preparation system where material accumulated, forming bottlenecks in the system. These bottlenecks eventually led to complete blockages and therefore waste feed interruptions. An improved pneumatic waste transport mechanism has been designed and has essentially eliminated the occurrence of feed blockages. This design change has provided a consistent feed to the mill and in turn into the eductor, resulting in a more stable combustion chamber temperature.

Eductor Operating Conditions

As reported in a previous paper (2), the PAWDS process complies with MARPOL Annex VI standards of the International Maritime Organization. Table I shows a comparison of typical experimental results as compared to the MARPOL limits.

Table I. Comparison of Experimental Results to MARPOL Limits

Type of Emission	MARPOL Limit	Typical Experimental Results
$O_{2,\text{ dry basis}}$	6-12%	9.0%
CO	200 mg/MJ[b]	40 mg/MJ
Soot Number	Bacharach 3 or Ringleman 1 (opacity <20%)	Opacity <5%
Flue Gas Temperature in Combustion Chamber	850-1200 °C	950 – 1100 °C
Unburned Components in Ash Residues	<10%	<3%
Flue Gas Temperature	200 °C max.	<100 °C

Although MARPOL regulates CO emissions and opacity, NO_x emissions are not regulated. In anticipation of future more stringent regulations, a study aimed at reducing NO_x emissions was undertaken.

In a high temperature combustion process, thermal NO_x forms from the dissociation of N_2 and O_2. High temperatures, excess oxygen and a low carbon concentration favour the formation of thermal NO_x in a combustion process. In view of this, maintaining a reducing environment in the eductor and providing sufficient residence time at a controlled gasification temperature are important in reducing the formation of NO_x.

Achieving and maintaining a proper reducing environment was only possible after implementing the previously described changes to the waste feed preparation system and achieving a stable feed rate. Further design modifications to the eductor combined with operating parameter adjustments have resulted in further improvements to the system emissions, beyond current MARPOL requirement, in particular with respect to NO_x.

A reducing environment in the eductor was achieved by decreasing the amount of air that conveys the waste from the mill into the eductor and also by increasing the waste feed rate. Figure 7 demonstrates the effect of reducing the total air injected at the mill on the system NO_x emission[c]. The waste feed rate was kept constant at the lowest setting used for this study. Lower carrier air flow rate reduced the total NO_x generated from close to 4000 mg/Rm3 to around 2300 mg/Rm3. At the highest carrier air flow rate, the estimated excess air for gasification (conversion of all carbon to CO) is greater than 1.5, as compared to 1.2 at the lowest carrier air flow rate used in this study.

Figure 8 demonstrates the additional effect of increasing the waste feed rate to the system on NO_x generation. A low carrier air flow rate was used for this series of tests. The NO_x concentration was further reduced from 2300 mg/Rm^3 to around 1400 mg/Rm^3 as the waste feed rate was increased. At the highest waste feed rate, there is essentially no excess air for gasification, which is ideal for minimizing NO_x formation.

Further reduction in NO_x emissions has been achieved through optimizing the geometry of the eductor to provide increased residence time for the gasification reaction. As can be seen in Fig. 9, increased residence time in the eductor has allowed the reduction of the PAWDS NO_x emission to below 300 mg/Rm^3. As can be seen by these test results, optimization of the plasma-fired eductor has led to significantly improved NO_x emissions, which are expected to be well within the limits of future stringent MARPOL regulations.

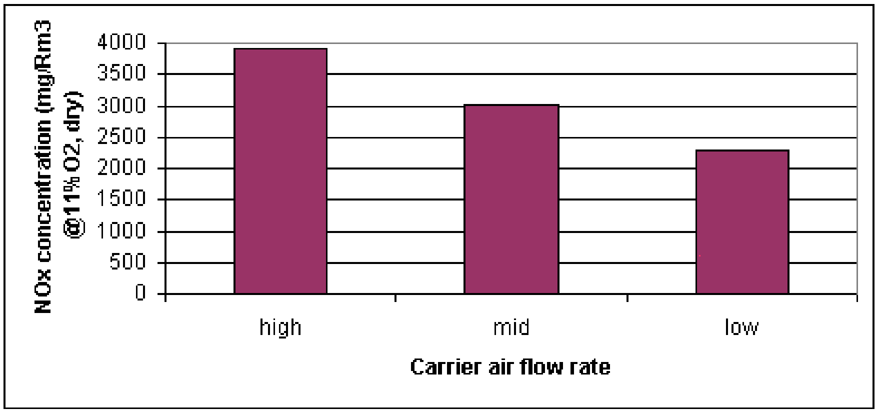

Fig. 7. Effect of Reducing Carrier Air Flow on NO_x Emission

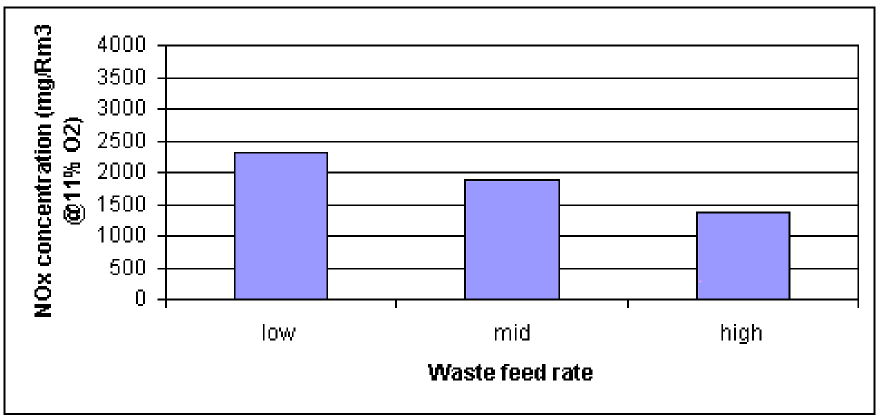

Fig. 8. Effect of Increasing Waste feed Rate on NO_x Emission

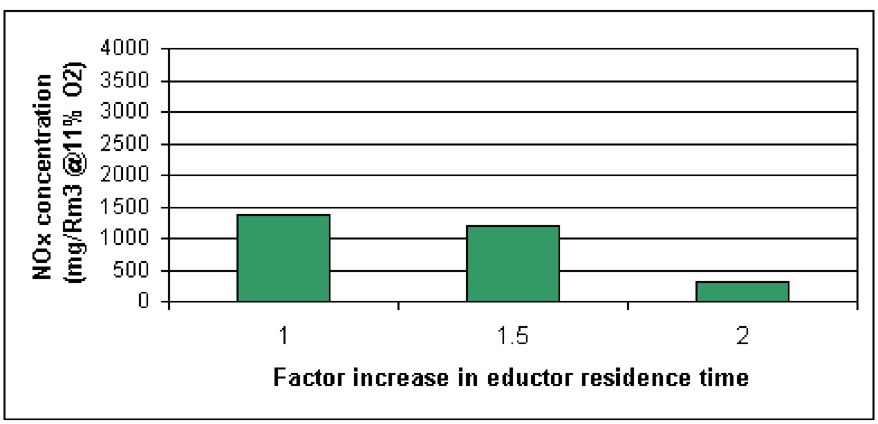

Fig. 9. Effect of Increasing Residence Time on NO_x Emission

CONCLUSIONS

The Marine Plasma Arc Waste Destruction System developed by PyroGenesis has been optimized and has resulted in an improved reliability and improved emissions, well beyond the requirements of current MARPOL regulations.

Optimal performance of the eductor and combustion chamber is achieved by maintaining a consistent waste feed rate and lint quality. NO_x emissions were dramatically reduced by maintaining a reducing environment and by allowing sufficient residence time in the eductor.

Future Work

The optimization described in this paper has allowed further system size reduction and will be used on the full-scale system designed for a commercial cruise ship vessel in the near future. PyroGenesis is currently designing a commercial Plasma Arc Waste Destruction System to be installed on a cruise ship in September 2003. The new design incorporates all of the design changes that have resulted from the optimization study reported in this paper.

FOOTNOTES

[a] The system combustion efficiency can be evaluated based on the volatile content of the final ash collected. Loss-on-ignition (LOI) tests at 575 ^{o}C were performed on samples of dry ash after thermal processing, as well as the milled waste collected after the mill. The combustion efficiency, based on the reduction in the volatile component, may be calculated as follows:

$$\frac{LOI_{milledwaste} - LOI_{ash}\left[\frac{100 - LOI_{milledwaste}}{100 - LOI_{ash}}\right]}{LOI_{milledwaste}} \quad \text{(Eq. 1)}$$

[b] Conversion based on 0.23 m^3 of evolved combustion gas per MJ of energy.

[c] NOx concentration was measured by CEMAS and is reported in mg/Rm3 (25°C, 1 atm, dry basis and corrected at 11%O_2).

ACKNOWLEGEMENTS

The authors would like to acknowledge the support provided by the US Navy Carderock Division during parts of this optimization study.

REFERENCES

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

2. Alexakis, T., Tsantrizos, P., Manoliadis, P., Beverly, D., Pelletier, S., Cofield, J.W., Nolting, E.E and Mann, J., "A Plasma-Arc-Assisted Thermal Treatment System for Shipboard Waste", Proceedings of the 21st International Conference on Incineration and Thermal Treatment Technologies, New Orleans, Louisiana (May 2002).