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Optimization of a Trash to Energy System

Drew Witte, IUPUI
Prof. Peter J. Schubert, IUPUI

Peter J. Schubert, Ph.D., P.E. is Professor of Electrical and Computer Engineering at IUPUI, and serves as the Director of the Richard G. Lugar Center for Renewable Energy. He has published 75 technical papers and ha 35 US patents. He has been the principal investigator on grants from NASA, DOE, DOD, USDA, and GSA.

Optimization of a Municipal Solid Waste (MSW) to Energy System

I. Introduction

The number of permitted landfills in the US has diminished from almost 8,000 in 1988 to 1,908 in 2009 while at the same time, generation rates of municipal solid waste (MSW, or "garbage") increased from 208.3 Million Metric Tons (MMT) to 243 MMT[1]. Recycling has mitigated some of this trend, however, communities are becoming increasingly resistant to siting of so-called "sanitary landfills", largely because they will all leak eventually[2]. The result is that tipping fees have increased from around $8 per MT in 1985 to $44 in 2010[3]. Places like Los Angeles and New York City are already running out of places to put their trash. The Puente Hills landfill in California is the largest in America, can be seen from space, and is full. It is scheduled to close in October 2013[4]. NYC has shifted all their MSW transfer stations to the waterfront, to provide more options for export of trash[5]. The "City that Never Sleeps" is already the biggest exporter in the US, sending trash as far away as Indiana and Texas. In the European Union, available space for new landfills has already vanished, and has sparked huge interest in converting waste into energy, thereby solving two problems at the same time[6]. In the US, a few waste-to-energy (WTE) projects are either being planned or are in pilot scale operation. For thermal energy only, a number of "mass burn" facilities exist which combust trash to produce steam, although the environmental suitability of this technology is a concern.

A new form of MSW WTE is being developed by a consortium of universities and private companies in the US heartland. This method is known as a gasification-plus-oxidation (GPOX)[7] system. This approach begins with the conventional process of gasification, whereby feedstock is ignited but only provided a sub-stoichiometric amount of oxygen, called "starved air" gasification. Heat from the smoldering feedstock pyrolyzes remaining feedstock, generating a flammable gas called synthesis gas, or "syngas" for brevity. The syngas is then combined with a surfeit of air in the oxidation apparatus, along with an ignition source, to generate heat that is used to create steam which is fed to a turbine to generate electrical power. The two-step approach of GPOX is slightly less efficient than mass burn, but provides much improved control of criteria air pollutants.

In this paper we describe the optimization of a GPOX WTE system for use with undifferentiated (unsorted) and non-comminuted (not shredded) MSW. The team includes 10 students in engineering and technology, two universities, a small company and a large company working on a pilot-scale prototype called "Old Blue." A number of improvements were made to the original design, and an updated control routine has been developed. We will outline the methods and outcomes employed in optimizing this system for use in the US and around the world. With this technology, the energy once thrown away in the solid waste stream can be used to offset use of non-renewable fuels to power the needs of society. To the extent this can be accomplished in a cost effective way, communities can improve their resiliency, sustainability, and economics.

II. Student Involvement

Because the "Old Blue" GPOX was located an hour and a half from our campus, a group of ten students participated in day-long site visits to study Old Blue, and made key design upgrades to the gasifier. The first site visit was on June 21, shortly after Old Blue was received at the facility of corporate partner SAIC (see Figure 1). During the first site visit, students were given an assignment from SAIC: "Make an assessment of the scope of work needed to re-assemble the unit, replace any missing parts (some electrical components were removed from the electrical cabinets), obtain feedstock, connect utilities, and get Old Blue back up and running, including number of trips needed."

Figure 1 - Students Assessing Conditions of Old Blue's Oxidizer

After a safety briefing, students donned Tyvek® suits, safety harnesses, and Latex gloves before penetrating into the gasifier chamber to assess the condition of the equipment. Char samples were collected from several places. Students also weatherproofed exposed openings and took an inventory of what was delivered with the system. Dimensional measurements were also taken of Old Blue to provide future information for design modifications. Finally, the students pored over hundreds of pages of literature delivered with Old Blue and developed working hypotheses on the operation of the gasifier and oxidizer unit.

After three hours of climbing, measuring, collecting, and taking inventory, the team of students assembled in a conference room to report on their findings. Along with their professors and representatives from SAIC, the students concluded that there were 5 major tasks in rebuilding and redesigning Old Blue: 1) Redesign existing loading door to make loading trash easier; 2) Repair a huge hole in the roof where the two sub-systems of the machine interfaced; 3) Replace aged and worn seals and insulation on the gasifier; 4) Research alternatives to a $10K butterfly valve that was broken; 5) Rebuild and redesign the electrical control system.

A team of three mechanical engineering students were given the assignment to redesign major mechanical systems having issues with the existing gasifier hardware. To address the hole in the roof of the gasifier, the students brainstormed different concepts on how to patch the roof. From this brainstorming session, the students wrote up a protocol that SAIC used as a basis for repairing the roof. The students also wanted to make it easier to load trash into Old Blue. They decided that instead of manipulating the door of the gasifier with a forklift, a swinging door on hinges would be better. Students made conceptual drawings of the hinged door and found suppliers for hinges that could support between 6,000 and 20,000 lbs. Finally, the students explored different design alternatives to replace the primary butterfly valve on Old Blue.

One mechanical engineering student was given the assignment to make a conceptual design for the next version of Old Blue which was dubbed "Spiral 2." This student used CATIA 3D CAD software to produce 3D drawings of four new design concepts of the syngas oxidizer/ electricity generation part of Old Blue. The 3D drawings were very important when analyzing the tradeoff between horizontal and vertical reaction chambers and different types of steam boilers. Finally, a hybrid design was chosen where during transport, the reaction chamber would lie down horizontal. After installation, the syngas burning chamber would swing to a vertical position for operation. A scaled model of the fresh and new conceptual design was sent to the 3D printer in our rapid prototyping lab (see Figure 2). This model practically stole the spotlight at the DoD Maintenance Symposium in November 2012.

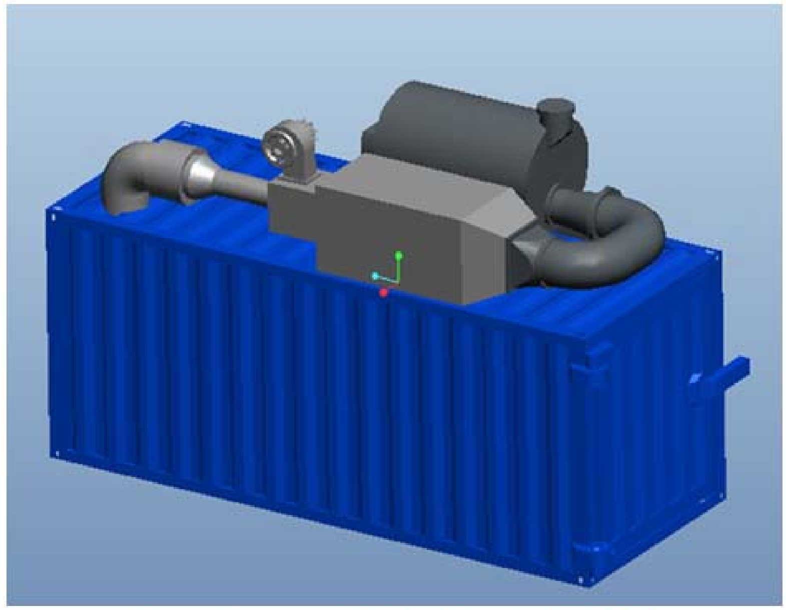

Figure 2 - 3D CAD Model of "Spiral 2"

An electrical engineering grad student was given the assignment to rebuild and test the electrical control system. The central computer (programmable logic controller, or PLC) and touchscreen was missing from Old Blue when it was donated. SAIC ordered a replacement PLC controller and touchscreen HMI (Human Machine Interface.) After receiving a copy of the PLC program from the previous owners, the student worked in the university PLC laboratory to confirm that the program was operational. This work included networking the Allen Bradley components and modifying the ladder logic of the PLC controller. The student also built a "breadboard" test platform to simulate the 60 electrical sensors and actuators on Old Blue (see Figure 3). Finally, the PLC controller and HMI were delivered back to SAIC with an updated PLC algorithm for testing Old Blue.

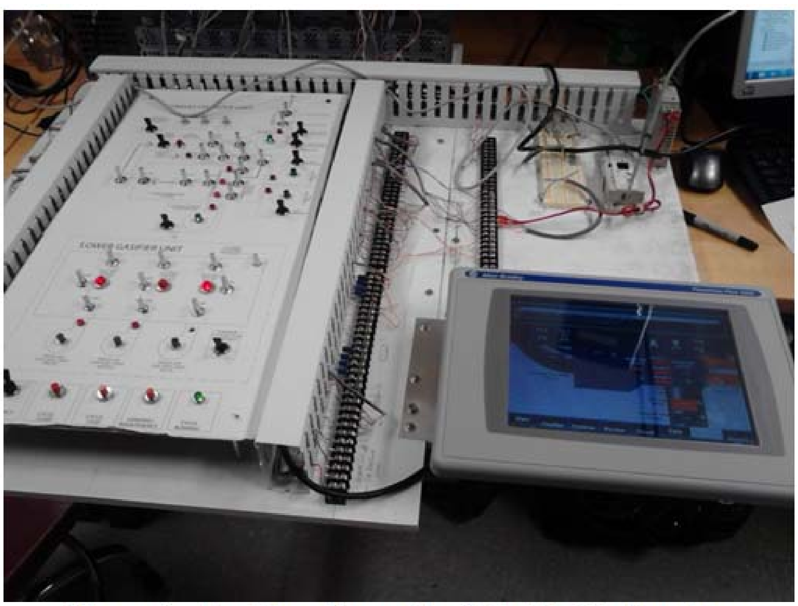

Figure 3 - Test Breadboard built in PLC Laboratory

III. Additional Potential Projects

Research funding from state and federal agencies in WTE is hard to come by. Corporations in this field fund research primarily to solve immediate needs. Therefore the research program must start with projects which can demonstrate economic benefit in a short time frame. However, the coalition has created a roadmap of projects to pursue as the applications improve continually over time. A sample of research topics is:

1. Pre-ignition light-off of syngas. Study how hot spots can burn off syngas before the heat reaches the steam boiler.
2. Airflow mixing in a batch reactor. The GPOX system is a batch process, and the headspace above the feedstock will have a mixture of air and syngas. Studies may identify internal structures such as baffles, and airflow methods such as blowers or exhaust/ syngas injection, which optimize energy conversion efficiency.
3. Duration reduction of GPOX. Studies will explore how to achieve initial feedstock light-off faster, even while considering the highly-variable nature of MSW. Cool-down cycles will be studied to find ways to shorten the cycle time to increase throughput and improve cost of ownership.

IV. PEWTER Organization

PEWTER is the name given to the coalition studying GPOX, and stands for Practical, Economical Waste To Energy Research. Engaging academics to such a collaboration generally requires research funding and publication opportunities. As mentioned above, funding for WTE is sparse. Attempts to engage industrial partners have been challenging. Downward pressure on electricity prices from the drop in spot prices for natural gas has softened the WTE market even further. In such an environment, it is difficult to attract participation because there are likely to be other avenues of pursuit with a higher probability of funding or publication. In an effort to overcome such inertia, the team from our campus visited the team from a university within 200 miles of our campus, introducing the leaders of the renewable energy centers at both campuses. The team discovered a wealth of analytical equipment available to conduct research at the partner's University Energy Center. Together with the policy focus from our campus' Energy Center a number of previously unexplored synergistic relationships were discovered. At least one technical paper is currently in press with co-authors from both universities.

One connection that was discovered during the trip to was between the Chemical Engineering and Electrical Engineering departments of our partner's engineering school and the Electrical Engineering department on our campus. A partnership has been forged with the goal of jointly publishing technical papers about the optimization of the control system of GPOX batch processes based on Old Blue. Both schools analyzed temperature traces generated from the data acquisition system when Old Blue was still operational. Figure 4 shows the temperatures in 7 different zones of the gasifier chamber during an 11 hour batch cycle. When the gasifier temperatures reach 932 F, which is the auto-ignition temperature of hydrogen, the temperature rise accelerates. This steep temperature rise is undesirable and is a place where Old Blue's control routine is in obvious need of optimization. Faculty of our partner university's Chemical Engineering department plan to develop state equations for the chemical reactions in the Old Blue process while members of the Electrical Engineering department of both universities will collaborate on optimizing the control system based on the state equations. The new control algorithm will be confirmed or modified based on actual tests in the GPOX.

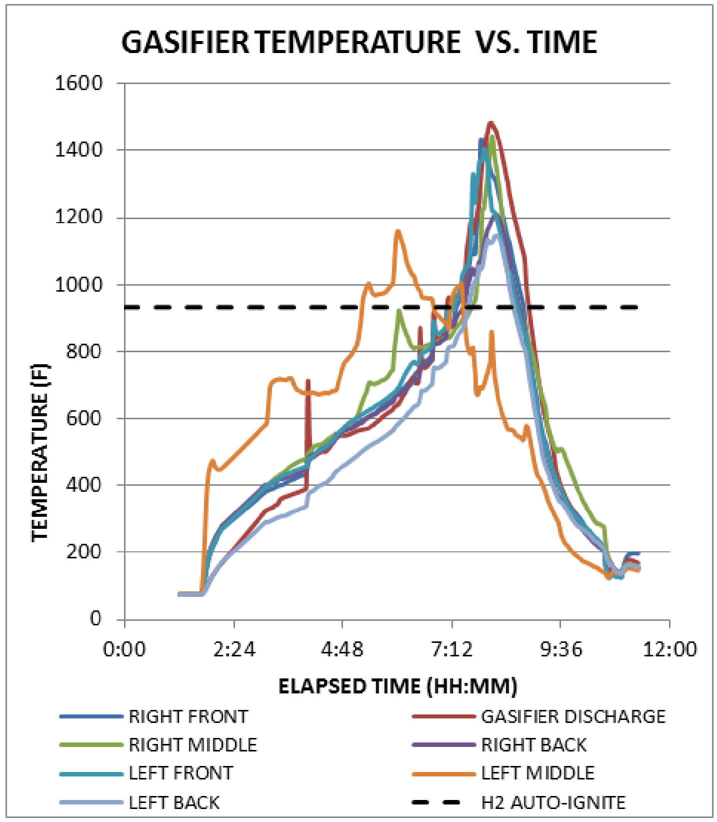

Figure 4 - Temperature Traces

The company SAIC is a diverse and widely-distributed corporation with at least two divisions working in WTE. The location at Bedford, IN was already home to the MicroGreen system. This State-funded technology uses fast pyrolysis to convert comminuted waste into pyro-oil, bio-char, and syngas, which is then used to produce electric power from an internal combustion generator set. Because SAIC has already received permitting for a WTE system, and has space available, this became a logical site for the installation of Old Blue. This location is also equidistant from the campuses of the two universities, making it an ideal neutral ground for collaboration.

A very strong benefit of this collaboration is that SAIC has already been conducting market research in WTE. This imbues the team with the relevancy needed in a less-than-glamorous technical field, and provides the team's output with pathways to realize the societal benefit of WTE. SAIC generously donated time and material essential to getting Old Blue running in an improved configuration. Old Blue was brought under the permitting umbrella of the Bedford facility, and a detailed health and safety plan was written. Conversion Energy Systems (CES) which donated Old Blue to our university has also provided operation software, engineering drawings, and raw data. These have greatly reduced the barriers to successful operation of this prototype WTE GPOX.

In December of 2012, an online survey was sent to the 10 students who participated in the WTE Old Blue project using SurveyMonkey.com. Figure 5 shows the results of the survey. One graduate student developed a Master's thesis topic around future optimization of the electrical control system of MSW GPOX's like Old Blue. Finally, the students listed technologies they had a chance to see while working on the Old Blue project that they had not previously seen in their classes. These technologies included: 3D printing, electron microscopes, high temperature insulation, Allen Bradley PLC control systems, and large butterfly valves. This hands on engineering project clearly had a positive effect on the students who participated.

V. Acknowledgements

The authors are grateful for the generosity of Conversion Energy Systems in donating Old Blue and its documentation. SAIC has provided secure outdoor laboratory space, an umbrella environmental permit, spare parts, and in-kind contributions of its employees to make needed modifications to the GPOX system, without which this work could not have been completed. Each of the faculty members involved in PEWTER has been working without external WTE funding, which is a testament to their interest in this topic. Of course, it is our sincere interest to remedy this lack.

Description	% of Students Responding
Students who had never seen a Waste to Energy (WTE) system before working on Old Blue.	75%
Students who understood more about WTE after working on Old Blue.	100%
Students who were more interested in WTE after working on Old Blue.	100%
Students who were more likely to look for a job in the WTE field.	75%

Figure 5 – Survey responses from WTE Students

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