Operating Experience in the Suspension Burning of Waste Materials in Cyclone Incinerators

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ABSTRACT

The technique of suspension burning has been utilized for the incineration of general and industrial waste materials. Four years of development work and successful application on various sized units incinerating wood products, paper, plastics, and other materials are described. Typical performance values for a unit 3 ft in diameter by 6 ft in length are a throughput rate of 3500 lb/h of material, an outlet gas temperature of 2800 F, and an exhaust heat content in excess of 28,000,000 Btu/h. This energy has been utilized for steam generation and other process heat requirements.

INTRODUCTION

The conversion of solid waste material to useful thermal energy is economically feasible. Suspension burning in a cyclone incinerator is a most promising method of conversion. This paper presents some operating experiences, equipment configurations, applications, and typical performance values for cyclone incinerators.

A range of Cycloburner* chamber sizes up to 6 ft in length has been tested, using various pulverized fuels including wood products, paper, and polyethylene scrap. A power level in excess of 28,000,000 Btu/h is achieved when burning 3840 lb/h of waste wood.

An economic analysis has shown that the cost of a Cycloburner installation burning wood planer shavings that have a market value of $5.00 per unit (200 ft³) instead of natural gas at 7 ¢ per therm (100,000 Btu) will be amortized in one year.

The Cycloburner

The Cycloburner (Fig. 1) is a horizontal cylindrical combustion chamber of refractory brick with one end closed. The other end has a large central hole through which the gases exhaust. A compartmented steel shell surrounds the refractory chamber forming an annular air space or plenum. Fuel is conveyed into the combustion chamber by way of a materials handling fan or a mechanical screw**. Combustion air is added through a number of tuyeres around the circumference of the chamber. Both the fuel and the air enter tangentially. Combustion can be completed within this primary chamber, or, by regulation of the combustion air, burning can be made to continue in a secondary chamber.

The steam boiler shown schematically in Fig. 2 is one of a number of typical secondary chambers into which a Cycloburner can exhaust. This and other uses for the process heat are discussed later in this paper.

When starting up, a natural gas burner located in the closed face is used to pre-heat the chamber for about 15 min. The fuel and combustion air are then introduced at a low rate which is increased until the brick reaches a temperature of 900 F. At this temperature combustion is self-sustaining, the gas burner may then be turned off, and the feed rate modulated as desired.

Table 1 lists the chamber sizes that have been built and tested.

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* Energex, Ltd. Tradename
** Subsequent installations have used airlock feed with pneumatic injection.
At maximum throughput, the Cycloburner residence time is 0.3 sec. During this interval, contained water is evaporated; about 80 percent of the solid fuel is converted to the gaseous state, mixed with the proper amount of air, heated to the ignition temperature, and oxidized.
The remaining 20 percent of the fuel is fixed carbon in the form of porous char and it too must burn in air to form carbon dioxide, all within the 0.3 sec interval. During operation, the refractory walls are incandescent and provide heat to the incoming combustion air as well as the fuel. Wall temperature balances out at a value 1000-1500 F lower than combustion gas temperature due to the cooling effect of the envelope of incoming combustion air next to the wall. When viewed through a sight port, the combustion gases are swirling violently in a near-white Cycloburner. When combustion is completed within the Cycloburner, the gases in the secondary chamber are transparent.

**Waste Fuel Materials**

Although a literature review has shown that the horizontal cyclone furnace has been used for the combustion of pulverized coal (Ref. 1, 2, for example) for many years, the use of the cyclone incinerator for the combustion of waste fuel materials such as sawdust, sludge, and plastic scrap is relatively new. Peculiarly, the Cycloburner has produced a somewhat greater volumetric heat release than the cyclone furnace, as will be seen later.

The short residence time requires that the surface-to-mass ratio of the solid fuel particle be large, and that the heat flux available to the incoming charge be high. In the waste fuel area, this requirement is often automatically met, as in the case for sanderdust, sawdust, and sewage sludge which need no further size reduction. Frequently, however, solid fuels must be reduced in size in order to meet the surface area requirement. Particles of sheet waste materials, such as paper and polyethylene scrap, up to \( \frac{3}{4} \) in. in diameter by 0.020 in. thick, have been successfully incinerated within the volume of the Cycloburner.

As would be expected, the percentage of moisture in the materials has a direct influence both on the net heat available and on the burning characteristics of the fuel. Although experience has shown that wood materials which contain more than 25 percent water by weight should be dried before burning, paper that contained 50 percent moisture has been successfully incinerated within the volume of the Cycloburner. As previously stated, two methods of feeding the fuel have been used extensively - fan conveying and mechanical screw feeding**. Low bulk density materials can be fan-conveyed satisfactorily. High bulk density materials are best screw-conveyed. This is due in part to the fact that higher air velocities are required to convey materials having higher bulk density. An additional problem arises as a result of having to maintain a given air conveying velocity independent of fuel rate modulation.

Table 2 lists the "as shredded" bulk densities of some of the materials burned to date.

**Table 2**

<table>
<thead>
<tr>
<th>Shredded Waste Material</th>
<th>Bulk Density, lb/ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paperback books</td>
<td>3 – 5</td>
</tr>
<tr>
<td>Postage stamps</td>
<td>5 – 7</td>
</tr>
<tr>
<td>Wood planer shavings</td>
<td>6 – 8</td>
</tr>
<tr>
<td>Commercial office waste paper</td>
<td>6 – 9</td>
</tr>
<tr>
<td>(including photographic film)</td>
<td></td>
</tr>
<tr>
<td>Sanderdust</td>
<td>8 – 20</td>
</tr>
<tr>
<td>Bark</td>
<td>15 – 20</td>
</tr>
<tr>
<td>Sawdust</td>
<td>20 – 25</td>
</tr>
</tbody>
</table>

**DEVELOPMENT UNITS**

**WFC–12**

The WFC–12 was the first development unit built. It had a 12 in. diameter by 36 in. long refractory lined combustion chamber with a natural gas ring burner on the rear or closed end. The fuel was fan conveyed into this unit through a central opening in the rear face. It was designed to dispose of shredded paper, and rates up to 500 lb/h were regularly achieved.

Although this unit was deficient in a number of ways, it remained in operation for two years and was part of a destruction service to San Diego industry. It was used for classified documents, U. S. postage stamps, merchants trading stamps, and other unidentified materials. Fig. 3 is a schematic diagram of the Classified Paper Destructor at Energex.

Material was hand fed into a paper disintegrator. The screen on the outlet side of the disintegrator had holes with diameters between \( \frac{1}{4} \) and \( \frac{3}{8} \) in., depending upon the waste material. The shredded material was air conveyed into a 600 ft³ live bottom holding bin, and then screw fed into a materials handling fan at various rates. A variable speed drive was used. The first fan used was a very light duty blower and was subsequently upgraded. In this initial unit the fuel was introduced axially rather than tangentially, the conveying velocity was higher than it should have been, and consequently the residence time was too short for proper incineration. Despite these faults, the Cycloburner performed the ignition function, but combustion was seldom completed until the material reached the secondary chamber. As a consequence, both the afterburner and the gas washer were in constant use.
In addition to burning paper, the WFC-12 was used to conduct burning feasibility tests on wet sewage sludge, fresh stable manure mixed with straw, rice hulls and grass clippings. One quantity of sludge was obtained downstream from a digester and proved to have insufficient heat of combustion to sustain burning. Primary sewage did burn satisfactorily, however, as did the stable manure and grass clippings. The rice hulls were not satisfactorily incinerated, due in part to the high silica content.

**WFC-36**

The next development effort was directed toward the incineration of wood products. Three WFC-36 units, 3 ft in diameter by 6 ft in length, were designed and built to burn wood products. Two were installed around the base of a 70 ft wigwam burner at a lumber mill in Oregon and were used to bring the inside temperature of the wigwam to 500-700 F prior to lighting-off the pile of waste wood which was introduced into the burner by traditional methods (Fig. 4). The Cycloburner fuel used for these tests was milled bark. Having the Cycloburner in operation for 30-60 min increased the ambient temperature of the wigwam sufficiently so that when the wood waste pile was manually ignited, the black smoke condition would clean up in 2 to 3 min. This is to be compared with a time of 45-60 min of smoke in excess of Ringlemann 3 that normally occurs on both startup and burndown.

In addition to the wigwam preheating tests, other wood wastes were shipped to the site and the feasibility of their destruction was determined in tests of 4-8 h duration. These included redwood bark, planer shavings, and sander dust. All of these materials burned satisfactorily when the moisture content was less than 25 percent. The time required for the removal of water when the moisture content is greater than 25 percent precludes completing combustion in the Cycloburner itself. At

![Fig. 4 Model WFC-36 Cycloburner firing into a wigwam/teepee to provide start-up capability and auxiliary heat for smokeless operation.](image)
about 55 percent, system heat losses prevent combustion from becoming self-sustaining.

The same sized unit was installed at a lumber mill in Northern California and the off-gases were discharged into a large secondary chamber prior to being discharged to the atmosphere. Round-the-clock operations were demonstrated here on planer shavings, sawdust, and sander dust.

Two methods of introducing the fuel were examined at this location. The first was an improved air conveying method in which the fuel was blown tangentially into the burning chamber at the closed end through a materials handling fan. One problem that occurred was that fan blades were damaged by the tramp metal which found its way into the waste material. A magnetic separator and higher quality fan blade material could have alleviated this problem. A second and more important problem associated with the air conveying system was that the air introduced through this blower could not be modulated with the fuel flow, and accounted for up to 50 percent of the total combustion air required. Further, this large amount of air was cold and it seriously disturbed the flame pattern. As a result, a second method of introducing the fuel was investigated. A standard screw feed mechanism was modified so that it could continuously introduce a full but not compacted cylinder of material into the chamber at the same location. Compressed air was fed into the hollow screw shaft. The shaft was fitted with a small tapered nozzle which kept the final 6 in. of material free-flowing. This device also insulated the screw from the chamber heat and prevented flashback into the feed system. Almost all of the combustion air could then be supplied by the combustion air fan, and this was easily coupled to the downstream thermal demand. A turndown ratio of 5 to 1 has been experienced.

A permanent commercial installation of a WFC-36 has recently been made at a lumber mill in Western Oregon. This unit is in constant use, automatically supplying all the heat required by four large drying kilns, and it replaces a pile burner that has been used for seven years. Fig. 2 is a good representation of the installation. This unit fires into a three pass firetube steam boiler. Fuel is fed from 30 ft away via mechanical screws. Some of the conditions and results are listed in Table 3.

It is interesting to consider that a 3 ft diameter by 6 ft long combustion chamber produced 700 boiler horsepower in this application. This size unit has accepted a larger flow of fuel and air and produced satisfactory burning conditions.

<table>
<thead>
<tr>
<th><strong>Table 3</strong></th>
<th>Cycloburner Firing into a Steam Boiler — Conditions and Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel:</strong></td>
<td>Hemlock planer shavings</td>
</tr>
<tr>
<td>Moisture content:</td>
<td>8% (on wet basis)</td>
</tr>
<tr>
<td>Heat of combustion:</td>
<td>8500 Btu/lb (bone dry)</td>
</tr>
<tr>
<td><strong>At maximum feed rate, the following conditions exist:</strong></td>
<td></td>
</tr>
<tr>
<td>Thermal output</td>
<td>28,000,000 Btu/h</td>
</tr>
<tr>
<td>Fuel flow rate</td>
<td>3840 lb/h</td>
</tr>
<tr>
<td>Air flow rate</td>
<td>462,000 scfh (70% excess)</td>
</tr>
<tr>
<td>Outlet gas temperature</td>
<td>2800 F</td>
</tr>
<tr>
<td>Steam flow rate</td>
<td>23,400 lb/h (at 13 to 15 psig)</td>
</tr>
</tbody>
</table>

**WFC – 24**

During the time that the field units were being tested, the WFC – 12 unit in San Diego was replaced by a WFC – 24 which has a 24 in. diameter by 48 in. long combustion chamber. Although up to 2000 lb/h of paper has been put through this unit, significant burning occurs downstream of the Cycloburner at this rate. At 1000 lb/h, combustion is completed within the Cycloburner.

In addition to the materials listed in Table II, shredded garbage (50 percent moisture) as well as polyethylene scrap have been burned in this WFC – 24.

The polyethylene material consisted of milk bottles shredded to pieces having maximum dimensions of the order ¾ by 0.02 in. It had a bulk density of 26 lb/ft³ and a heat of combustion of 20,000 Btu/lb. The warm up to steady state was purposely slow (about 3 h); the volumetric heat release was a very high 800,000 Btu/h-ft³ of combustion chamber. This compares with values of 15,000 to 30,000 Btu/h-ft³ for standard multiple chamber incinerators and boiler furnaces. Ref. 1 credits a cyclone furnace with a volumetric heat release of 560,000 Btu/h-ft³.

Perhaps more important than large volumetric heat release is the fact that the plastic feed was continuous. The feed rate was 565 lb/h, combustion was completed within the Cycloburner, and the exhaust gas contained no carbon monoxide or visible smoke. The afterburner was not used.

As a result of this and subsequent pilot plant tests, it is believed that suspension burning in the Cycloburner overcomes the conventional objections to incinerating plastics – clogged grates and incomplete combustion. These results indicate the feasibility of incinerating most
plastics in a continuous flow process, using the proper scrubbing devices to neutralize any toxic off-gases that may be generated.

Problem Areas

As previously discussed, two of the most significant areas that have required development to date have been chamber size as it relates to residence time, and method of introducing the fuel.

Another problem area concerns the removal of ash or slag from the system. The ash content of wood usually lies between 0.4 and 1 percent. In a system that burns 3800 lb/h of wood, such as the WFC-36, up to 800 lb of ash must be disposed of every 24 h. As a result of the high gas temperatures experienced, a large part of the ash is fused to slag. Other than permitting the ash or slag to accumulate in the secondary chamber for later removal, no special accommodation has as yet been required for its disposal. Removal techniques used with coal fired cyclones have been reviewed and a system for wood is presently under development. It is felt that slagg ing the ash might eliminate the need for a scrubber.

Still another but related problem concerns the quantity of excess air to be used for best overall performance. The Cycloburner will operate over a very wide range of fuel-air ratios, from less than theoretical to 200-300 percent excess air. Maximum energy conversion requires maximum fuel throughput but since the system is volume limited, theoretically correct fuel-air ratio is indicated. Gas temperature at this condition is in excess of 3100 F, however, and this is too high for good brick life in addition to being in the regime wherein nitrogen oxide production becomes significant. Present practice calls for Cycloburner discharge temperatures between 2600-2800 F.

CONCLUSION

Cycloburners have been built in sizes up to 3 ft in diameter by 6 ft in length and have produced volumetric heat releases of 800,000 Btu/h-ft³, compared to values of 15,000 to 30,000 Btu/h-ft³ for standard incinerators and boiler furnaces.

Some of the waste fuel materials burned to date have been paper products including postage stamps, wood products including bark and planer shavings, and plastics including polyethylene. One hundred percent polyethylene scrap was burned continuously without the use of an afterburner and the exhaust gas contained no carbon monoxide or visible smoke.

Energex, Ltd. has utilized the principles of the original coal-fired burner and we believe we have advanced the state of the art of suspension burning significantly. Incineration of many combustible materials producing CO₂ and water vapor with no visible effluent has been reduced to practice. Suspension burning in a Cycloburner makes sense on an ecological as well as an economical basis. Industrial and commercial organizations are finding it increasingly advantageous to dispose of waste while using the energy contained therein.

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REFERENCES