Solid Waste as an Energy Source

The GIPO Cycle

A. E. EVANSON

CH2M/HILL, Inc.
Corvallis, Oregon

The subtitle of this paper may seem curious. It is un­
less one remembers that today no undertaking seems to have much impact unless it can be described by an acro­nym. The one above is borrowed in part from the com­puter business which has a vast collection of them. In that business they have a similar one “GIGO” which means “Garbage in, garbage out.”

Hopefully, the system to be described here will provide
a means of putting garbage in while getting power out. There is, however, a double meaning in the acronym, as pronounced, which may be known only to those familiar
with the lumber industry in the west. A similar term, “Gyppo” is widely used in this industry, and generally connotes a small independent contractor who performs a part of a total lumber harvesting or manufacturing opera­tion on a payment by results basis. The term “Gyppo” is probably a corruption of “Gypsy” and these operators have the reputation of being able to make a profit out of apparently unprofitable parts of a total operation. In the industry some say that a Gyppo is one who does the job for you at a lower cost than you can do it yourself, still makes a profit, and only “gyps” you if he must!

Having disposed of that bit of garbage we can get down
to the serious business of developing a profitable method of disposing of our growing mountain of waste. In an earlier paper [1] the author described the historically available methods as “burn it, bury it or throw it in the river,” and commented on the fact that the last method was in great disfavor even at that time (1964).

Burying it also becomes less and less feasible as the waste grows in volume and the available labor force shrinks. Burning is considered by many to be wasteful, but this is true only if no use is made of the energy. It is not true if the energy is recovered, especially if it can be made available in the most commonly used form of electricity. It may be worthwhile here to take a moment to point out that this use of garbage is a true recycling process. Today’s garbage consists mostly of paper products. Paper is made from trees and trees are our only renewable fossil fuel. Trees use the CO₂ in the atmosphere to grow. The contrib­ution which can be made by waste is only a small percentage of today’s soaring power demands, but it is not negligible. In the lumber industry almost all the re­quired power for manufacturing can be developed from the waste. In the paper industry about two-thirds of the requirement can be filled in this way.

On the face of it, burning waste under a steam boiler and using the steam to generate power does not seem to be a very great problem. It isn’t. Where the prob­lem begins is in doing this at a cost comparable with the cost of alternative methods of power generation. To see why this is so it is necessary to consider briefly the general economics of power generation.

The cost of power delivered at the station bus bars is made up of three major components. These are fixed (capital) costs, fuel, and operating and maintenance. Table I shows some typical costs for large modern installa­tions. Capital costs per kWh are calculated on a basis of 18 percent total interest amortization and profit, and base load operation of 8,000 hours per year.
Table I

<table>
<thead>
<tr>
<th>Item</th>
<th>Nuclear</th>
<th>Steam Capital, $/kW</th>
<th>Fossil</th>
<th>Steam Gas Generation Costs Mills/kWh</th>
<th>Waste</th>
<th>Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>350</td>
<td>250</td>
<td>350</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>9.0</td>
<td>5.5</td>
<td>9.0</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>1-2</td>
<td>3.6</td>
<td>2-5</td>
<td>2-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O &amp; M</td>
<td>1-2</td>
<td>1-1.5</td>
<td>2-4</td>
<td>2-2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>11-13</td>
<td>9.5-13</td>
<td>13-18</td>
<td>13-15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures rounded to nearest half mill

The most striking thing about these figures (for which only relative accuracy is claimed) is the very large influence of the capital investment on total cost. It should be noted that the capital cost figures shown are for base load operation. For lower load factors they become proportionally higher.

Power generating plants are generally classified in one of three categories. Base loaded, mid-range and peaking plants. The names are self-explanatory. Again, on a comparative basis and without going too deeply into the reasons, the currently acceptable economic characteristics for each of the three classes can be presented as follows in Table II:

Table II

<table>
<thead>
<tr>
<th>Class of Plant</th>
<th>Capital</th>
<th>Fuel</th>
<th>O &amp; M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Load</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Mid-Range</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Peaking</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Considering this tabulation in conjunction with the figures in Table I, it can be seen that the waste or garbage fueled plant does not fit anywhere into the requirements shown in Table II. The capital cost is very high, the fuel cost only low to moderate, and O&M costs are high. At this point it may be asked why the fuel cost can not be considered as very low, bearing in mind that the delivered cost may actually be negative, i.e., there may be a charge for accepting fuel at the plant.

Although the fuel, as received, may cost less than nothing, it will have an appreciable value before it can be delivered to the furnaces. The reason lies in high volume, low calorific value and very variable character. A simple consideration of the relative figures will make this clear.

These figures, which paint a rather gloomy picture already, are really still quite optimistic. What the power engineer is interested in is not the total Btu’s which can be liberated from the fuel but the net Btu’s available in the boiler output. This output can be 85-88 percent of the input so far as coal or oil is concerned, but less than 80 percent for waste fuels.

Another major problem in utilizing garbage as a fuel is stockpile storage. This is generally impossible for aesthetic and health reasons. However, no one would seriously suggest operating a major electric utility on a hand-to-mouth basis so far as the fuel supply is concerned. Such operation is not practical; the fuel must be available to follow the load; the converse is generally not acceptable. Labor and transportation problems are inevitable over any long term and fuel must be stockpiled to circumvent them. The British coal strike of 1971 was a good example when, in spite of substantial coal stockpiles, power cuts were necessary to an extent which seriously damaged industrial output.

These considerations seem to point to one conclusion; namely that the utilization of waste fuels for power generation is economically feasible only as an auxiliary to the use of more conventional fossil fuels. While generally true this statement should not be taken to mean that power generation may not be the most economical means of disposing of waste under some circumstances.

A second conclusion follows from this and from consideration of the costs shown in Table I. Because the installed cost of the waste fueled plant is high, there is only one type of fossil fueled plant which can be economically combined with it — the gas turbine. A novel and simple method of doing this is the subject of this paper.

There is nothing new about the idea of combined steam and gas turbine plants. The U.S. Navy carried out full scale tests on such an installation nearly 20 years ago. Combined cycle power plants are currently being marketed by several major suppliers. An excellent review of the latest of these plants was published in Mechanical Engineering in 1973 [2]. Several such plants have now been in service for years [3,4]. These plants have a high thermal efficiency, obtained by utilizing the waste heat in
the gas turbine exhaust to generate steam. Most of them can be adapted to burn supplementary fuel under the steam generators but this fuel is usually limited to gas or oil and is used at much lower efficiency. No waste heat boilers which can successfully utilize solid supplementary fuel, even coal, have yet been constructed to the author's knowledge.

Refuse burning boilers themselves are generally rather highly specialized in design, especially the combustion chambers and stokers. Because the fuels are of high moisture content, preheated air is essential for stable combustion. The basic boiler design, therefore, usually provides for the recovery of most, if not all, of the flue gas heat by way of the air preheater. In a waste fueled combined steam and gas turbine system, if preheating of the combustion air is an integral part of the waste fueled boiler, then the simplest and most attractive method of utilizing the gas turbine exhaust is not available. This method is, of course, the direct use of the exhaust as a combustion air supply.

The high temperature, 850 degrees F, or more, is very attractive for waste fuel burning and the system is already well proven; but it is not easily applicable to a boiler which already uses an air heater as its principal heat recovery system. The difficulty can best be illustrated by the simplified cycle diagram shown on Fig. 1.

In this combination the waste fueled steam plant is considered to be essentially a base load operation, as it must be if all available garbage is to be burned on a year around basis. When operating in this manner, preheated combustion air is necessary and is supplied by the air preheater shown. Because the boiler waste heat is recovered in the air heater, little if any of it need be recovered in the feed water. Thus, the feed cycle is available to use regeneratively the heat in steam withdrawn from the turbine.

As is well known, this system yields the best possible thermal efficiency. Such a system meets the requirements for a low fuel cost specified for a base load plant in Table II. However, the capital and O&M costs are unacceptably high.

Addition of the gas turbine capacity shown reduces the overall capital cost to an acceptable level and should also reduce operating costs. However, since there is no place in this steam cycle where the gas turbine exhaust heat can be economically absorbed it is necessary to provide a separate waste heat boiler. Such a boiler will generally operate at a pressure and temperature less than that of the fired steam cycle. Thus both the capital and fuel costs are increased and the benefit of adding the gas turbine to the waste burning cycle is greatly reduced.

A solution to this problem can be found by borrowing a little technology from an industry which already uses both liquid and solid wastes as fuel, namely the Kraft pulp industry. Strangely enough, the technology which we propose to use is that applied not to the solid waste-fired units but to the liquid waste fueled ones.

The recovery boiler, which burns the concentrated black liquor rejected from the pulping process, is crucial to the economic operation of the Kraft process. It is a highly developed sophisticated unit, upon which a great deal of design effort has been expended over some 40 years. Research work on these units has been accelerated in the last few years in search of solutions to two pressing problems.
problems, furnace explosions and stack odor emission. It is the solution developed for the latter problem which can be applied to the waste burning boiler in general.

Black liquor is burned at a concentration of 62-65 percent solids and preheated air is used. In the older recovery boilers the air preheat was obtained from steam coils in the fan discharge. There were two reasons for not using conventional tubular type air heaters behind these boilers. One was that they are subject to plugging on the gas side; the other was that all the available heat in the flue gases could be used for the final direct contact evaporation of the liquid from 50 percent solids to the burning concentration of 65 percent. The design change came because direct contact evaporation was a prime source of odor emission and this is no longer acceptable. With the outlawing of the direct contact evaporator came the design problem, how to utilize the heat in the flue gases without the use of an air heater which would be subject to plugging troubles.

The solution was simple and ingenious. The designers placed the largest practicable bare tube economiser behind the boiler, raising the feed temperature almost to the saturation level. They then diverted the high temperature feed water through the air preheating coils before it entered the boiler. The feed temperature was of course reduced, but the air preheat was obtained from the flue gases without using an apparatus which presented severe operating problems. The general scheme of this system is illustrated in Fig. 2, which is reproduced from the 1973 edition of “STEAM” by courtesy of Babcock & Wilcox.

In a thermal power plant there are available alternative sources of heat for the feed water. These are generally either the boiler exhaust gases or steam bled from the turbine stages. Either process is regenerative in nature in that heat otherwise rejected from the cycle is recovered and recirculated. The two processes are often used together and there is no reason why they should not be used alternatively in the same cycle. If they can be so used, then we have a solution to the problem of utilizing the gas turbine exhaust heat in conjunction with a refuse fired boiler, while still having available the preheated air essential to the refuse combustion when the gas turbines are not in use.

The proposed system is illustrated in Fig. 3. This particular system was developed to burn up to 750 tons/day of garbage in conjunction with wood waste as the supplementary fuel. The consumption of wood waste could amount to some 4,000 tons/day. However, the system is not restricted to the use of wood waste as an auxiliary fuel; any other fossil fuel could be used. For coal, oil or gas there would be substantial reductions in the estimated capital cost but corresponding increases in fuel cost.

Comparing Fig. 3 with other combined cycles now available, it will be seen that in this cycle the ratio of gas turbine to steam turbine power is about reversed. The systems which recover only gas turbine exhaust heat for the steam cycle usually have about two-thirds of the generating capability in the gas turbines; one-third in the steam system. While this division of capability may be acceptable in a large system, with several stations grouped around, but remote from a major load center, it is probably not the optimum for the average mid-range station. This type of station is usually located close to a city load center. Very high voltage transmission lines are not available in such a location. Thus the station output must follow the local load curve if excessive transmission losses are to be avoided. For this type of operation the proportions shown in the present arrangement with two-thirds of the capability in the base loaded steam cycle and one-third in the gas turbine system for peaking, appear more useful.

In the particular case under study when this system was developed, the choice of capacity division was made initially for this reason. As the study progressed it became apparent that this choice also matched the basic requirements that the system be capable of incinerating the available garbage and wood fuel. A waste incinerating facility is best located fairly close to a city load center. The reason is similar to, but the reverse of that for the electric generating facility. In the one case it minimizes

FIG. 2 RECOVERY BOILER, ECONOMIZER-CIRCULATION WATER-AIR-HEATER SYSTEM.
the cost of bringing the fuel in. In the other it minimizes the cost of taking the power out.

Another requirement for this particular case was that the station be able to supply up to 600,000 lbs/hour of district heating and process steam at 300 psig. This demand led to the development of several other unique features which are incorporated into the system as diagrammed. Although these are not essential features of the general system they have been retained in the diagram because an ability to supply process or district heat is often an economic advantage for a waste disposal system. Before proceeding further with description of the system, it may be as well to offer a short explanation of the reasoning behind the choice of the pressure and temperature levels indicated.

The highest practicable pressure and temperature levels are desirable for the best overall cycle efficiency. In European central station practice the present standard temperature maximum is 1050 degrees F. (565 degrees C.) and the corresponding pressure level is 2400-2800 psig. In U.S. practice, 1005 degrees F. is the temperature limit, but supercritical pressures are common. Both pressure levels require the use of reheaters. The largest waste (wood) fired boilers so far built in the U.S. have not exceeded 970 degrees F. at 1400 psi, and no waste fired boiler has yet incorporated reheat. In Germany superheater and reheater corrosion problems have been experienced in burning fuels containing 15 percent garbage at the higher temperature. Having regard to the potential problems of superheat and reheate temperature control and the known existence of a corrosion problem at temperatures over 1000 degrees F., the choice of 950 degrees F. as a temperature maximum appears prudent. With this initial temperature limit and without reheate an increase of pressure beyond 1450 psig would not be useful. Indeed, a level of 950 psi would have been acceptable had it not been that, in the particular case studied, there was a demand for a large amount of extraction steam at a relatively high pressure.

Considering Fig. 3, a single boiler is shown for clarity and the general similarity to the recovery boiler design of Fig. 2 is apparent. These designs are now service proven up to at least 600,000 lbs/hr and units of similar rating have been built for waste wood firing. For the system capability shown two units would be used and the size would not represent a significant extension beyond present experience. If the auxiliary fuel were to be coal oil or gas then, of course, a single boiler could be used.

In base load waste fired operation, the large economiser heats the feed water from 335 degrees F. to 500 degrees F. The heated water then passes through the air preheating coils, raising the air temperature to 450 degrees F. and reducing the water temperature to 378 degrees F. The water then passes through the high pressure feed heater where its temperature is again increased to 440 degrees F. before delivery to the boiler. If the cycle economics
justify the expense, this latter operation could be a two-
stage process with the second heater, fed from an addi-
tional turbine bleed point, raising the feed temperature to
about 500 degrees F.

The turbine generator with its condensing and feed
heating systems follows normal practice. The heater string
shown is for illustrative purposes and does not necessarily
represent the optimum arrangement but serves as a basis
for comparative calculations. Other components shown in
this system, such as the evaporators, are provided to meet
the needs of the specific system studied. They are not
essential to the general concept but do affect operation to
some extent and will be discussed later.

To maintain good economy of fuel consumption over
the largest possible load range, the gas turbines are installed
in units each capable of 25 Mw continuous output. The
gas generators are of the aircraft derivative type, with two
units, each supplying gas to its own power turbine, and
the two-power turbines coupled to a common generator.
Alternative designs in which two gas generators supply a
common power turbine are equally applicable. However,
units in which the gas generators are rigidly connected to
the power turbine (single shaft gas turbines) are not quite
as suitable to this system for reasons which will be
explained.

The gas turbines exhaust to a common duct system
which carries the hot gases to the boiler furnaces. The
turbines can easily accept exhaust back pressures much
higher than those necessary to overcome duct and grate
resistance. Thus, the F.D. fans(s) can be shut down when
a gas turbine is started. When this is done a number of
important events take place purely automatically without
need for operator or other control.

First, the air temperature to the furnace(s) is imme-
diately increased and, of course, the heat input to the
furnace. The boiler output increases accordingly. Second,
the feed water passing through the coils in the F. D. fan
discharge is no longer cooled but passes on at the full
temperature of 500 degrees F. through the H.P. heaters to
the boiler. The increase in feed temperature produces a
further increase in boiler output, and the total increase
due to this and to the greater furnace input is available
for additional generation.

Third, the feed water entering the high pressure
heater(s) at 500 degrees F. cannot condense any steam in
these heaters. Therefore, there is no longer any extraction
from the highest turbine bleed points and turbine output
increases accordingly.

The total result of starting the gas turbine(s) then is to
produce peaking capability not only from the gas turbines
themselves but also a very useful increase in steam
turbine output.

This steam turbine peaking capability is obtained at
low capital cost by providing it in the turbine only, not in
the alternator. It will be seen from Fig. 3 that the alter-
nator rating in MVA is almost the same as the turbine
capability in kW. This differs from standard practice in
which the alternator rating in MVA would be 25 percent
greater than the turbine output in kW to permit operation
at 80 percent power factor. When the system shown in
Fig. 3 operates at anything less than maximum output,
the gas turbine generator is not fully loaded. Therefore,
it can supply the reactive power.

This combination of steam and gas power provides a
very flexible system well matched to the highly variable
fuel conditions to be expected in any waste burning sys-
tem. If the fuel is poor, one gas turbine can be started.
This helps combustion of the poor fuel because of the
high air temperature and also makes the reactive capabil-
ity of the gas turbine generator available to carry peak
loads on the steam unit. If fuel is good but station load is
only a little in excess of normal steam capability, one gas
turbine can be used without substantial fuel cost penalty
because the exhaust heat is recovered. For the same
reason, the gas turbine generator can be used essentially
as a synchronous condenser if required. The very severe
fuel rate penalty generally associated with gas turbine
operation at idle or low load is largely avoided.

Obviously there has to be a catch in all this. We are
getting just too much for nothing. The penalty surely
must be in the overall heat rates and so in fuel cost,
particularly since the gas turbines burn a relatively ex-
pensive fuel. When detailed calculations of fuel consump-
tion and output are made it is gratifying, but surprising,
to find that the overall fuel cost remains almost constant.
The heat rate, which is over 12,500 Btu/kwh for the
simple steam cycle burning low cost fuel, actually im-
proves to less than 10,000 Btu/kwh when the gas turbines
are in use. This improvement more than offsets the much
higher cost of the gas turbine fuel. This result is not really
as surprising as it first appears. We began the analysis with
a relatively inefficient system with a low initial tempera-
ture, limited by the capabilities of waste fired boilers.
The use of the gas turbines increases the average initial
cycle temperature from about 1400 degrees R. to about
1625 degrees R., while changing the average heat rejec-
tion temperature very little, because the bulk of the
rejected heat is still in the cooling water. The effect on
cycle efficiency is obvious.

This completes the description of the proposed system
so far as the generation of electric power is concerned. It
was stated earlier that some special features had been in-
cluded in the system shown in Fig. 3 to meet the design
objectives of the specific situation which was being
studied when the system was developed. A short discussion of these features may be of interest and will help in understanding the operation of this system.

One of the major design objectives was to produce a system capable of supplying an initial district heating load of 100,000 lbs/hr which would rise in future to 600,000 lbs/hr. Because final usage would be largely industrial a high pressure (300 psig) was required.

Condensate returns from a district heating system are usually meager and of a quality totally unsuited for use in a high pressure boiler without considerable clean-up. Therefore, it was decided to recommend the use of evaporators (re-boilers) to generate the process steam. The evaporators can operate with a much lower feed quality but of course they require that the generating steam which would be extracted from the turbine be a higher pressure than the output steam. Borrowing again from the technology of the pulp industry it appears that the evaporators could be constructed and installed in units, each of about 200,000 lbs/hr capacity. The unit system makes it possible to defer capital investment until the demand requires the extra capacity.

The evaporators would operate with steam supplied at 390 psia from the turbine, with reducing and desuperheating systems provided for emergency use. This extraction pressure is peculiarly suited to a turbine designed for an initial pressure in the 1200-1500 psi range, because it is close to the optimum reheat pressure for such a cycle. Thus an essentially standard turbine design can be used, the extraction point being at the hp turbine exhaust where the steam normally goes to the reheater before crossing over to the IP or LP cylinder. At least one of the major turbine manufacturers has indicated that this design is easily adaptable to controlled extraction operation and should be economical to build.

In a normal reheat cycle it is not usually desirable to have a turbine bleed point upstream of the hp turbine exhaust. Penetration of the turbine cylinder presents problems which have relatively expensive solutions. For this reason, the high pressure heater in the system shown is limited to operation on 390 psia steam. There would be an efficiency gain and a reduction in size of the feed water to air heaters if a higher bleed point was also used to provide an additional heater stage. Whether or not this was done would be a purely economic choice depending upon the fuel costs for any specific installation.

A minor detail which may be confusing in the diagram is the provision for recovery of the high temperature condensate heat from the evaporator. In order to make effective recovery possible at all combinations of electrical and process steam load it was necessary to provide an alternative to the return of this condensate to the direct contact heater which is thermally the most desirable point. The provision of this alternative is the purpose of the system shown.

Before closing it should be pointed out that the proposed system, whereby the heat recovery device can be used alternatively as either an economiser or an air heater, is equally applicable to any combined cycle whatever the fuel may be. In general applications of this type it appears to have substantial advantages over the more usual systems wherein the steam and gas turbine systems must operate together and at base load to realize the highest efficiencies.

In closing the author would like to take the opportunity to restate an opinion which he has consistently advanced for many years. This is that satisfactory and acceptable solutions to our energy and waste disposal problems are already available using existing proven technology. The problems cannot be solved in an acceptable time if we defer the use of existing techniques on the grounds that we are developing something better and that all it needs is the money for a pilot plant and a development time and budget. Long experience should have made us very much aware of the risks in such an approach. This statement is not intended to decry or discourage the development of totally new combustion or conversion systems. Such systems may well be part of the next generation of power production and waste disposal systems. The problem however, is here now in this generation. The solutions are here also if we can but see them.

REFERENCES