		1977	1980
Costs:			
Auxiliary Fuel (2,000 Btu/lb of waste) × (100-Efficiency of heat recovery)			
50 × 0.9 × 8.33 × 2,000 = 750,000 Btu/hr			
0.750mm × $1.50/mm × 5000 hr/yr × 0.4		$ 2250	
$2.00/mm			$ 3000
Maintenance		2000	2400
Labor (2 men, ¼ time)			
2 × $12,000 × ¼		6000	7200
	TOTALS	$10,250/yr	$12,600/yr

$$\text{Justification factor} = \frac{\text{Equipment cost + installation}}{\text{Savings} - \text{costs}}$$

$$1977 \quad = \frac{70{,}000 + 10{,}000}{33{,}435 - 10{,}250} = 3.5$$

$$1980 \quad = \frac{84{,}000 + 12{,}000}{41{,}250 - 12{,}600} = 3.3$$

Gaseous wastes (No Heating Value)

Case used. 10,000 SCFM, 4000 hr/yr.
Total heat required for 1600 F incineration = 17mm Btu/hr
Heat recovery section sized for 4mm Btu/hr duty

Savings:	1977	1980
Fuel equivalent of heat recovery section		
4.0mm × $1.50/mm × 4000 hr	$24,000/yr	
$2.00/mm		$32,000/yr

$$\text{Justification factor} = \frac{\text{Equipment cost + installation}}{\text{Fuel equivalent} - \text{maintenance}}$$

$$1977 \quad = \frac{25{,}000 + 5000}{24{,}000 - 2000} = 1.4$$

$$1980 = \frac{30{,}000 + 6000}{32{,}000 - 2400} = 1.2$$

Key Words: Combustion, economics, energy, incineration, pyrolysis, refuse, waste heat.

Discussion

R. E. Hofmann[1]

I believe there are a few technical points presented in this paper that should be clarified. The method of operation of these units, when solid waste is charged, is critical in both the production of energy and the affect of the effluent gases on the boiler tubes. After subjection to a starved air atmosphere in the primary chamber, the effluent gases entering the secondary chamber (or afterburner) definitely have an appreciable amount of particulate carry over. The efficient and automatic action of the excess air condition and retention time in the secondary is essential to burn off these particulates and produce a clean exit gas (below 0.08 grains of particulate per standard cubic foot of dry flue gas) so that APC equipment will not be required and boiler tube corrosion can be controlled.

There are minimum charging rates at present, below which energy production does not appear practical. This should always be considered on an hourly basis, not daily. A Hofmann rule of thumb for an individual waste heat exchanger (or boiler) is 1500 lb/hr minimum feed of waste to the primary, under the current state of the art.

Further, for energy production, heavy "batch" feeding is impractical. Hofmann rule number two is that, due to the dynamics of volatile release in solid wastes, feeding should be continuous while energy is being produced, either by ram charges or by conveyance automatically. Ram charging may be termed a form of "batch" feeding, but the maximum elapsed time between charges should be no more than 6-7 min.

Hofmann rule number three is that automatic ash removal systems should be installed only when: (*a*) the quantity of waste charged into a single primary exceeds an average of 40 lb/min; and (*b*) continuous 24 hr/day operation is required. Under the present state of the art, it can not be justified otherwise. The alternative is obviously 3-hr burn down, and 8-hr cool down, then clean out, in each 24-hr operating period. Thus daily start-up will increase auxiliary fuel about 37 percent.

Rule of thumb number four is that combustion units and boilers (or heat exchangers) must be close-coupled, with *automatic* control of gas temperature, pressure, volume and rate into, through, and out of the heat exchanger.

Rule five states that corrosive action on boiler tubes is low only if automatic controls are used to regulate the gas into, through and out of the boiler. Assuming the gas is low in particulates by EPA Method 5 test, it can still have serious corrosive qualities. Gas *temperature* is then the key factor in reducing tube attack. Entry temperature into the first section of boiler tubes must be held at between 1800 F and 1870 F with waste heat boilers. Exit temperature should never drop below 800 F. To prevent loss of energy production from a high exit temperature, boiler design must be slightly sophisticated (economizers, etc.) so that as much exit heat as possible can be used (recycled).

Residues from properly designed solid waste combustion systems are lower than stated. By *volume* they do not exceed 5 percent of the raw, "as received," waste in municipal plants, 2½ percent of institutional waste, 3½-5 percent of "average" industrial waste.

Heat recovery of the latest solid waste systems is higher than stated. The total system efficiencies (Btu value of charged waste, less auxiliary fuel input, compared to steam produced) averages between 65 percent and 73 percent depending on the system design and the component manufacturers. The input into total energy of the auxiliary fuel does not exceed 3¼ percent with the best designed 1978 systems using 24 hr/day cycles, and less than 1 percent when automatic ash removal/continuous loading systems are used. Further, under the present state of the art efficiencies

[1] Ross Hofmann Associates, Coral Gables, Fla.

deteriorate when steam pressures over 150 psig are desired, due to the current designs of the waste heat boilers being coupled to the combustors.

The economics are really more complicated than the formula used in this paper would indicate. While a justification factor approach can be used, many more elements should be added to it.

The most important omission concerns the desirability of matching energy production to energy demand. Energy production from burning waste is normally an auxiliary to the production of heat from fossil fuel (whether for steam, cogeneration or straight electricity production). As a result, energy from waste is being used more and more on a flexible production basis, particularly to match and shave peaks of demand when fossil fuel would normally be used most heavily.

Any economic evaluation must therefore concentrate on hourly figures, rather than daily, weekly, monthly, or yearly figures in order to arrive at the practical savings from waste fuel combustion. The days are over when a systems engineer works only from yearly or monthly waste availability matched against energy requirement. Calculations are now based (the same as they would be for any fuel) on the hourly demand for energy, and matched against the peaks and valleys rather than straight line production. Further, calculations must accurately predict the hourly changes in volatile release and Btu values of the waste rather than deal in averages (such as 6000 or 10,000 Btu/lb), as these must tie in closely to the charging rates. Oversimplification of heat values, charging rates and release rates can result in calculations of results that are off considerably. This required approach would change the "justification factor" formulas used in this paper rather drastically.

This is rule of thumb number six. The charging of waste should be on a "Btu demand basis," which in turn produces energy in the heat exchanger on a more sophisticated basis. This should match the user's demand for waste-produced energy in a manner that creates the greatest savings in his alternate fossil fuel energy production system.

R. L. Merle[2]

Industry must make its decisions on the basis of economics because our purpose is to supply a product at a profit. Other factors such as polution, public relations, proprietary nature, etc., may be instrumental factors, but the solution will be the most cost effective.

This paper does not go far enough in evaluating the economics of a system. The justification factor must be used judiciously along with other information.

Other cost comparisons such as a present worth evaluation or a cash flow rate of return can better show the manager what is the best way to spend his money.

Author's Closure

Reply to R. E. Hofmann

It was not the intent of our paper to put forth design and operational technicalities in anything more than a "broad-brush" manner. Thus, the technical points brought out by Mr. Hofmann are all acknowledged and generally agreed to. One exception is the figure of 1500 lb/hr as a minimum input rate with solid wastes. We are aware of cases where only 500 lb/hr of waste justified an incineration-heat recovery installation. The Btu value of the waste has a marked influence on the justification factor, as pointed out in the paper.

Reply to R. L. Merle

We agree fully that the variables given in our paper to produce the calculated justification factors are not the only matters to consider. However, every plant and every waste generated will have its own peculiarities and we were only attempting to provide a relative measure of the justification factors involved.

[2] Eastman Kodak Company, Rochester, N. Y.