Considerations in the Construction of Large Refuse Incinerators

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DISCUSSION by W. M. Harrington, Jr., Whitman, Requardt & Associates, Baltimore, Md.

Mr. Nowak’s paper finally puts European incinerator practice in its proper perspective. It is interesting to note that incineration is selected for the disposal of refuse for the same reasons in his country that are usually used in our country. Perhaps the decision to generate steam from refuse in this country will follow their decision process.

Mr. Nowak has pointed out that burning refuse in a steam generating boiler offers different operating concepts and some special operating problems not encountered in refractory furnace operation or in fossil fuel fired boiler operation. While this is obvious to most engineers, it is imperative that policy level public officials recognize this if heat utilization is to meet with success in the U.S. It will be necessary to hire operating personnel who are capable of operating the more complex systems and then to develop a training program to maintain personnel efficiency. If budgetary deficiencies prevent the hiring of adequate operating staffs, the concept is again doomed to failure. While economic conditions under which steam is generated in Germany differ from those we experience here, it is readily apparent that the utilization of the heat content in refuse is one of the most realistic ways to use some of our wastes to help preserve our natural resources. To accomplish the resource-saving utilization of the refuse heat content, a level of boiler maintenance cost must be developed which can be accepted as a part of the cost for refuse disposal in a community. As is indicated in this paper, a lower boiler availability (“between 60 and 80 percent”) must be recognized and adequate boiler capacity installed initially and maintained throughout the life of the facility. The stated fact that the sale of steam only reduces the operating cost of the facility and does not eliminate the cost for disposal must be acknowledged. When this message is accepted by the public, then, and only then, will large scale steam generation from solid waste meet with any measurable degree of success in this country.

I suggest that we forget the “travelogue” papers of the past by uninformed proponents of refuse steam generation and begin with the papers being presented here to form a new foundation on which to consider steam generating incinerators.


The author has made an excellent presentation of the considerations in the design and construction of municipal incinerators. Not only are basic principles set forth, but there is also frank discussion of problems encountered and what has been done in Europe to overcome them. This description of European practice and experience helps to guide the American engineer and the research scientist in their efforts to solve some of these common problems.

It is indicated that incineration is the favored method of solid waste disposal for large cities, and that in Western Europe boilers are used to reduce the temperature of flue gas, with the generation of steam and power as a “fringe benefit”.

Advantages in the use of boilers over other methods of cooling flue gas are mentioned. It avoids the use of large quantities of water, as in spray cooling, and the problem of disposing of the resulting polluted water. Excess air can be used, but that requires large fans with a considerable power consumption, and perhaps objectionable noise. The production of power avoids the purchase of power for plant operation, and in Europe, where power plants are often municipally owned, may provide credit to the incinerator for power or steam exported to the municipal system.
It is of interest to note from the figures shown with this paper that the furnace and boiler are built as one unit with the boiler directly above the grates. Water wall construction extends down to the area just above the grates. Baffling is used to control the flow and mixing of the gases of combustion. This design illustrates what may be called the "power plant approach" to incineration. It is a concept worthy of consideration by designers in the United States.

In recommending incineration with boiler installation for cooling of gases and heat recovery, the Author states however that this method has its special problems. The emphasis is on the problem of corrosion. In general this problem is said to be due to aggressive flue gas and dust. It is stated that, because of corrosion, boiler availability is between 60 and 80 percent for refuse fired boilers. This relatively low availability points to the need for a boiler design in which maintenance is as convenient as possible. From our experience, it is suggested that this indicates that the boiler should be of the natural circulation type with wide tube spacing. In Europe a tube spacing of approximately 7 in. is said to be common.

In commenting on the factors which make the flue gas aggressive the Author mentions the reducing character of the gases of combustion, particularly in the range of the flame tips; inadequate turbulence in the overfire area; the presence of molten, complex alkali compounds which deposit on the tubes; the oxides and sulphates of heavy metals; and finally the chlorine in plastics such as PVC. It is not stated that these compounds have been found and identified in the gases of combustion or in the deposits on the tubes, but they are in the refuse being burned.

A number of methods are mentioned for reducing the effect of these corrosive factors. In Europe additives to the fuel have been tried without success. Metallic spraying also has not been effective because the porosity of the coating permits corrosion to start. This information is helpful in any studies to be undertaken in the United States.

It is stated that the effect of corrosion can be to some extent alleviated by maintaining good combustion conditions. This includes mixing refuse in the pit to make it as uniform as possible, feeding uniformly, good distribution on the grates, and maintaining adequate turbulence in the gases above the fuel bed. One means of obtaining good turbulence is by proper combustion chamber design. It is stated that good chamber design is being determined by model tests, using water as a flow medium. This method is known in the United States, but has seldom been used in incinerator design. A second method of producing good turbulence is by the proper use or overfire air, and this also is subject to test determination. These procedures illustrate the technical approach to the solution of incinerator problems common in Europe, and which are worthy of consideration.

Finally, after all measures have been applied for minimizing corrosion, European operators have found it advisable to cover the lower boiler tubes by lining the lower portion of the combustion chamber with plastic refractory. Studs of a special heat resisting steel are used to anchor the refractory to the tubes.

In summary, the Author favors incineration as the best method of disposal of solid waste for large cities, with the installation of boilers of water wall design to cool combustion gases and yield a fringe benefit of power or steam production. Corrosion of boiler tubes can be minimized by good design and operation, but covering of the tubes in critical areas is advisable. This overall concept is recommended for consideration by designers in the United States.

DISCUSSION by Richard B. Engdahl, Battelle Memorial Institute, Columbus, Ohio

Mr. Nowak's experienced conclusion that water-walled incinerators must trend upward toward 100 percent excess air or more to avoid tube wastage is disquieting but important. It is a reflection of the highly variable "fuel" being burned which can give reducing conditions near the wall at one moment and oxidizing conditions soon after, potentially a very corrosive cycle. Mr. Nowak has apparently concluded from furnace experience and model studies that good gas mixing in the furnace provided by special furnace design and by 25 percent of the total air being delivered overfire cannot completely counter the nonuniformities produced by the inhomogeneous fuel bed.

It would be helpful to have further description of the overfire jet systems tried. There are many possibilities involved in the introduction of overfire air. They should be systematically and thoroughly explored, both by means of valid models and on full scale furnaces.

Mr. Nowak's numerous contributions to the development of water-walled incinerators provide an impressive basis for his advice in this paper.
DISCUSSION by David R. Pearl, Consulting Engineer, West Hartford, Conn.

Mr. Nowak has performed a valuable service to the incinerator engineers and to the refuse disposal decision-makers of this country by presenting the practical lessons learned in four years of operation, in controlled experimental fashion, of two 20 ton per hour steam generating mixed refuse incinerator furnaces by the city of Stuttgart. Certainly he has lucidly and logically presented the case for the generation of steam to cool the gasses and to extract the most useful byproduct, available energy, during the refuse incineration process.

It appears to me that two of his points deserve extra emphasis because they have seemingly been ignored by American incinerator engineers, despite the fact that they are accepted as good practice in the design of other utility and industrial furnaces and boilers.

The first point is that since the mixed refuse is being used as a fuel, it should be treated as a fuel! It should be sized, conditioned, mixed, distributed and redistributed during the combustion process if optimum volume reduction, complete combustion and controlled furnace conditions are objectives. A skilled furnace loader, a gravity feed hopper and a gentle grate feed are not always enough to insure these. Mechanical shredders, powered roller feeders (as in Japanese incinerators) and vigorous stoking action should be considered.

The second point is that boiler tube construction and arrangement, gas velocities and air heater surface for incinerator use must be differently designed than for fossil fuel furnaces. It is interesting to note that many of the problems of tube slagging, corrosion and air heater fouling have been successfully overcome in the specialized boilers and heat exchangers built for the Sulphate Recovery boilers used in the Kraft paper making process. These solutions should be considered for applicability to the design of steam generating refuse incinerators.

DISCUSSION by William T. Reid, Battelle Memorial Institute, Columbus, Ohio

There seems little question but that the present trend in the United States is to build large water-cooled incinerators of the European type typified by the units operating in Stuttgart, described so well by Mr. Nowak. Background in designing and operating large boiler furnaces will be helpful in arriving at the most practical incinerator design, but the fuel, over which the incinerator operator has no control other than by mixing while temporarily in storage, has and will pose wholly new problems with external corrosion and deposits. The temperature of 575 F mentioned by Mr. Nowak where incinerator deposits remain sticky and sinters indicates the difference in the problems in incinerators compared with those in coal- or oil-fired boiler furnaces.

External corrosion of heat-receiving surfaces in incinerators has proved to be a particularly troublesome point in some installations. Too little is known as yet of the way in which such metal wastage occurs to explain the corrosion mechanism now. Investigators at Foster Wheeler attribute such problems in part to the metals, lead and zinc, that are frequently found in deposits in corrosion areas, yet serious metal loss has been found in some cases where these metals are absent or in low concentrations in deposits. The reducing conditions mentioned by Mr. Nowak whereby CO is blamed for corrosion has not been substantiated experimentally and is based on assumptions indirectly related to corrosion. The fact that CO occurs from time to time at levels even up to 1 percent does not signify that metal loss occurs then, even though opinions have been voiced in Germany that alternate periods of reduction and oxidation are responsible for metal wastage. That point has not been proved.

Experience with corrosion in oil- and coal-fired boiler furnaces is helpful but not fully applicable to incinerators. The two points of greatest similarity undoubtedly are that gas-phase oxidation almost certainly is not important, and that a liquid phase must be present on the surface of the metal to cause rapid metal loss. Chlorine greatly accelerates corrosion rates in coal-fired boilers where sulfates are also present, and chlorine also may be a major contributor to problems in incinerators, although the blame is still largely circumstantial.

Under a grant from the Bureau of Solid Waste Management of the Public Health Service, Battelle is presently investigating the causes of external corrosion in municipal incinerators, using a controlled-temperature probe in full-scale incinerators, and laboratory-scale studies where metal specimens are exposed to various environments under closely controlled conditions. It is still too early to discuss even the preliminary findings from this research. A year hence some definitive data and explanations of possible corrosion mechanisms may be available.
DISCUSSION by Paul D. Miller and Horatio H. Krause

Mr. Nowak has made a valuable contribution to the technology of incinerator operation. In connection with the tube wastage results which he mentioned, we can report that current corrosion studies at Battelle-Columbus under a grant from the Bureau of Solid Waste Management, U.S. Public Health Service, confirms rapid corrosive attack. This combined field and laboratory study has shown wastage of carbon steels ranging from 6 to 18 mils over the temperature range 300 to 900 °F in 325 hours on a probe installed in a municipal incinerator at Miami County, Ohio.

The present research has also furnished some clues as to the causes of the attack. For example, electron microprobe analyses have shown that chlorine, sulfur, zinc, lead, and potassium are found in the scale on the specimens. The chlorine, zinc, and potassium were concentrated at the metal scale interface whereas the sulfur was highest some distance from the interface. This is interpreted to mean that these elements are playing an important role in the corrosion process. It is believed that chlorine in particular, and present as hydrogen chloride in the flue-gases, is of great importance.

It should also be pointed out that sulfide, detected by the azide test, is usually associated with corrosion on metals exposed in incinerators in the temperature range 350–1200 °F. Significantly, sulfide is detected on corroded metal specimens exposed to mixed sulfates-chlorides under flue gas atmospheres, 80 percent air, 10 percent CO₂, 10 percent H₂O, and 250 ppm SO₂ at 800–1000 °F in our laboratory. Thus severe attack of metals can occur under oxidizing atmospheres. In this case, the sulfide must result from the action of metal sulfates on the metal surface.

We have concluded that reactions of boiler construction materials with sulfur-containing compounds are also of importance in incinerator corrosion.

DISCUSSION by Georg Stabenow, IBM Martin Incinerator Group, East Stroudsburg, Pa.

Mr. Nowak has presented an outstanding, frank presentation on the experiences gained from the problems which occurred during the initial operation at the Stuttgart Incinerator Plant.

The revised design for the third unit shows that serious consideration has been given to improvement in furnace design, gas velocity, reduction in possible slag deposits for the purpose of obtaining less outages and more reliable and continuous operations. Tests on a model scale for determination of combustion chamber configuration with water are always difficult to evaluate and may not necessarily show the true results, as model size and gaseous conditions under the influence of combustion and temperature variations will result in entirely different flow patterns.

Recent experience in one of the largest incinerators has led to the decision to remove the front nose and to increase the effectiveness of the overfire air supply. Also in this direction, good results have been reported from other European installations in a paper presented by Mr. Maikranz of Munich.

Modern incinerators should operate on the same basis and with the same reliability factor as modern electric power plants.

With today’s ever increasing refuse delivery which at this time has already reached a per capita rate of 5 lb and over per person per day, it is essential that we must utilize our incinerator plants on a 24 hour per day and seven day per week basis for continuous operation over long periods.

To accomplish such reliability we must take into account all the experiences gained by Mr. Nowak and in fact give special consideration to the differences between the European refuse and the American refuse with a view towards the continuously heating value, which will cause increases in the furnace temperature, and the rising quantities for which ample furnace volume must be provided.

The values for new incinerator design as presented in Mr. Nowak’s paper include: 1) Silicon Carbide covering of studded waterwall sections up to 16 ft above the grate level to prevent tube wastage in the areas of stratified gas; 2) Wide convector tube spacing for the velocities to permit ease of cleaning by sootblower operation for long periods of operation; and 3) Proper high jet air pressure, overfire air distribution for better combustion results, which have already been incorporated in two new incinerator plants presently under construction in the United States.

The gas velocities have been greatly reduced to well below 15 fps and the furnace volumes increased. Also the velocities in the electrostatic precipitators have been reduced to less than 3.5 fps to permit deposit of all paper char on the collector plates thus assuring operation with clear stacks under all conditions.

We wish to thank Mr. Nowak for his valuable
contribution to the art of incinerator design which now becomes part of the new incineration development in the United States.

DISCUSSION by Alexander W. Luce, Tennessee Technological University, Cookeville, Tenn.

Although he has given no comments on large refractory incinerator furnaces, we are indebted to Mr. Nowak for an excellent treatment of considerations in large heat recovery units. The fringe benefit of heat recovery will be important to us until we find some more rewarding fringe benefits such as were found in metallurgical coke production with coal tar by-products.

In the light of the paper by Messrs. Zinn, LaMantia and Niessen, it seems reasonable to question the authors' statement of 90 percent of the ash on the grate being clinker. We can agree with the authors' observation that coal-burning experience is not wholly transferable to refuse incineration.

In summary, Mr. Nowak's paper will be helpful to the increasing number of municipal officials who are going to make choices of incineration equipment. We thank him.

DISCUSSION by R. E. Sommerlad, Foster Wheeler Corp., Livingston, N.J.

Mr. Nowak is to be complimented for coming to the United States to share with us his experiences in burning refuse in high pressure steam generators. Not only has he reported on the success of his plant but also on the operational problems.

Foster Wheeler Corporation along with Aerojet General Corporation and Cottrell Environmental Systems, Inc., has had an opportunity to study European practices in refuse burning under a National Air Pollution Control Administration contract entitled, "Systems Evaluation of Refuse as a Low Sulfur Fuel." We were indeed fortunate to have had the cooperation and assistance of Mr. Nowak and also Mr. Hillsheimer who also presented a paper at this conference.

In retrospect, most readers of these papers might not be aware that the units at Stuttgart and Mannheim are among a recent vintage of plants that have gone into service only in the mid 1960's. Most of these units have relatively high steam pressures and temperatures, and are used either directly or indirectly for power generation. It is pointed out that before this generation of plants there was no previous experience with refuse burning at high steam pressures and temperatures. Previous refuse burning units with steam generation had been in service before these units but at lower pressures and temperatures. These high pressure units were all commissioned around the same time without the advantage of much operational experience at these steam conditions.

In comparison with fossil fuel, refuse is a fouling fuel, i.e., it has a high alkali content in the ash. As a result of our studies we have found that the minor ash constituents of sulfur, sodium, potassium, zinc and lead, and their concentration in relation to one another appear to be among the most important factors in the ash deposit-corrosion problem. It is important to recognize that the difficulties experienced in the European units in the convection sections of the steam generators have been dependent upon tube metal temperatures. These difficulties have been experienced at metal temperatures above 750 F. In contrast to the high pressure units at Stuttgart and Mannheim as well as other high pressure units, there are in operation in Europe similar units with low steam pressures and temperatures with subsequent low tube metal temperatures, that have had no fouling.
or corrosion problems. The refuse burning steam generators at the United States Naval Station at Norfolk, Virginia, are low pressure units which have shown no fouling or corrosion problems.

Mr. Nowak and his associates are to be complimented in showing us their application of flow model testing as a means of improving the shape of the combustion chamber. The results of these studies should be of great value in their attempts to eliminate localized reducing atmospheres in the furnace. Flow models can also be of great value in designing the convection sections of the steam generator, especially for areas where erosion has previously been shown to contribute to tube wastage.

We agree with Mr. Nowak’s main conclusion that for large municipalities the modern method of waste disposal is incineration. In spite of many operating problems that Mr. Nowak has experienced and shared with us, his confidence is well demonstrated by the decision of the Technische Werke der Stadt Stuttgart to proceed with the new unit in which refuse will be burned and used to generate steam for power generation.

**AUTHOR’S CLOSURE**

In reply to W. M. Harrington, Jr.

I believe that it is possible to convince the public of the necessity to incinerate refuse even though they have to pay the costs required to keep the air and water clean.

In reply to C. R. Velzy

There is, in my opinion, not much to answer as the discussor is in complete agreement with my views. I would like to point out that I only presented general design considerations, without going into details. These design considerations or criteria need to be improved and expanded in the future. Experiences in the different incinerator plants in Germany will most probably bring more improvements and revisions to present design criteria.

In reply to R. B. Engdahl

At Stuttgart we are presently using 60 percent to 80 percent excess air. In the future, as indicated in the paper, we feel we will have to use still more excess air. When more excess air is required, the underfire air will be left at present levels and the additional air will be introduced overfire to promote turbulence and mixing and control the oxidation-reduction conditions.

We consider the underfire air to be combustion air. Secondary air should be at a temperature approximating that of the gases in the furnace. If this air is much cooler than the furnace gases when it is introduced into the furnace, the result will be stratification and poor mixing. The secondary air at Stuttgart is preheated to 200 to 250 C. There must also be sufficient pressure to force the secondary air into the combustion gas stream. Model tests were conducted on the proposed third unit at Stuttgart to optimize the furnace configuration and assist in the determination of nozzle locations and proper air pressures. These tests were not used to locate specific individual nozzles since formation of slag beards will alter air discharges into the furnace.

Model tests cannot be expanded to the real conditions in a hot combustion chamber but, of course, certain guidelines can be recognized. In the paper I presented in Duesseldorf, I indicated to which degree the Model-Laws in models with the dimensional ratio 1:50 were obeyed, and the conditions under which the tests were conducted. Comparative tests in existing plants will be necessary to check final results. Model tests should be continuously controlled and improved according to the experiences gained in full size plants. This has already been started with the two existing boilers in Stuttgart and will be continued with the third boiler which is under construction. By comparing the results of measurements in full size plants with the model test results, we will be able to improve and correct the operation of the boilers.

In reply to D. R. Pearl

The author agrees with the importance of conditioning the refuse as emphasized by Mr. Pearl. However, vigorous agitation, as such, is not advisable as this would tend to increase the air pollution potential. On all grates (traveling, VKW, Martin) burnout of summer refuse is essentially complete after 1/3 ± of the grate length (on the traveling grate after the second drop; on the VKW after the third roller). A minimum time for burnout is required.

The Japanese method of feeding is good for controlling the rate of feed onto the feeding grate. However, this method should not be used to feed directly onto the ignition grate. The fuel bed should be quiescent on the burning grate before ignition or there will be a tendency to increase the air pollution potential.

The author cannot comment on Mr. Pearl’s second point since he doesn’t know the details of construction that Mr. Pearl had in mind.
In reply to W. T. Reid

The author agrees with Mr. Reid that oxides and sulphates of lead and zinc support corrosion but are not the basic cause. They accelerate the corrosion action.

The author did not state that carbon monoxide is the basic cause of corrosion. Rather, it is an indicator of the existence of an atmosphere that results in corrosion. Dr. Wickert of Berlin made laboratory tests with two different atmospheres, both occurring in incinerators (both atmospheres contained H₂S, HCl, CO₂, H₂O, etc.), one atmosphere being oxidizing and the other reducing. He found that the corrosion intensity was much higher in the reducing atmosphere as opposed to that in the oxidizing atmosphere. A continuously changing atmosphere speeds up the corrosion. The published results of these laboratory tests agree with the author's operating experience. The author shows in his paper that the atmosphere in the furnaces at the Stuttgart plant is constantly changing from reducing to oxidizing and back to reducing. This is an even more severe condition than the exposure to a constant reducing atmosphere. While this has not been proven by laboratory and/or experimental tests, it is supported by their observations of actual results at plants.

If tests similar to those conducted by Dr. Wickert are performed at Battelle Institute, Columbus, Ohio, the data already available should be taken into consideration in order to prevent duplication of previous tests.

The worst corrosion problem at the Stuttgart plant is in the combustion chamber where the tube metal temperatures are the lowest. Scientists are still arguing the chemistry and exact mechanism of the corrosive action in these furnaces. Therefore, we could spend days on a discussion of the chemistry of corrosive action.

The author agrees with Mr. Reid that blaming chlorine as the cause of corrosion is largely circumstantial, especially in light of several industrial plants in West Germany (Bayer in Leverkusen, BASF in Ludwigshafen) burning wastes high in chlorides in waste heat boilers with no corrosion problems. However, chlorine is a serious air pollution problem.

In reply to Georg Stabenow

These discussors pointed out that there may be differences between the refuse in Germany and USA. This may be possible. However, except for the high caloric value, there should not be any specific differences because of the greater amount of plastic material. Thus, according to the latest surveys in West Germany, approximately 2 percent of the refuse are plastics with ¼ of this percentage PVC. In comparison, refuse in America contains 1 percent PVC at the most, based on the total amount of refuse. PVC content is more of a consideration with respect to air pollution, than it is a danger for the boilers. In any case, the refuse in America is probably no more of a potential hazard than it is in West Germany.

One should optimize configurations of the combustion chamber by means of model tests. The same can be said for the amount, the pressure and the point of introduction of secondary air.

It is doubtful that definite constructional guidelines can be established from model tests. The thermal effects caused by the hot flue gases can certainly not be duplicated in a model test, therefore, comparison measurements will have to be made in boilers built according to the newest design criteria to achieve the best control of operation.

I would like to warn of exaggerated optimistic hopes that refuse fired boilers can be operated with the same efficiency and with comparable availability as that obtained with conventional fuels.

I am convinced that it will be possible under good management, which includes a well trained staff, to improve the incinerator plants in regard to availability more and more.

In reply to A. W. Luce

In my original paper in German, I spoke of slag, which is not necessarily identical with clinker. In the Berlin plant, for instance, they have to reheat the slag in order to produce a compact clinker. By raising the bed temperatures to 1100 C – 1200 C a certain amount of the slag dripped through.
The mentioned difficulties with mattresses and other bulky wastes are avoided here, as all bulky and coarse materials are ground. Certain materials, like sheet-metal, are not accepted as they would disturb the burning process.

Tires can only be burned if they are cut up. If they are uncut, they will not burn or will burn only partly.

In order not to endanger the operation, we came to an understanding with the refuse collectors in regard to sorting of the refuse.

The SO\textsubscript{2} and HCl-emissions are at present so low that there is no danger for the neighborhood in the near future. The mentioned model tests will probably be published.

In reply to R. E. Sommerlad

The suggestion to perform model tests to control erosion is not new. Kohlenscheidungs-GmbH Stuttgart has undertaken tests for certain fuels but not specifically for refuse boilers. Nevertheless, conclusions drawn from these results make further tests unnecessary. That heavy metals have an influence on corrosion is already recognized by laboratory tests by Dr. Wickert and also various tests performed by Foster Wheeler. However, so far, it is not known why metal wastage occurs in certain parts of the heating surfaces due to concentration of heavy metals. The mechanism by which these concentrations occur is, indeed, a problem in itself.