

THE ACHIEVEMENT OF "GOOD COMBUSTION" BY IMPROVEMENT OF SECONDARY AIR INJECTION AT THE MONTGOMERY COUNTY WASTE TO ENERGY FACILITY

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INTRODUCTION

Modern refuse incineration plants are required to achieve complete burnout at all times, even with greatly varying refuse qualities. It is a further requirement that refuse incineration plants already in operation will comply with the steadily increasing severity of environmental protection legislation and will continue to do so whatever future regulatory requirements may impose.

In the recent past the main effort has been directed towards the introduction of complex flue gas cleaning technologies (secondary measures), but future developments must concentrate on the actual combustion of the refuse and attempt to develop low-emission firing technologies (primary measures).

To some extent these efforts have been in response to the most recent legal requirements for the monitoring of firing systems and the quality of the solid waste combustion residues. The draft rules for the "Instrumentation and monitoring of combustion conditions in accordance with the 17th Federal German Emission Protection Law" and the "Technical Rules for Domestic Refuse", which have been issued in Germany, are expected to become the model for environmental protection laws not only in the European community but also in the U.S. and Canada, as experience has shown that German laws tend to develop into international standards. According to our present state of knowledge, these new strict requirements can only be complied with by an optimized in-furnace combustion management.

THE THEORY BEHIND "FURNACE MANAGEMENT"

Objective of Combustion

The main objective in the design of modern combustion systems is to provide low-pollution combustion, e.g., utilize "good combustion practice". This does not mean the addition of secondary cleaning processes for the flue gas produced in combustion, but rather the reduction of pollutants on the firing side.

Not all pollution emissions can be reduced by primary measures. For example, CO₂, SO₂, HCl and HF are very little affected by modifications in the furnace. This applies also to the volatile heavy metal compounds. A certain degree of control can be obtained over fly ash and NO_x, because these are not only fuel, but also combustion related and therefore can be reduced by the adoption of specific measures in the furnace. Considerable control can, by contrast, be achieved over those materials and compounds which occur as the products of incomplete combustion and are capable of further thermal decomposition, such as carbon particles, CO, hydrocarbons and the halogenated hydrocarbons such as PCB's, which are extremely toxic.

An exception to this are the chlorinated hydrocarbons (dioxins and furans) which are destroyed in the combustion process but can reform under certain conditions when the flue gas is cooled down. Measures such as "instantaneous" flue gas cooling which could prevent re-formation,

TABLE 1 EFFECT OF "GOOD COMBUSTION PRACTICE" ON POLLUTANT

NO EFFECT	SOME EFFECT	LARGE EFFECT
CO ₂ SO ₂ HCl CL ₂	Particulates NO _x	C _m H _n Halogenated Hydrocarbons C CO

are impractical for systems which make use of the waste heat in the flue gas. It is also not possible to completely exclude certain metal compounds with a catalytic effect which encourages this de novo synthesis. On the other hand it is well known that fly ash contains both carbon and also catalysts of this type. It therefore follows that an effective reduction in the fly ash emissions will also tend to reduce the reformation of dioxins.

The boundary conditions for low-pollution combustion are already determined by national emission laws. Essentially these conditions include:

- Maximum temperature during combustion
- Minimum oxygen content
- Long residence time

It should be noted that a low temperature can be compensated for by an increased residence time and, conversely, reduced residence times can be compensated for by higher temperatures. It is merely necessary to ensure that comparable reaction conditions prevail in the flue gas at all points by appropriately distributing the oxygen.

In addition to the above, the entrainment of solids in the flue gas can be taken as an additional design/operating criterion. Therefore four process parameters can be used as the most important design criteria for the firing system:

- Temperature
- Residence time
- Oxygen content
- Particle size

Independent control over these parameters can only be exercised to a small degree because of their mutual effect upon each other.

Basic Principles of Combustion on the Grate

Stoker firing systems represent the method of choice for the combustion of household refuse. A stoker firing system offers the advantages of adequate residence times to allow good burnout even with moist refuse, and on the other hand is robust enough to transport the high proportion of inerts (stones, glass, scrap iron) in the fuel without any negative effect on the combustion process.

All grate systems are supplied with primary combustion air from below the grate. Typically, the grate is divided into four functional zones as shown in Figure 1, using a

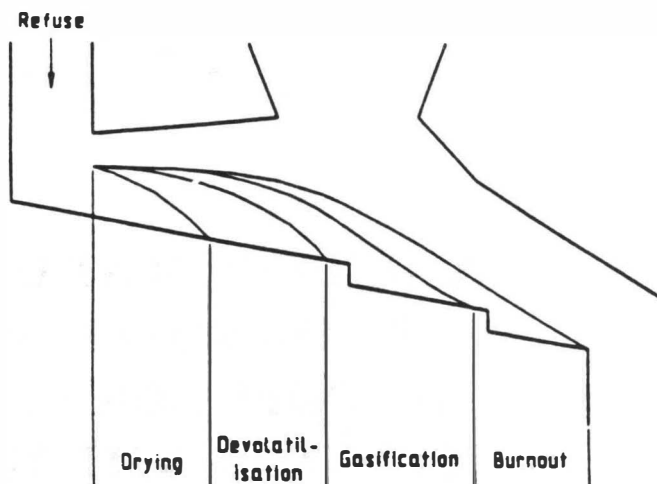


FIG. 1 REACTION ZONES ON A FORWARD MOVING GRATE

step grate as example. The size and number of these zones varies in accordance with the nature of the fuel.

In the drying zone the surface moisture in the refuse is evaporated. The primary air in this zone, which can be preheated in order to accelerate the drying process, serves merely to remove the water vapor from the fuel. The quantity of air however is not adequate to produce effective drying by itself, and in fact, the heat radiating from the furnace into the fuel bed has a far greater effect.

In the volatilization zone the volatile fuel constituents are driven from the refuse into the furnace. The amount of combustion air required in this zone can be significantly substoichiometric. Combustion of the volatile constituents therefore takes place not in the fuel layer, but above the grate within the furnace itself.

In the following zone the remaining carbon in the fuel is largely burned as a result of gasification to CO. The residence time in this and the subsequent combustion section is the main factor influencing the residual carbon content in the bottom ash from the grate.

Figure 2 shows schematically the different air requirements for refuse with strongly contrasting net calorific values. With the decrease in net calorific value as a result of increased moisture in the refuse, the conversion in the fuel layer, and therefore the local primary air requirement, is moved towards the end of the grate. In order to counteract this tendency, the combustion air distribution below the grate must be controllable for the varying fuel characteristics. The majority of stoker firing systems achieve this by separate and controlled admission of primary air to individual undergrate zones.

It is further desirable to have a variable distribution capability between primary and secondary air in accordance with the net calorific value of the fuel for effective secondary combustion. From Figure 3 it can be seen that with increasing calorific values the proportion of primary air

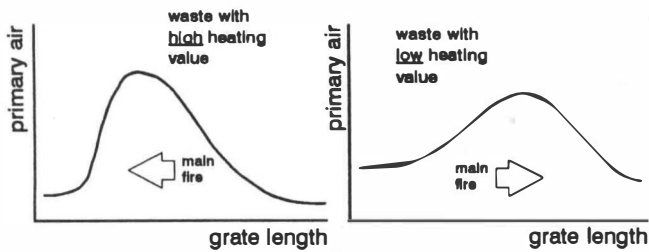


FIG. 2 UNDERGRATE AIR SUPPLY VS. GRATE LENGTH

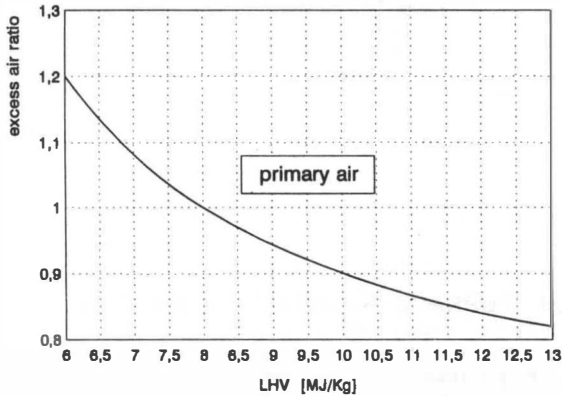


FIG. 3 PRIMARY EXCESS AIR VS. LOW HEATING VALUE (LHV)

in the overall combustion air can be reduced in favor of more secondary air. These relationships are governed by the fact that the proportion of volatile constituents in the refuse increases with increasing heating value of the fuel. However, the volatilized fuel constituents can only undergo complete burnout above the grate, i.e., in the area where secondary air is admitted. Low calorific value fuels require a larger proportion of primary air for predrying and for an improved combustion reaction in the fuel bed.

THE FIRING CONCEPTS

The shape of the furnace has a considerable effect on the flow of the off-gases from combustion, both within the furnace, and in the transition to the radiation pass. Stoker system and furnace shape are however closely connected, since the shape of the furnace must be coordinated with the specific features of a given stoker system. The systems most commonly used are (see Figure 4):

- Roller grate with co-flow firing
- Backward reciprocating grate with counter-flow firing
- Forward reciprocating grate with center-flow firing.

Comparison of Stoker Firing Systems

The roller grate transports the fuel by continuous rotation of the grate elements. The fuel mass transported by

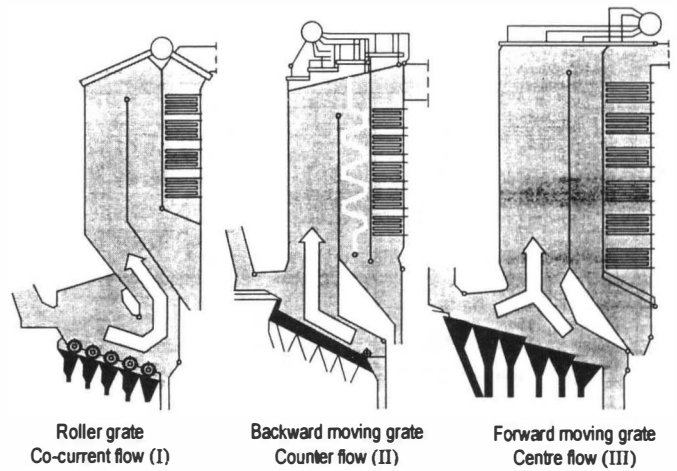
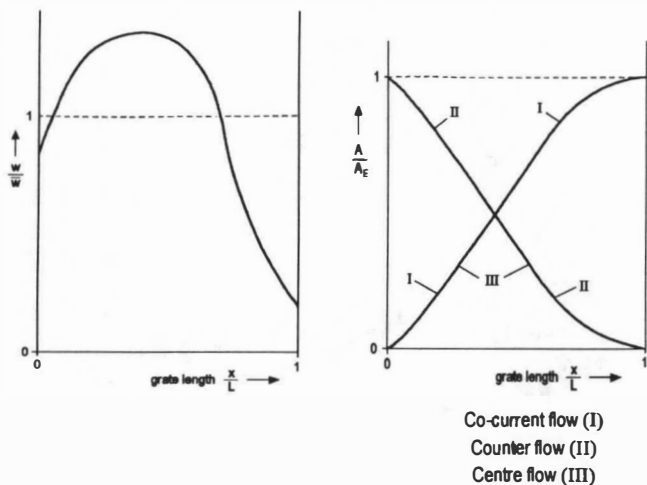


FIG. 4 FURNACE GEOMETRIES

the moving rollers tends to slip into the gap between two rollers after passing the apex. As a result, the combustion air introduced via the rollers tends to concentrate at the top of each roller, resulting in alternating O₂ rich and O₂ starved gas flows. In order to improve burnout, the off-gases are transported in co-current flow with the refuse in facilities employing this type of combustion system. Simultaneously, high turbulence is created by the injection of high velocity secondary air into the furnace.

On a backward reciprocating grate the movement of the fuel is caused by the movement of the grate bars in the opposite direction of the grate movement. Drying and volatilization occur largely before the refuse reaches the grate, and the main combustion zone is at the beginning of the grate. As a result the degasified fuel constituents could bypass the region of maximum temperature. This grate/furnace arrangement has the disadvantage that uncombusted streams of material can enter the radiant space without undergoing secondary reaction. For this reason intensive mixing of flue gas and secondary air is necessary, which may require up to four rows of injection nozzles at the entry to the radiant space. Because of the steep inclination (26°) of the grate in the direction of fuel and ash transport, and because of the backward reciprocating movement, it is extremely difficult to ensure controlled transport, and therefore combustion of the refuse on the grate. In order to ensure that fuel is not inadvertently discharged from the grate, e.g., by large clumps of unburnt material rolling down, a separately controllable extraction roller is arranged at the end of the grate which allows the ash to be discharged in a controlled manner.

Forward moving grates continuously transport the refuse over alternating rows of fixed and moving firebars towards the end of the grate. The inclination of the grate surface can, depending on the manufacturer, vary between 0° and 18°. By incorporating steps it is possible to improve the mixing of the refuse and facilitate the breaking up of refuse clumps. Typically, the main combustion zone



FIGS. 5/6 VELOCITY AND CROSS SECTION FUNCTIONS

lies towards the middle of the grate, although the exact position of the main fire on the grate can vary somewhat, depending on the fuel quality. By appropriate arrangement of the secondary combustion zone or the first radiant pass above the midpoint of the grate, the volatilized fuel constituents and the uncombusted particles are forced to pass through the hottest part of the furnace. Uncontrolled and non-uniform gas streams and the mixing of all off-gas constituents at the point of secondary air injection can be further improved by narrowing the cross-sectional area at the entry to the radiation pass.

Furnace Shape

Grate system and furnace form must be considered as a unified system. Therefore each grate system, co-flow, center-flow or counter-flow firing system, has associated with it a definite furnace design. The following considerations will assist in clarifying the effect on furnace design:

Figure 5 shows a typical reaction-dependent velocity distribution over the grate. Its maximum lies in the main combustion zone. If the velocity function is integrated from left to right, the cross-section function of the furnace with co-flow firing system (I) is obtained. By contrast, integrating from right to left gives the cross-section function of a counter-flow firing system (II). Combining both parts of the graph below the point of intersection will result in the cross-section function for center-flow firing (III) (Figure 6).

From this the furnace geometry, schematically shown in Figure 7, is obtained for center-flow firing systems. In a similar way it is possible to develop the basic geometries for co-flow and counter-flow firing systems. Corrections of the cross-section function become necessary if secondary air is already admitted immediately above the grate. On the other hand, the thermodynamic considerations of the

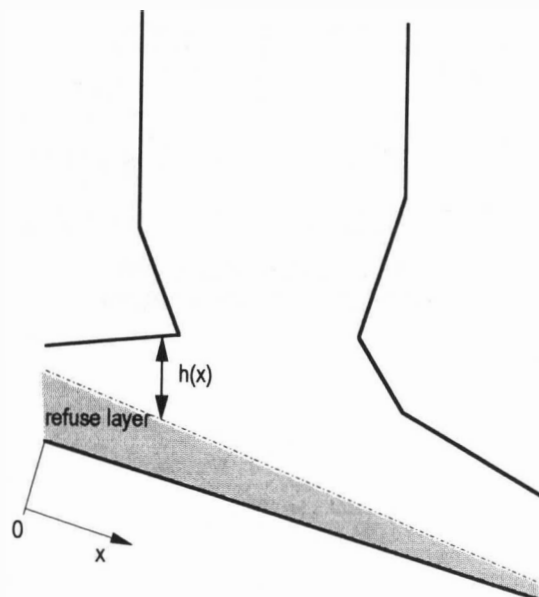


FIG. 7 FURNACE GEOMETRY CENTRE-FLOW FIRING

final design must also be taken into account. It is clear that a center-flow firing system permits the adoption of a relatively compact furnace, because the flue gases are moving towards the center from both sides.

THE FIRING CONCEPT FOR THE MONTGOMERY COUNTY WASTE-TO-ENERGY FACILITY

The Montgomery County waste-to-energy plant serves as a typical model for the concept of a center-flow firing system combined with a step moving grate (see Figure 8). The following table summarizes the design features:

TABLE 2 DESIGN FEATURES—MONTGOMERY COUNTY WASTE-TO-ENERGY FACILITY

Grate and Furnace	Center-flow firing system combined with natural circulation steam generator of vertical tube construction.
Boiler	4-pass boiler with three vertical radiant passes (executed as open passes) and a horizontally arranged convective pass with superheater, evaporator and economizer heating surface banks.
Grate	Twin-track moving grate, each track with 5 separately controllable grate zones.
Air Admission	Primary air via the five undergrate air compartment hoppers (separately controllable); secondary air via 32 nozzles in the front and rear wall of the furnace below the constriction. Primary/secondary air ratio approximately 60/40 percent.
Air Preheat	Primary air preheating to maximum 250°F.
Auxiliary Fuel Burners	Three light fuel oil burners mounted in the front wall above the constriction.
Furnace Protection	Silicon-Carbide refractory to approximately 26 feet above grate.

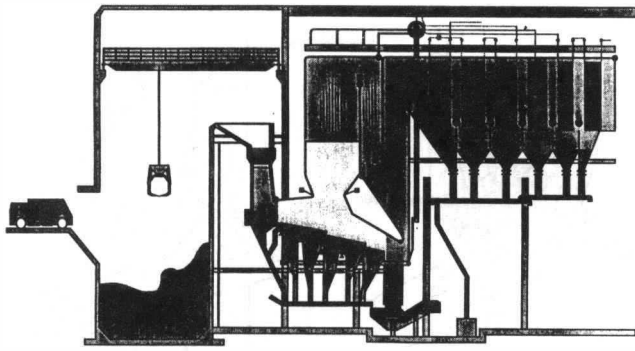
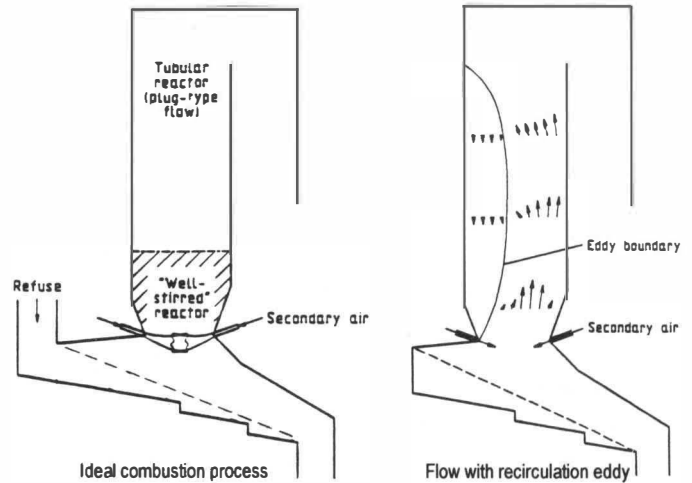


FIG. 8 WASTE INCINERATION PLANT (LONGITUDINAL SECTION)



FIGS. 9/10 PRINCIPLE TASKS IN COMBUSTION AND FLUE GAS FLOW

Objectives for the Design of the First Radiant Pass

The form of the furnace was designed in accordance with the requirements of an ideal combustion process which can be divided into two zones (see Figure 9):

In the first zone, intensive mixing of the flue gas and combustion air provides the necessary conditions for a complete combustion reaction. In order to achieve a maximum degree of turbulence, the furnace is restricted in cross-section before entry to the secondary combustion zone, where the gas is mixed with a powerful jet of additional burnout air (secondary air). This flow form approximates the ideal conditions of an agitation reactor.

In a second zone, which follows above the constriction, it is desirable to have as uniform a flow distribution as possible in order to improve the secondary combustion reaction. The ideal form corresponds to a tube reactor with a plug-type flow distribution. A long residence time is desirable.

At the transition between the two forms of flow, a more or less large lateral recirculation zone exists on each side because of the turbulence. On the one hand, such recirculation is desirable because the back flow of completely burned flue gas protects the furnace walls from corrosion. On the other hand, because of the smaller available effective flow cross-section, the recirculation tends to shorten the residence time for the core flow. Figure 10 shows the example of an unfavorable flow condition with pronounced recirculation along one side.

OPERATION OF MONTGOMERY WASTE-TO-ENERGY PLANT

Initial Operating Experience with the Selected Firing Concept

The two Montgomery County refuse incineration trains went into commercial operation in February, 1992 and the reliability of the plant concept selected was confirmed by

the relatively high availability of 97% in the first year, which was increased in the second year to 99%. Nevertheless, the critical startup phase did not proceed without difficulties. In some cases the problems which occurred were recognized and remedied right at the commissioning stage, but as far as the firing system was concerned, there were still a number of detail problems which required solution. These can be divided into three groups:

- Minimizing of cooling air flow to the burners.
- Assurance of gas side burnout by adequate mixing of secondary air in the secondary combustion zone.
- Optimization of flow in the first radiant pass.

When not in operation, the three auxiliary fuel burners are supplied with cooling air from the secondary air fan. Because the fan capacity was based on secondary air requirements, an unexpected severe leakage air problem via the auxiliary fuel burners reduced the available air flow for secondary combustion. The installation of additional dampers into the burner air supply ducts resolved this problem by reducing the cooling air to the required minimum flow.

The position of the secondary air nozzles below the furnace constriction and the steep injection angles of -30° for the nozzles had a pronounced effect upon the primary combustion on the grate. As a result of the impact of secondary air on the fuel bed, the flames were severely constricted. As a result, the accelerated flue gas flow entrained excessive amounts of ash and light fuel fractions from the fuel bed into the first radiation pass. This nozzle angle also prevented complete mixing of the flame with the secondary air. This was further confirmed by the associated CO peaks in the core flow observed during test measurements.

The stability of the flue gas flow in the first radiation

pass is a general and well known problem in thermally affected flows. All gas flows become unstable during expansion because of the Coander effect. Only small disturbances can cause the flow to travel along one furnace wall, either front wall or rear wall, and cause large recirculation flow regions on the opposite side. Worse still, the non-uniform flow thus produced in the radiation pass is then stabilized in this condition as a result of the density differences arising from cooling of the flue gas. By modifying the secondary air distribution between front wall and rear wall, it was possible to detach the flame from the wall, but it proved impossible to achieve a stable long-term central gas flow pattern.

After approximately 9 months of continuous operation, a routine check of the furnace tube wall thickness revealed unacceptable high corrosion rates in the first radiation pass. The region of tube wastage started directly above the top of the refractory lining. This wastage has been attributed to frequent overload operation because of high fuel heating value but, more importantly, also to an inadequate secondary air supply and distribution.

Since, for economic reasons, the operators were not prepared to reduce the refuse throughput, a two-step plan of remedial measures was worked out in agreement with the plant manufacturer:

- Application of a corrosion protection cladding to the wasted evaporator tubes
- Optimization of the secondary air supply to improve the gas-side burnout.

In order to provide a backup check on the planned modifications to the secondary air supply system, it was additionally intended to carry out flow investigations on an isothermal flow model.

Flow Model Testing and Implementation of Results

With the aid of an isothermal furnace model, the operating settings adopted so far were first reproduced and then optimized by stepwise modification of the relevant parameters.

For the investigations, the contour of the furnace, the combustion grate, and the first radiant pass were reconstructed to a scale of 1:18.5. The investigations concentrated on the following points:

- Depth of penetration of the secondary air and its effect on the primary combustion zone
- Mixing effect of the secondary air streams in the secondary combustion zone
- Stability of the flue gas flow

For this purpose the following were altered:

- Angle of injection nozzles
- Position of nozzles

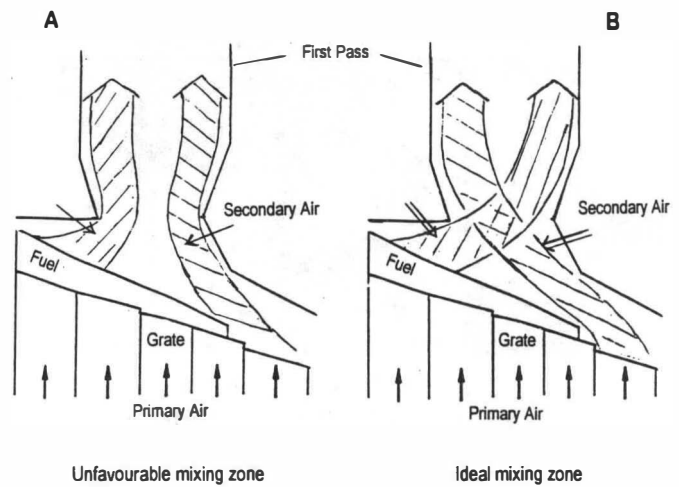


FIG. 11 EFFECT OF NOZZLING MOMENTUM

- Number of nozzles as well as jet velocity and nozzle diameter (injection momentum)
- Distribution of the air over front and rear walls.

The results of the model investigations can be summarized as follows:

- The operating settings adopted in the facility with a comparatively low proportion of secondary air had a deleterious effect on the intensity of the mixing in the secondary combustion zone and the stability of the flue-gas flow (See Figure 11).
- By altering the position of the nozzles to the narrowest cross-section of the constriction, it proved possible to operate them with practically no effect on the primary combustion taking place on the grate.
- For the formation of an effective mixing zone, a negative injection angle of -20° to -10° (to the horizontal) is advantageous; however, the optimum angle depends on the momentum of the mixing flow (see Figures 12 and 13).
- The change in the number of nozzles exhibited only a slight effect on the flow pattern when the mass flow was unaltered. The same applied to the nozzle arrangement (exactly opposite each other and offset arrangements).
- Splitting the air flow between front wall and rear wall in a ratio of 60/40 as originally envisaged for the full size plant had already proved to be unsatisfactory during commissioning as a result of its effect on the position of flow within the furnace. This did not change when the arrangement of the nozzles was altered. It was therefore decided to aim for a 50/50 split between front and rear walls, the optimum figure being heavily dependent on the position of the fire on the grate.

On the basis of the results from the model investigations, it was decided between the operator and the equipment

Angle of nozzles = 0°

Angle of nozzles = - 30°

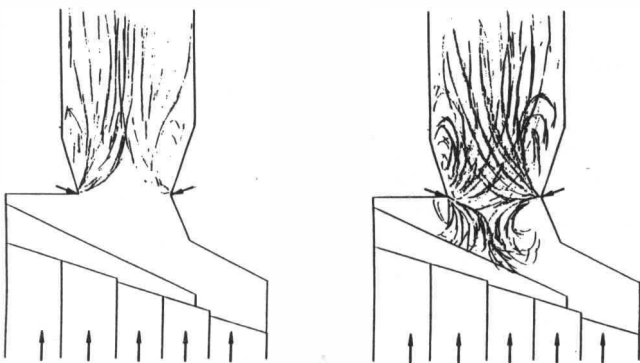


FIG. 12 FURNACE FLOW MODEL

Angle of nozzles = - 10°

Angle of nozzles = - 20°

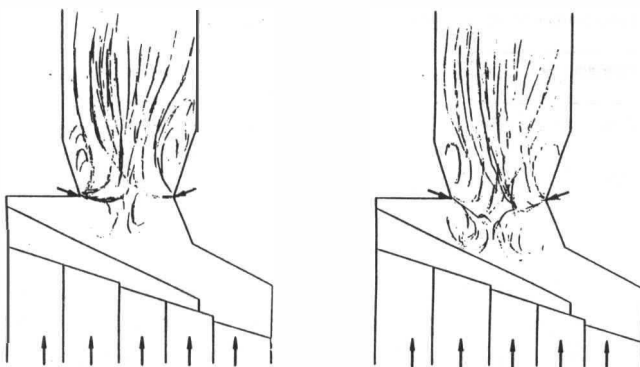


FIG. 13 FURNACE FLOW MODEL

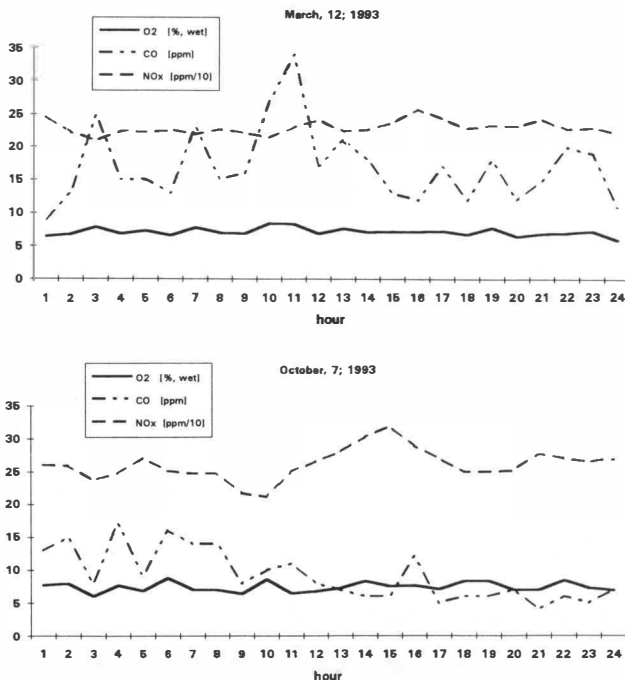


FIG. 14 COMPARISON OF EMISSION DATA

- Secondary air distribution
- Primary/secondary air ratio
- Primary air distribution over the grate zones.

For each operating setting the following parameters were measured:

- Gas temperature and gas velocity in the first radiant pass over the furnace height and depth.
- O₂, CO and NO_x in the flue gas over the furnace height and depth.

Each setting was also visually assessed in terms of position of fire on the grate and flow pattern. In addition, all pertinent operating data as obtained from the DCS and the CEM were collected and analyzed.

Figures 14 and 15 offer a comparison of the measured CO and NO_x values before and after the secondary air nozzle modification. Both data sets were taken under optimized firing conditions at essentially equal load. The data show that because of the better burnout of the volatiles achieved with the improved secondary air injection, CO emissions were reduced; however, NO_x emissions increased slightly.

The increase in NO_x emissions is being attributed to the improved secondary air/gas mixing effect which now results in somewhat higher oxygen availability in a high temperature zone. Similar results were obtained previously during attempts to reduce NO_x emissions by changing the primary/secondary air ratio in another waste-to-energy facility (reference 2).

supplier to modify the secondary air system. The Montgomery County plant was finally modified in August, 1993 in accordance with the following specification:

- Replacement of the secondary air nozzles to the narrowest point of the furnace constriction with 17/17 nozzles in front wall/rear wall arranged at an angle of -15° to the horizontal. As a result of the larger number and increased diameter of the nozzles, the free flow cross-section, as compared with the old design, was increased by some 15%.

In October, 1993, a one-week test program was conducted to investigate the effectiveness of the modifications under a large number of different operating settings. The following parameters were considered:

- Excess air
- Air temperature

TABLE 3 DESIGN PARAMETERS

DESIGN MEASURE	EFFECT ON	DESIRED CHARACTERISTICS
Dimensioning of first radiation pass	Gas residence time	Large volume
	Equalizing flow	Slim shape
Form of furnace constriction	Flow guidance in first radiant pass	Symmetrical form
Position of furnace constriction above grate	Flow guidance in furnace	Grate middle or grate end
Position of secondary air nozzles	High intensity mixing with gas flow	On front and rear walls, within constriction
Angle of secondary air nozzles	ditto	-5° to -20° horizontal
Number, diameter of secondary air nozzles	ditto	2.5 to 3 nozzles/m; high outlet velocity
Refractory lining of radiant pass	Temperature reduction	High level of refractory lining in furnace

RESULTS AND FORECAST

The nozzle modifications have confirmed the results obtained from the flow model tests. The impact of secondary air on the fuel bed was visibly reduced and it was also possible to simultaneously obtain a better fire distribution on the grate. The increased momentum of the secondary air greatly improved off-gas mixing in the secondary combustion zone. Both these observations were confirmed by the excellent burnout figures in the gas flow downstream of the secondary combustion zone.

The example of the Montgomery County Waste-to-Energy Plant shows that it is possible to obtain an optimum setting of the refuse firing system in terms of emission behavior and reduction of heating surface corrosion on the basis of theoretical considerations for improved furnace management. Model test and subsequent local measurements obtained under real operating conditions have shown extremely good agreement of the expected and obtained results.

The experience obtained here can be utilized on a broad basis for the establishment of design guidelines as well as operating methods for such firing systems. By evaluating the most important parameters affecting primary and secondary combustion, and relating these to a given firing system design, an optimized combustion system/furnace configuration, as well as an optimized operating method can be established which will assure to meet "Good Combustion Practice" requirements.

TABLE 4 OPERATING PARAMETERS

OPERATIONAL MEASURES	EFFECT ON	DESIRED CHARACTERISTICS
Excess air	Furnace temperature	Low air index
Air distribution	Local gas burnout	Staged combustion
Trimming of secondary air nozzles	Position of gas flow stream	Ditto
Air preheat	Reaction conditions on grate	High primary air temperature
Presorting of raw refuse	Reaction conditions	Homogenous fuel

TABLE 5 EFFECT OF DISTURBANCES

DISTURBANCE VARIABLE	EFFECT
Short-term change in refuse calorific value	Variation in steam quantity and gas temperature
Heterogeneous composition of refuse	Inferior burnout of solid material
False air distribution over grate zones	Unfavorable position of fire on grate and gas flow
False primary/secondary air ratio	Inferior gas burnout, high fly ash entrainment
Infiltration air	Unfavorable O ₂ distribution in furnace and radiant pass
Uneven feed to grate	Inferior primary air distribution on grate
False control setting	Uneven fuel bed height

The following tables (Tables 3, 4 and 5) give important guide values for optimization of burnout conditions. Since refuse incineration plants do not really achieve steady-state operating conditions because of the non-uniform refuse composition, it is extremely important to have good knowledge of the possible variables which could cause disturbances. Such experience can be of considerable significance in producing an optimized control concept for a refuse incineration plant.

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