In the late 1960's, when the Nottingham City Council was responsible for refuse disposal, a feasibility study was commissioned into incineration because of the shortage of suitable tipping space within reasonable distance of the City limits.

Incineration having been shown to be a viable proposition, investigations were then carried out into the possible use of waste heat from incineration, at precisely the same time that the National Coal Board were seeking new outlets for their products in the district heating field.

As a result of these events, a partnership was formed between the City Council and the National Coal Board to build and operate a combined scheme which would get rid of the City's domestic and trade refuse and at the same time supply heat to new housing developments on the outskirts of the City, new major commercial City centre developments and other educational and institutional premises.

The original intention was to build a new coalfired boilerhouse adjacent to the incinerator plant but, fortunately, at that time the Boots Pure Drug Company Limited, who had built a boilerhouse relatively near in 1952, found this plant to be surplus to their requirements as their business was extending elsewhere and the City were able to buy this existing plant and lease it to the NCB (Fig. 1).
Fig. 1 - The London Road Heat Station, capable of producing 43 megawatts of heat from its coal-fired boilers, but also housing the turbine hall and central supervisory system and the pumphouse for circulating the heating water.
Arrangements were made, therefore, for the necessary money to be raised jointly by the two parties whereby the City built the incineration plant and financed the installation of secondary mains within the new housing areas and the NCB financed the refurbishing of the coal-fired plant, the inter-linking steam mains between the two main heat sources and also the primary mains and sub-stations to serve the various load centres.

The coal-fired plant consists of three Babcock and Wilcox cross tube marine water tube boilers each with a maximum continuous rating of 45,000 lbs (20,500 kg) steam per hour at 350 psi (24 bar) and a final temperature of 650°F (343°C). They are fitted with Senior economisers and International Type L chain grate stokers which are supplied with \( \frac{1}{2} \)" (13mm) washed bituminous smalls supplied from a colliery within five miles of the plant.

Fortunately within the existing Boots boilerhouse there were two English Electric turbo-alternators with a total output of 2.6 MW which now supply house power to the two boilerhouses and the main pump house and also send surplus power to the National Grid.

The main pump house (Fig. 2) at the rear of the Heat Station is built on three levels. The ground floor accommodates the main circulating pumps (5 fixed speed and 2 variable speed) together with electrical and other ancillary equipment. On the first floor level are two 35'0" (10.7 m) long by 10'6" (3.2 m) diameter direct contact heaters and also a nitrogen pressurisation vessel used to cushion variations in pressure in the event of, say, failure of electricity supply to the pumps. At roof level are located 4 air-cooled dump condensers, each with a two speed control so that, when waste heat from incineration is above the system's requirement, heat can be dumped to atmosphere at 8 alternative rates up to a
Fig. 2 - London Road Heat Station. Pump House - housing main circulating pumps & auxiliary plant on ground floor, 30' long x 10'-6" dia. direct contact heaters on first floor which are fed with back pressure steam from the turbines to produce high temperature primary hot water, & at roof level are situated the dump condensers for the discharge of superfluous waste heat in summer time.
maximum of 100,000 lbs per hour of steam (4,5360 kg/hr). The existence of the turbines determined the initial design conditions such that back pressure steam from the turbines at 60 psi (4 bar) is passed to the two direct contact heaters where hot water is produced at 285°F (140°C) at a pressure of 50 psi (3.3 bar).

The main pumps on the ground floor increase the pressure to 150 psi (10 bar) for supply to the primary mains.

Nottingham being an old City, full advantage was taken to minimise the installation below ground of these primary mains by carrying them along canal banks and through an existing railway tunnel into the City centre itself (Figs. 3 and 4).

Sub-stations within the housing areas and in the major commercial and institutional premises break down the supply to a flow of 190°F (88°C) with a return at 130°F (54°C) at a pressure of 100 psi (6.6 bar).

Heat is now being supplied to 4,700 local authority dwellings, two major commercial developments, consisting of department stores, shops, offices, licensed premises, restaurants, etc. together with the Trent Polytechnic, a major educational institute and many local authority administrative buildings, health centres, libraries, clinics, swimming baths, old people's homes, Police and Fire Brigade headquarters etc. etc. The operation of the scheme is such that the maximum advantage is taken of heat from refuse with the coal-fired plant only coming into operation to meet peak loads with which the incineration plant cannot cope.

This means that in the summertime when refuse still has to be consumed and when heat cannot be sold, steam has to be passed to the dump condensers on the roof of the main pump house so that heat can be discharged to atmosphere. Negotiations are currently taking place
Fig. 3 - 16" dia. high temperature primary hot water mains (before screening) leading from the pump house along the canal bank to the broad marsh area & thence on to the Victoria Tunnel & the Victoria Centre.
Fig. 4 - 16" dia. primary hot water mains thru old railway tunnel
for the sale of this heat to local industry to avoid this waste and improve the revenue of the scheme.

Currently we are burning refuse at the rate of 100,000 tons (101,600 tonnes) per annum and having a calorific value of 3856 Btu's per lb (9.462 MJ/kg) we are saving the equivalent of 33,000 tons (33,400 tonnes) of fossil fuel per annum.

In view of the importance of energy conservation at this time the intention of the paper is to describe the plant in some detail and to outline problems which have occurred and which have had, and still have, to be overcome.

1. General Description of Incineration Plant

1.1 Reception Area

The Nottingham Incineration Plant, designed by Pell Mørch and Partners of London, has an elevated tipping floor some 23'3" (7.15 m) above ground level and refuse collection vehicles enter and leave the tipping floor by curved ramps at each end. (Fig. 5). The floor has 12 tipping bays and a 12" (280 mm) high curb is installed at the edge of the tipping chutes which are at an approximate angle of 30° to the horizontal. "Stop" "Go" lights are fitted at the entrance to the tipping floor and red and green lights are set above each tipping bay. Television cameras on fixed focus and view, allow the refuse crane driver to monitor the off loading of vehicles at tipping floor level.

1.2 Cranes

The two refuse silos are each 65'0" (20m) deep from the tipping floor level, 46'4" (14.25 m) wide and 65'0" (20 m) long. These were designed to supply four incinerator lines but as two lines have only been installed so far refuse can

202
Fig. 5 - Eastcroft Incineration Plant
be stored in one silo above the level of the tipping chutes, leaving tipping space in the remaining six bays. The total weight of refuse which can be stored is about 3445 tons (3500 tonnes), depending greatly upon the degree of compaction, moisture level etc. Two cranes are installed for transfer of refuse from the silo to the incinerator chutes, each having a capacity of 6.35 tons (6.35 tonnes) with travelling bogies, the rails being supported on concrete corbels. The motor capacities are as follows:

- **Main hoist**: 73 HP (54.4 kW) @ 900 rpm (94 rad per sec)
- **Cross traverse**: 4 HP (3.0 kW) @ 900 rpm (94 rad per sec)
- **Long travel**: 10 HP (7.5 kW) @ 900 rpm (94 rad per sec)

All are one hour duration with class E insulation.

The Cactus Grabs have six petals hydraulically operated. Each petal is plated to give a complete enclosure on the base when closed. The general arrangement is shown in the cross sectional view of a plant shown in Fig. 6.

1.3 **Stokers**

Each stoker, produced by Josef Martin of Munich, Germany, is a fifteen step grate, inclined at an angle of 26°, in two halves with spring tensioned central dividing bars. (Fig. 7). The total grate area is 320 sq. ft. (30.3 m²) and is designed to burn 11.5 tons (11.68 tonnes) of domestic refuse per hour which produces a burning rate of 79.2 lbs per square foot per hour (380 kg/m²h). The grate stroke, hydraulically driven, is 16\(\frac{1}{4}\)" (420 mm) of which the last \(\frac{1}{4}\)" (20 mm) is designed to give a clearing action between adjacent bars. Ash is discharged from the grate over a clinker roller into a water cooled trough and thence by means of a hydraulically
operated ram into the residual silo. The metal used in the bars and wearing plates is generally a high grade heat resisting chromium alloy steel.

1.4 Residual Plant

The residual silo is 16'3" deep (5 m) by 19'6" wide (6 m) by 72'3" long (22.2 m). This pit also receives the grits from the electro-static precipitators and some of the effluent created during water washing. The residual, containing, as it does, oxidised ferrous metal, is then grabbed from the pit using a clam shell grab with a capacity of 4½ tons (4.826 tonnes). The motor for the residual grab is 9.3/30 kW. The residual is disposed of to landfill sites after passing through a magnetic recovery plant where ferrous scrap is recovered and bailed in a Lindeman hydraulic press.

1.5 Boiler Plant

Each of the two boilers or lines is designed to produce 52,500 lbs (23,860 kg) of steam per hour at 400 psi (27.6 bar) and at a final temperature of 700°F (371°C) with refuse at an average gross calorific value of 3856 Btu per lb (9.462 MJ/kg). The boilers are of a fully water-cooled furnace type with membrane water wall construction. The gases pass from the combustion chamber through a row of widely spaced screen tubes over a plain water cooled baffle and through a pendant superheater tube bank before passing to the near vertically mounted shell and tube heat exchanger. The heat exchanger has 780 tubes with an internal diameter of 2½" (57.15 mm) and a length of 19'0" (5.8 m) approximately. It is stated that approximately 60% of the total heat recovery from the flue gases takes place in this exchanger. The maximum design
inlet gas temperature is 1463°F (795°C) whilst the normally full load gas exit temperature to the electro-static precipitator is 600°F (315°C) with a maximum of 617°F (325°C). The respective areas of the heat transfer services are:

- Combustion Chamber: 3907 ft.² (370 m²)
- Superheater: 4192 ft.² (397 m²)
- Shell & Tube Heat Exchanger: 9514 ft.² (901 m²)

1.6 Electro-Static Precipitators

Each of the two incinerator lines is equipped with a Lodge Cottrell electro-static precipitator (Fig. 8) of the single horizontal plate type with two banks in series. Each bank is an assembly of braced catch-space type collectors and mast supporting the twisted wire discharge electrode system with the lead-through insulators housed in the wrapping gear compartment above and out of the gas stream. Both collectors and discharge electrodes are mechanically rapped. Each precipitator is energised from the two static HT rectifier sets with a rated output of 60 kV 125 ma and automatic voltage control equipment. The specification for each precipitator bank is as follows:

- Waste gas flow rate: 75,000 cfm (36 m³ per sec)
- Gas temperature: 600°F (315°C)
- Inlet dust burden: 1.64 gr/ft³ (3.75 g per m³)
- Emission: 0.05 gr/ft³ (0.11 g/m³)

1.7 Fans

Each of the two forced draught fans (1 per line) has a normal design duty at 68°F (20°C) of 30,500 cfm (53,400 m³ per hour) against a discharge pressure of 18" (460 mm) wg, with a maximum design duty of 37,000 cfm (65,000 m³/h) against
Fig. 8 - The precipitators at the Incinerator
a pressure of 19.5" (485 mm) wg. A combined suction intake for both fans is fitted at high level in the refuse silo hall with the aim of providing a positive air flow into the silo at the tipping chutes. The forced draught is split into undergrate and secondary air supplies. The air supply to the front and rear arches is controlled by manually adjustable dampers. The undergrate air is split into 12 zones by manually adjustable dampers. The total forced draught pressure is remotely controllable by adjustment, from the control room, of dampers on the forced draught fan discharge, but the individual adjustment is by manual trimming. 'Normal' pressures for operation at boiler rating are as follows:-

<table>
<thead>
<tr>
<th>Description</th>
<th>Pressure (inches of water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total forced draught pressure</td>
<td>16.5&quot; (4020 N/m² or 410 mm wg)</td>
</tr>
<tr>
<td>Total undergrate air pressure</td>
<td>15&quot; (3628 N/m² or 370 mm wg)</td>
</tr>
<tr>
<td>Zone 1 undergrate air pressure</td>
<td>1.2&quot; (411 N/m² or 42 mm wg)</td>
</tr>
<tr>
<td>Zone 2 undergrate air pressure</td>
<td>2.2&quot; (588 N/m² or 60 mm wg)</td>
</tr>
<tr>
<td>Zone 3 undergrate air pressure</td>
<td>2.4&quot; (539 N/m² or 55 mm wg)</td>
</tr>
<tr>
<td>Zone 4 undergrate air pressure</td>
<td>1.4&quot; (294 N/m² or 30 mm wg)</td>
</tr>
<tr>
<td>Zone 5 undergrate air pressure</td>
<td>Zero</td>
</tr>
<tr>
<td>Secondary air pressure front nozzles</td>
<td>2&quot; (490 N/m² or 50 mm wg)</td>
</tr>
<tr>
<td>Secondary air pressure rear nozzles</td>
<td>6&quot; (1471 N/m² or 150 mm wg)</td>
</tr>
</tbody>
</table>

The individual induced draught fans are driven by 217 HP (162 kW) electric motors at 986 rpm (104 rad/sec). The induced draught fans are controllable by inlet vane type dampers to maintain a suction at a point immediately in front of the superheaters.

1.8 **Flue Gas Emissions**

The boiler design was based upon a flue gas analysis as
shown below when using a fuel with a gross calorific value of 4075 Btu's/lb (9.46 MJ/kg or 2260 kcal/kg):

<table>
<thead>
<tr>
<th>Gas</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>9.64%</td>
</tr>
<tr>
<td>O₂</td>
<td>8.08%</td>
</tr>
<tr>
<td>N₂</td>
<td>68.45%</td>
</tr>
<tr>
<td>H₂O</td>
<td>13.79%</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.03%</td>
</tr>
<tr>
<td>HCl</td>
<td>0.007%</td>
</tr>
<tr>
<td>HF</td>
<td>0.003%</td>
</tr>
</tbody>
</table>

The guarantee on electro-static performance was that the emission would not exceed 0.05 grains/ft³ (0.1144 g/m³) with an inlet burden up to 1.64 grains/ft³ (3.752 g/m³) in a total gas volume of 75,000 ft³/min. (2124 m³/min) at a temperature of 600°F (315°C). It was further guaranteed that, providing the furnace temperature is maintained at specific levels, odour would be destroyed.

1.9 Boiler Feed Pumps

The plant is equipped with two feed pumps; an electrically driven pump, a Weir EF10 driven by a synchronous electric motor with a rating of 124 HP (92.5 kW) and a Weir TFR7. The steam turbine is a single stage impulse turbine by Hayward Tyler Model T600 with a design speed of 3,600 rpm (379 rad/sec) and an estimated horsepower of 124 (92.5 kW). Steam conditions are:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pressure/temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>400 psi (27.6 bar) at 698°F (370°C)</td>
</tr>
<tr>
<td>Exhaust</td>
<td>60 psi (4.1 bar)</td>
</tr>
</tbody>
</table>

The exhaust steam from the turbine is designed to pass into the direct contact heater to raise the feed water from a temperature of approximately 230°F (110°C) to 280°F (138°C) (when the turbine is not operating, the steam is passed through
a reducing/de-superheating set into the direct contact boiler). The pumps are designed to be hydraulically balanced during normal operation with no substantial bearing to take up thrust. The bearings are cooled with a separate closed circuit water system. The pumps are also fitted with internal DU bush seals cooled and purged by water from the pump itself. A small constant leak-off is provided on each pump to prevent the pump operating against an entirely closed feed water valve.

1.10 Boiler Control

The control of forced and induced draught fans has been referred to in Section 1:7 on the Fans, and it will be noted that there is no auto control on the forced draught. Auto control on the induced draught fan is to maintain a positive suction in the boiler. Originally no form of combustion rate control was fitted. Boiler feed water is controlled individually to each boiler by a pneumatically operated valve controlled by the rate of change in drum water level trimmed by the rate of steam flow from the boiler. Operation of the stoker is entirely manual, the variables being the ram feeder speed and ram feeder stroke length, grate speed and grate stroke length, and discharge roller speed. It should be noted that, whilst stroke lengths are adjustable on both ram feeder and grate, these are designed to be set up on commissioning; the proximity switches locked into position and no adjustments made. The grate stroke in particular is critical.

Practical Plant Experience

2. Refuse Reception and Handling

2.1 In the case of Nottingham, the available site resulted in a layout as shown by cross section in Figure 6. The principal
disadvantage from an operational point of view with the layout is the considerable crane time involved in grabbing back material from the tipped position at the front of the silo, to re-deposit it at the back of the silo. This "dead" travel in a vertical sided bunker with poor sight lines for the crane operators, has caused considerable mechanical damage to the grabs. The pendulum effect of the grab at perhaps 65 ft (20 m) down, is considerable. There is also the possibility of developing a substantial spin which could put as many as 6 twists in the hoist cable. When the twisted cable trapped the electrical power cable feeding the hydraulic motor in the pulley sheaves, the damage was immediate and obvious. It was not easy to bring the grab into the maintenance bay in its closed state with only 19" (0.5 m) clearance over the guard rails around the silo. The grab then had to be opened manually, depositing the load of refuse on the maintenance floor, before it could be lowered into a stable open position. The wear on ropes was also considerable and rope life depressingly short.

2.2 These particular problems have been largely overcome by the construction of a robust back plate and guide above the pulleys which have reduced the tendency for the grab to spin and make it very much more difficult to trap the power cable in the pulleys. Improved operation and maintenance have also played an important part. A modified and more robust grab has also been delivered and indications are that this will give better performance. Future possible modifications to the grab are the elimination of the plates on the tines which seem to serve no useful function other than a possible increase in the compaction of the refuse.
2.3 The improvement of sight lines for operators in the crane cabin has not yet been possible since structural problems are involved. One solution - to give a transparent blister type front - would be difficult and costly.

2.4 The original design was intended to provide substantial natural light. However the glazed external cabin wall faces south. Sunlight shining through this gives strong reflections on the glazing into the silo hall itself. Under these conditions, the operator can hardly see the grab. The glazing has now been modified to give a subdued light. Work is also now completed on equipment to pressurise the cabin to keep out dust. This is an important improvement in the event of fire.

2.5 The geometry of the silo and the crane position has also caused difficulties with the crane rail itself. The crane rail is supported on a concrete corbel which, on the south side, overhangs the silo. This is the side on which tipping occurs and on which considerable grabbing activity occurs. Considerable side thrust can be experienced when the crab of the crane comes up to the cross travel end stops. This, coupled with careless operation, has caused damage to the rail securing ties and involved excessive maintenance to a section of the rail to which access is poor. Improved hydraulic buffers have been fitted. Modifications to the control circuit preventing approach to the south rail at speed have been made to ameliorate this.

2.6 The incinerator plant is open for reception of refuse eight or nine hours a day. The bulk of the refuse is in fact delivered in about a three to four hour period which usually
has two peaks. Turn round of vehicles should ideally be as rapid as possible. It has been found that the control light system installed to control the tipping floor is difficult to use. Discipline and cleanliness on the tipping floor have only been achieved by the employment of two men in the reception hall at times of peak tipping.

2.7 One result of the uneven delivery pattern is that a high rate of trimming is necessary in the silos at peak times and rarely is it possible to have twelve tipping bays available. The chute and the friction factor between the refuse and the chute is such that once the refuse comes to rest on the tipping chutes it will not, by its own weight, run down. It is important therefore to keep grabbing the material from the base of the chute and trimming it to the back of the silo. Trimming is also necessary when 'storing' for use during weekend or holiday periods. The original duty cycle envisaged was: from the grab open position on the pile of refuse to grab closed, 11 seconds, hoist at a rate of 140 ft/min (711 mm/sec), traverse at a rate of 180 ft/min (914 mm/sec) to incinerator feed chute etc. The envisaged average cycle time of about 134 seconds has not been achieved. The crane motor should therefore only have one start operation about every minute and the grab hydraulic motor a similar duty. Instead of this, the number of stops and starts recorded in one hour of fairly typical operation greatly exceeds this. The implications of this on the heating of the electrical motors will be readily appreciated. The results have been troublesome. The electric motor in the grab has burnt out a number of times. The main hoist motor and spares have been
rewound and replaced with higher duty motors. Thermal trips have been incorporated in the windings of the electric motors driving the hydraulic motors. The high load factor on the crane has of course had its effect on other crane equipment, as for example, the crane brakes, maintenance and adjustment of which has to be frequent. In the past, poor operation and brake failure has on occasions caused the grab to 'free' fall into the silo, causing centrifugal bursting of the rotor.

2.8 Dust is, of course, a hazard and a nuisance in the silo hall both to operators and equipment. It is difficult to suppress dust but experiments may be tried with simple bar sprays and high pressure atomising jets at the tipping chutes in an effort to agglomerate dust particles during tipping into the silo. Certain types of industrial waste are particularly troublesome in this respect.

2.9 There is always a high fire risk with domestic refuse and fires are by no means uncommon. They arise either from hot cinders, as delivered, or from 'heatings' in refuse stored over a long period. In general these fires are not dangerous. There was one serious fire however at a time when one silo was full. In this case reactive industrial and commercial waste was on top of domestic refuse which had been in the silo for some time. The main problem created by a fire is the dense volume of smoke which quite rapidly fills the silo hall. If the fire can be dealt with before the smoke becomes serious, the fire can be grabbed and put into the incinerator feed chutes. Otherwise, extensive damping down is necessary until the seat of the fire can be located. The question of fire detection and elimination is currently under examination.
Equipment for the rapid opening of roof vents to allow smoke to leave has now been fitted.

2.10 Safety is an important operational factor on all industrial plant. It has been impossible to adopt measures which deal with all contingencies on this plant. As the refuse goes to the incinerator unsorted, the possibility of discarded war mementoes entering the boiler must be acknowledged. On one occasion two 143 lbs (65 kg) propane gas cylinders were delivered in refuse. One of these was half full of gas. Fortunately, these were large enough to be seen by the crane driver and did not reach the combustion zone. To date, one vehicle has continued with its contents into the silo, luckily without its crew. It is a matter of debate how dangerous the tipping floor chutes are - perhaps a good deal less dangerous than the average underground railway platform at rush hour.

3. Stokers or Incinerator Grates

3.1 One of the factors affecting the original decision to choose the Martin stokers was the quality of the burn out achieved. There is no regular monitoring of the burnout quality but, in the acceptance tests carried out in October 1975, the following results were achieved:

<table>
<thead>
<tr>
<th></th>
<th>Guarantee</th>
<th>No. 1 Line</th>
<th>No. 2 Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible in residual ash (% dry ash)</td>
<td>Not more than 5%</td>
<td>3.7%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Putriscibles in residual ash (% dry ash)</td>
<td>Not more than 0.3%</td>
<td>0.06%</td>
<td>0.07%</td>
</tr>
</tbody>
</table>

The quality of burn out is therefore very good and well within the original guarantee specification.

3.2 There have been a certain number of problems resulting from chute blockage. Refuse is burned in the 'as received'
state. There is no continuous separation or shredding. Such items as large cardboard bales or long cardboard tubes can cause blockages in the feed chutes. The large amount of trimming does help to some extent in reducing these problems. The crane operators also pick out, when visible, such large items as refrigerators. The developed technique of feeding the chutes, in which the grab is emptied over the slope of the hopper, and the refuse is allowed to slide gradually down the incline into the opening of the parallel section has minimised the problem. The hopper must never be overfilled and the refuse must not be dropped directly into the vertical opening. Because the operator cannot see the opening, the 'low level' alarm is used as a signal to fill up the hopper.

It is unfortunate that the chutes were not designed with a two or three degree divergence, with the narrowest section at the top of the chute section, i.e. with the base of the chute wider than the top. The chutes could then have been rodded clear more easily. Fires have occurred in the chutes for three reasons: a) in the refuse as charged; b) due to burning back caused by pressure conditions in the furnace; or c) due to too high a suction coupled with a low refuse level in the charging chute.

3.3 Experience has shown that, apart from those occasions when the refuse is very wet, it is easily ignited and supplementary firing is not necessary at light up or any other time.

3.4 Maintenance costs on the grates have been high, a situation aggravated by the cost of spares from Germany although improvement in Sterling will help in this respect. Service from Germany has been excellent, both in terms of advice and
the supply of spares. The principal reasons for the high costs are twofold. Firstly, heavy wear between grate bars can occur when particles become jammed between adjacent bars and will not work out. Martins make great play on the cleaning action caused by relative movement of adjacent bars in the last $\frac{3}{4}$" (20mm) of a $16\frac{1}{2}$" (420mm) stroke. If for any reason this action is lost, for example, a broken bar, build up on the driving crank or faulty limit switches on grate stroke, wear can increase. It is felt that this relative cleaning action is rather a delicate process for a refuse burning stoker. The second factor, which can enormously reduce grate bar life, is speed. At one time, the grates were being run at speeds of up to 60 strokes per hour to break up heavy clinker formations. On the advice of Martins, additional raking noses were fitted to certain bars and the grate speed reduced to 45 strokes per hour. This reduced grate wear considerably. The original proximity switches were also replaced by a positive micro trip switch and the grate stroke and speed carefully monitored.

3.5 The central division bar, which is spring-tensioned to take up clearance between grate bars, does not all times work. Discussions have been held with Martins and it is obvious that it is an area where the design is still developing.

3.6 There have been other minor problems. For example, those with the oil mist lubrication system undergrate which has not kept all bearings lubricated as designed.

3.7 Steam from the incinerator boilers is used to provide power from the turbo-alternator sets and to the district
heating scheme. Any shortfall in the steam output from the plant must be made good by three water tube boilers fired by coal. The refuse delivered to the incinerator plant is now less than half that originally envisaged at the time when the economics of the scheme were considered. The consequences are not difficult to imagine as far as the balance sheet goes. In the winter of 1976/77, refuse was dug up from tipping sites to be used as fuel. While every effort was made to be selective towards drier, higher calorific value material, this was only a limited success. Small pebbles from the tip cover found their way between stoker bars, there was an increased fire risk due to the start of the biological breakdown processes, there was trouble with the transport drivers carrying this rather 'ripe' load and so on. In the present heating season we are burning the local colliery discard, called Middlings. This is against the advice of the grate manufacturers. The material in use has an ash range of 40% to 60%, and an ash fusion point of +2,552°F (1400°C). Experience has been limited to under 2953 tons (3000 tonnes) and we are watching the equipment very carefully. So far, there have been no significant problems. In some ways, colliery discard is preferable to domestic refuse. There are no ballbearings to lodge between the bars, there are no rapid flare ups, etc. etc. Big clinkers have been made but have, so far, been 'digested' by the discharge mechanism.

4. Residual Plant

Experiences with the residual grab and the ferrous scrap recovery plant have been mixed. A major problem has been the water which accumulates in the base of the residual silo. This
requires frequent pumping since the base is below both ground level and the water table. In winter, in cold high humidity conditions, steam rising from the residual material reduces visibility to less than one metre. This makes life difficult for the crane driver who expresses his problem with a little spirit. Under these conditions, heavy condensation occurs on the electrical equipment. There is no reserve crane or other system for discharging the residual silo. Until this problem is adequately dealt with, the whole plant is vulnerable.

5. **Boiler Plant**

5.1 The major problem which has occurred with the boiler has been the loss of availability due to fouling on the tube plate and a short way up the tubes of the plate and tube heat exchanger. The deposit appears to be of the bonded type and consists largely of calcium sulphate with a high proportion of zinc and lead. Analysis of the deposit is given in Table 1. The mechanism of formation is not fully understood and, indeed, there seems to have been little fundamental work on it. It does seem probable however, that volatile zinc and lead salts sublime on to the heat exchanger plate at the hot end and the tubes and there act as an adhesive surface for trapping calcium sulphate. It should be noted that the gas temperature at this point is of the order of $1022^\circ F$ ($550^\circ C$), well below the softening point of calcium sulphate.

5.2 The introduction of a baffle which has extended the gas flow downwards before it rises to the base of the heat exchanger has extended the campaign life of the latter from about twenty one days to forty days.

5.3 Considerable effort has been spent investigating possible methods of cleaning the tubular heat exchanger and the
<table>
<thead>
<tr>
<th>Constituent</th>
<th>Sample No. 1</th>
<th>Sample No. 2</th>
<th>Top of Tubes Sample No. 3</th>
<th>Bottom Sample No. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>ZnO</td>
<td>3.67</td>
<td>10.0</td>
<td>3.17</td>
<td>1.68</td>
</tr>
<tr>
<td>PbO</td>
<td>10.45</td>
<td>12.5</td>
<td>1.36</td>
<td>2.42</td>
</tr>
<tr>
<td>SnO₂</td>
<td>1.51</td>
<td>1.90</td>
<td>0.52</td>
<td>0.53</td>
</tr>
<tr>
<td>SiO₂</td>
<td>10.5</td>
<td>7.7</td>
<td>31.6</td>
<td>45.4</td>
</tr>
<tr>
<td>CaO</td>
<td>16.0</td>
<td>8.2</td>
<td>11.4</td>
<td>9.0</td>
</tr>
<tr>
<td>MgO</td>
<td>0.36</td>
<td>0.73</td>
<td>2.91</td>
<td>1.58</td>
</tr>
<tr>
<td>Na</td>
<td>4.97</td>
<td>4.60</td>
<td>4.53</td>
<td>3.34</td>
</tr>
<tr>
<td>SO₃</td>
<td>30.6</td>
<td>32.4</td>
<td>10.5</td>
<td>4.39</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.15</td>
<td>0.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.71</td>
<td>0.49</td>
<td>1.25</td>
<td>1.00</td>
</tr>
<tr>
<td>MnO</td>
<td>0.10</td>
<td>0.14</td>
<td>0.37</td>
<td>0.21</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.67</td>
<td>2.60</td>
<td>5.43</td>
<td>9.8</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>5.90</td>
<td>5.54</td>
<td>17.7</td>
<td>15.3</td>
</tr>
<tr>
<td>K</td>
<td>3.15</td>
<td>6.10</td>
<td>3.32</td>
<td>2.08</td>
</tr>
<tr>
<td>Cl</td>
<td>0.38</td>
<td>2.92</td>
<td>2.88</td>
<td>0.37</td>
</tr>
<tr>
<td>L.O.I. @ 400°C</td>
<td>5.37</td>
<td>0.65</td>
<td>1.52</td>
<td>0.98</td>
</tr>
<tr>
<td>L.O.I. @ 800°C</td>
<td>7.3</td>
<td>6.1</td>
<td>5.0</td>
<td>3.45</td>
</tr>
<tr>
<td>Softening Point °C</td>
<td>1120</td>
<td>1150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting Point °C</td>
<td>1150</td>
<td>1170</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes on the above table:
(i) Sample No. 1 taken after a full term plus wash.
(ii) Sample No. 2 taken after 14 days.
(iii) Bulk samples Nos. 3 & 4 taken after 14 days.

The dust samples collected from the top and bottom of the tubes were found to be very similar but the bottom samples had rather higher silica content combined with a lower loss on ignition and higher softening and melting points as compared with deposits from the top tube place. Deposits on the bottom tube sheet showed higher sulphate contents both before and after working.
improvements likely to be achieved with those in use. With a winter heat load in excess of the output of one line and a normal refuse input greater than the burning rate of one line, cleaning time is expensive. Some of the more unconventional solutions to the cleaning problem remain to be tried, for instance, ultrasonics and some chemicals. The most successful solution so far obtained has been by the use of high pressure water washing at a pressure of 12750 psi (850 bar). Cleaning times have been sharply reduced using this method from the original two or three weeks to a record of 26 hours which when including cooling time, boxing up and re-heating gives a maximum down time of 48 hours.

Since the plant has not been designed for water washing however the cleaning water is a considerable problem in a plant which is difficult to maintain in a clean condition without this additional burden.

5.4 In the longer term, it is believed that there should be a scientific examination of the method of formation of the deposits. One suggestion is that a screen tube baffle, capable of being shock cooled, at the inlet to the shell and tube heat exchanger, could cause deposition of the material on the outside of these tubes, which could then be shock cooled, causing the material to break off.

5.5 Until April 1976, there had been no evidence of the other problem frequently associated with incinerators, that of corrosion. On the annual examinations in 1974 and 1975, no appreciable wastage of tubes had been detected, though it had been noted that the silicon carbide refractory was spalling off areas of the side walls, and also the front and rear arches.
The boiler manufacturers contended that replacement of the refractory was not necessary. The consultants did not agree with this view and, at their suggestion, trial areas of missing refractory on the front arches were replaced. The application, using the existing studding, was not however very satisfactory. In April of 1976, tube failures were encountered on the front arch below the front secondary air nozzles. The trouble was then limited to No. 2 incinerator. Further ultrasonic inspection, however, indicated thinning on all sections of both boilers along the front arch. These sections were replaced as well as sections in the side walls particularly around the forward inspection door.

5.6 After considerable discussion, extensive refractory repairs were carried out on both lines during the 1976 maintenance period. The existing silicon carbide refractory was entirely stripped off the front and rear arches and from the side walls of No. 2 line to a level with the front secondary air nozzles. The existing studding was substantially augmented by stainless steel sprigs spot welded to the membrane wall. The front and rear arches on both boilers were then covered by a refractory concrete containing carbon steel fibres gunned on. This material has a high density and low porosity but also a low thermal conductivity. Whilst its use was acceptable to the boiler designers on the front and rear arches, it was not acceptable for use on the side wall, and silicon carbide was again applied to these as being the only material with a high thermal conductivity despite the lack of positive assurance of performance from the manufacturers.

5.7 The actual mechanisms of the wasting of these sections has not been established. The general appearance is one of metal
wastage over the front area of the tube. It is felt that it has been caused in areas where combustion is occurring generally with reducing atmospheres. A possible significant difference between No. 1 and No. 2 lines is that No. 1 has a modification enabling it to burn low grade coal if refuse is not available. This modification involves the use of a guillotine which can be lowered to give a controlled bed thickness and there is an air gap at the guillotine slot through which air is drawn under normal combustion conditions. This may have increased the partial pressure of oxygen under the front arch. Failures on the side walls of No. 2 line are less easy to explain and the only significant factor appears to be that the refractory on No. 1 line is in a better condition than on No. 2 (It should be noted that facilities for injecting steam into the side panels and to the shell and tube exchanger are fitted for use when warming a line up from cold, so that corrosive condensation on cold boiler surfaces does not occur.)

6. Electro-Static Precipitators

6.1 The performance trials on the electro-static precipitators indicated that they were performing to specification. The results were as follows:

<table>
<thead>
<tr>
<th></th>
<th>No. 1 Line</th>
<th>No. 2 Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas volume actual</td>
<td>96700 cfm (47 m³/sec)</td>
<td>90140 cfm (43.8 m³/sec)</td>
</tr>
<tr>
<td>Gas temperature</td>
<td>500°F (260°C)</td>
<td>532°F (278°C)</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>12.7%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Inlet dust burden actual</td>
<td>0.51 grains/ft³ (1.81 g/m³)</td>
<td>0.64 grains/ft³ (1.46 g/m³)</td>
</tr>
<tr>
<td>Emission actual</td>
<td>0.026 grains/ft³ (0.059 g/m³)</td>
<td>0.04 grains/ft³ (0.10 g/m³)</td>
</tr>
</tbody>
</table>
6.2 There have been signs of slight surface corrosion within the precipitators but no evidence of any aggressive acidic corrosion, which seems to indicate that as yet there has been no acidic condensation at the excess air and temperature values used.

6.3 The discharge from both of the two cells passes into a horizontal screw conveyor before passing through a rotary lock valve into a wet conditioning screw. It would have been preferable to have a separate rotary valve on each cell which would have ensured more positive clearance of the grits from each cell. Maintenance on the conditioning screw has been high and water has now been taken off the sprays. A curtain type spray has been fitted where the conveyor discharges into the residual silo to prevent dust. An air slide conveyor would probably have been preferable to the screw conveyor.

7. Fans

7.1 There have been no unusual operational problems with either induced or forced draught fans. Power consumptions are of course high compared with those of a coal burning boiler producing the same output. In the case of the Nottingham scheme, the power is generated on site, the excess being sold to the electricity distribution authority in the area. While the power used must be costed at the selling value and not, as is usual, at the purchasing price, usage is a matter for detailed consideration.

8. Pumps

8.1 There have been a great many problems associated with the feed pumps which have been responsible for a considerable loss of plant availability. This is surprising since the pumps
are manufactured by a highly reputable company, operating on a world-wide basis. The only factor which makes the duty in any way different from normal boiler plant experience is the short term variation in heat flux to the boiler which reflects in rapid movement of the feed water control valve. This subject is dealt with under the section on control, but the implications for the pump are that the discharge pressure varies quite sharply.

8.2 Whilst the pump manufacturers say that the pumps are capable of dealing with this swing, it is self evident that they are not. The main bearings on both pumps have failed many times and on five occasions the pump shaft has fractured at its weakest point. The fracture of the shaft has also had expensive consequences on the electric motor and on the turbine.

8.3 The reasons for the failures have been obscured by many other factors such as engineering performance, poor grouting of pump bases, apparent stress from steam pipework to the turbine, difficulties in lining up prime mover and pump to the satisfaction of all parties and questions as to the quality of the bearings themselves.

8.4 The solution pursued was the purchase of another pump which, whilst secondhand, is of an older and more robust design with outboard bearings and seals. This was installed but here again a less than adequate performance has resulted. The pump discharge is being modified so that a constant pressure discharge is achieved. The two existing pumps are being modified too, so that high stress points on the shaft are eliminated and the seals improved.
9. **Boiler Controls**

9.1 Refuse, particularly unshredded refuse, is a very variable fuel and, whilst rarely difficult to burn, its rate of combustion varies considerably. The boiler absorbs short term pulses of heat very adequately and is obviously generously designed from the point of view of heating surface. There is no indication that boiler efficiency varies significantly at these times and the superheat control is very good. The steam output does, however vary considerably and quite rapidly and this complicates the control of the system.

9.2 It soon became fairly obvious that some form of output control was desirable. With the co-operation of the consultants, a simple form of control, based on the use of the steam flow rate to stop and start the feeder ram for short periods, was introduced. Whilst improving the situation, this did not give the desired result. The most successful idea for the control of the combustion rate came from discussions with Martin Combustion. They had also found limitations in using steam flow as a control value and they had started using furnace top temperature. A system was devised following these discussions using two short thermo couples, one on either side, in series to give a mean temperature in conjunction with a modified solid state temperature controller. This system works very much more rapidly and effectively and the boiler output can, within limits be regulated by adjusting the control temperature. Manual override by the operator is necessary under certain conditions but stability of steam output has been improved.

9.3 One consequence of a variable steam output in a boiler with relatively low water content is a rapid change in the feed water
requirement. The drum level was controlled extremely well by the controller installed but at the expense of a rapid movement of the feed water control valve which in turn causes the variation in demand on the feed pumps referred to in the previous section. The valve characteristic is not helped by the variation in pressure upstream and the modifications referred to previously will, it is believed, help in reducing the valve movement. The movement of the valve has also been limited to improve stability. If, for any reason, control of drum water level is lost, the low water alarm will trip both forced and induced draught fans. Recently some widening of the control on the drum water level appears to have improved the feed pump operating conditions to the point where the incidence of breakdowns is reduced.

CONCLUSIONS

The variability of the fuel and the down time required for gas-side cleaning should be fully borne in mind when specifying plant, particularly as far as the size and number of lines is concerned. This is particularly so when power generation is involved.

With two lines only installed and when one line is down for cleaning and/or maintenance, failure of the second line due to chute blockages etc. could lead to shortage of steam very quickly and therefore the necessity for maintaining some of the fossil fuel fired plant in a stand-by condition. The installation of three smaller lines at, say, 8 tons of refuse per hour would have obviated this necessity.
The Department of the Environment, the Department responsible for refuse disposal in the United Kingdom, is generally against incineration at the present time. Their two main reasons are the incidence of technical problems and the relationship between capital and operating costs for such plant when compared with controlled tipping costs.

In my personal view, we have not built sufficient plants, and therefore do not have sufficient operating experience, to understand and overcome all the technical problems but this in itself is not sufficient reason for necessarily giving up and resorting to controlled tipping in country areas.

Admittedly, plant of this type is capital intensive but where the heat produced can be used and a partnership such as we have removes the operational costs from the local authority, then the net costs are at an acceptable level. Costs to the County for incineration were quoted as £4.94 per ton for the year 1975/76. Apart from this, pressures on the environment and the need for energy conservation bring other factors to bear apart from pure cost.

Finally, the management and operational labour required for this type of scheme is of a specialised nature which brings its own problems during commissioning and the early months of operation.

Consideration should be given to operational training before commissioning, on an international basis if necessary, and we should be happy to co-operate in this respect.