Refuse Destructors and Their Use for Generating Electricity: A Century of Development

D. G. Tucker

Introduction

After a period during which town refuse in Britain has been almost universally disposed of by 'controlled tipping', refuse incineration is now being adopted as a preferable, often necessary, improvement—necessary usually because no suitable land can be found for tipping. In some cases, an effort is being made to use the heat developed by the burning refuse to serve some worthwhile purpose, such as district heating or the generation of electricity, and to use the solid residue also. These modern incinerator plants follow a pattern to a large extent in regard to their basic processes and also in regard to their architecture.[1] Plate 1 shows a modern plant at Derby (grid reference SK 384 344) which, built in 1969 at a cost of around £400,000, was one of the first of the new generation of incinerators. The only modern plant where electricity generation has been the aim is that at Edmonton (TQ 36 93), where the burning of about 1,500 tons of refuse per day leads to the production of about 0.5 million kWh of electricity.[2]

What is very curious, however, is that it seems to be generally forgotten that this is the second cycle of the development. All the discussion about the undesirability or difficulty of tipping, and the need to incinerate town refuse, and the desirability of making good use of the products, including the generation of electricity, was gone through practically a century earlier. Moreover, the discussion led to practical results; by 1912 there were about 338 municipal refuse incinerators in Britain, as listed in Appendix 1, and over 80 of them also generated electricity for the town supply. This latter figure meant that about 20 per cent of all electricity generating stations providing a public supply at that time used refuse to supply at least part of their output. Some of these refuse incinerators (generally called 'destructors') and combined destructor/electricity generating stations still stand (as shells, generally used for some other purpose), and form a good subject of study for industrial archaeologists, as I hope to show. Some of them were in use for their original purpose even after the Second World War. Indeed, some were not very old then; for instance, the large combined station at Govan (Glasgow) was opened in 1928, burning 640 tons of refuse per day and generating a peak electrical power of 10 MW.[3] In view of this it is surprising that they have been so generally forgotten.

It is fair to refer to the earlier work as largely forgotten, as even the *Journal of the Institution of Electrical Engineers* said in an editorial about fourteen years ago[4] that 'although many local authorities have disposed of refuse in incinerators, the heat produced has not been used for electricity generation'. A government report on refuse disposal published in 1971 barely notices the early work on destructors, and ignores their use for electricity generation.[5]

In the first cycle (*c.* 1876-*c.* 1914), the development of the refuse destructor, and even more of the combined refuse destructor and electricity station, was an essentially British one. Not only were the British the pioneers, but there was for some time little emulation of the ideas in other countries. The reasons for this remain obscure. Nowadays the position is largely reversed.

In this article I shall show that the development of refuse destructors from *c.* 1876 was largely dominated by economic considerations. There was a strong case for the idea that it was cheaper to burn the refuse and to sell the products than to dispose of the refuse by tipping. In Britain this case appealed to local authorities who, even then, found resistance to the paying of what then seemed high rates. By contrast, in the United States of America, the tradition of encouraging commercial enterprise led, to the formation of companies who undertook the treatment of town refuse as a commercial operation, paying nothing for the input material, and trying to sell the output. It seems that they were unsuccessful in making a profit whatever system of treatment they used; in refuse incinerators, for example, it was found necessary to use coal to help burn the refuse—typically 1 ton of coal to 14 tons of refuse in 1902.[6] As British destructors did not need coal, there must either have been a great difference in the nature of the refuse, or British designs were superior. That it was the latter seems demonstrated by the fact that continental Europe, Canada, South America, India, Australia, New Zealand, etc., all used British designs.[7] Whatever the reason, however, American destructors were something of a failure, and as they were at first, in most places, a purely commercial venture, their numbers remained relatively small for some time. However, by 1908 there were apparently about 200 'municipal incinerators'[8] in the USA and there are now some 300 of various ages, of which only about six make use of the heat generated.[9] Heat from the destructor was rarely used, outside Britain, for the generation of electricity until quite recent times; this was partly a matter of economics but probably more a matter of design ability.

In the remainder of this article, only the British scene will be discussed. My aim is to provide a background against which industrial archaeologists can study the physical remains of this vast activity, and I hope to encourage this study by the examples of extant buildings which I give at the end of the article.

Early history and economics of refuse destructors

The idea of using refuse as a fuel for the generation of electricity for public supply arose as a result of two themes which developed in the late nineteenth century and became concurrent. The first of these was fuel economy, quite an old theme indeed, highlighted by the extravagance of Newcomen's steam engine and Watt's success with his separate condenser, but taking on a new significance when the generation of electricity for public supply began to develop in the 1880s. Competition with gas for lighting meant that electricity had to be generated as cheaply as possible if it was to succeed. The second theme was hygiene, particularly the disposal of town refuse (which included faecal matter) in a way that was not harmful to health and not too objectionable in terms of amenities or what we would now call environmental factors.

Up to the 1870s nothing was done about town refuse except to dump it in stinking and insanitary heaps on the outskirts of the towns. Epidemics of cholera and other diseases had for decades emphasized the need for proper disposal of such waste. Although even in the 1970s, after a century of development, it cannot be said that the problem has been adequately solved—we still pour raw sewage on to holiday beaches—it was around 1875 that serious efforts started to dispose of refuse by incineration. It eventually became accepted that to destroy the refuse very high temperatures were needed, and that heat was generated in the process; it was a short step to the idea of making good use of this heat for the generation of steam. It was not until late 1893 that the first public demonstration of its application to the generation of electricity took place.

Early efforts at refuse treatment concentrated on turning the objectionable refuse into useful, harmless, and even profitable products. In 1872 special furnaces were manufactured for converting sewage into innocuous manure,[10] but these absorbed heat and were coal-fired all the time they were in use. By 1878 the principles of refuse disposal were clearly displayed in terms which remained acceptable for some decades, the chief proponent being Alfred Fryer of the firm of Manlove, Alliot, Fryer & Co of Nottingham. He treated refuse by separating it into three components, (a) dust-bin, ash-pit and midden refuse, (b) garbage, i.e. vegetable matter, sweepings from the markets, etc., and (c) urine.[11] Part (b) was carbonized into a useful charcoal, and part (c) was concentrated into a useful manure. It is part (a) which we are concerned with. The plant for treating it was called a destructor, and comprised a furnace with certain distinguishing features. These were:

(1) once combustion had been started, the heat of combustion kept the material at a high temperature,

(2) a reverberatory roof reflected the heat on to the burning mass to ensure the maintenance of the high temperature,

(3) the hot gases produced circulated in a flue in such a way as to dry out the incoming wet refuse and so make it suitable for combustion,

(4) the destructor required little attention; the slope of the pre-heater, the grate, and the furnace mouth were such that the material tended to feed itself through,

(5) the product taken from the destructor was of about one-third the mass of the input, and could be ground with lime into an excellent mortar.

Fryer's system was used, apparently with success, at Birmingham, Manchester and Leeds, by 1878. During the next decade, several firms entered the field of manufacture of refuse destructors, which came to be envisaged as steam producers; and the

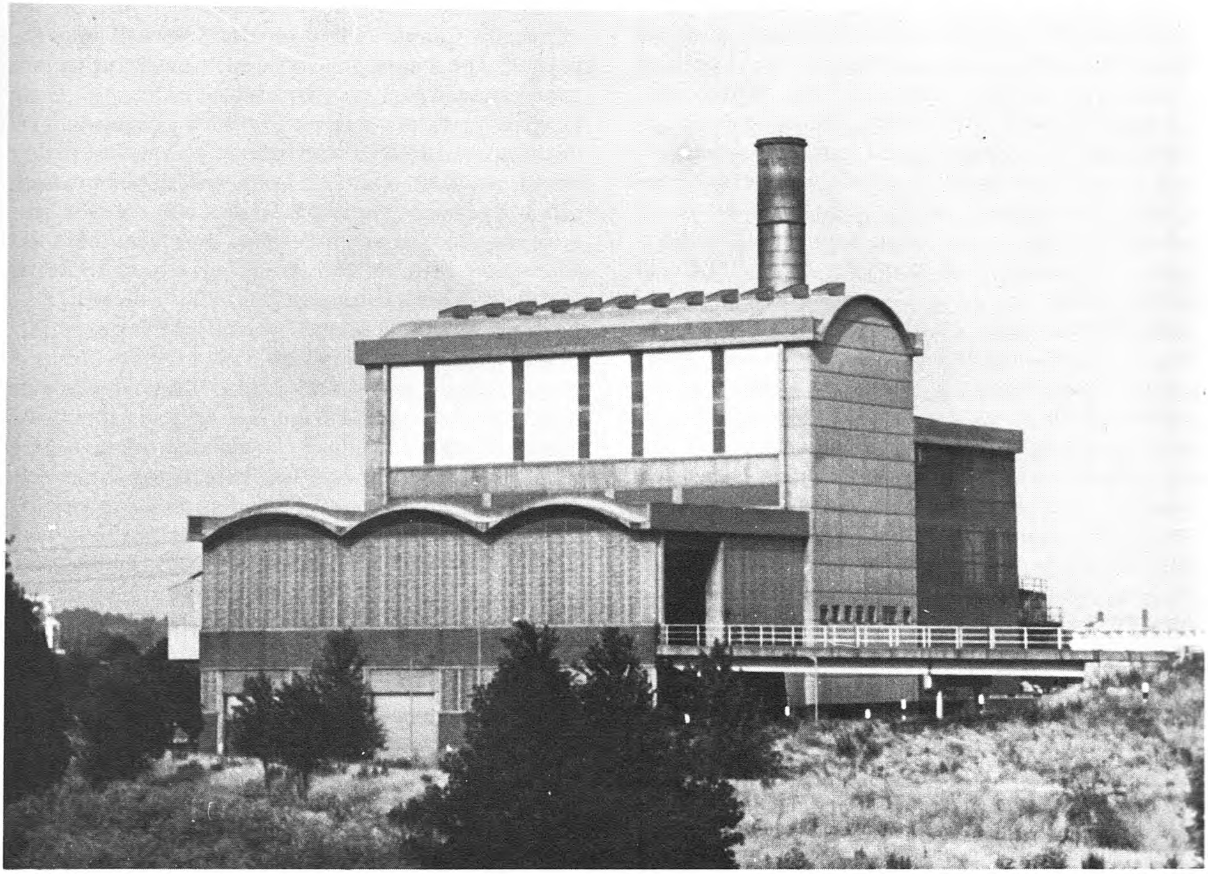


Plate 1 Modern refuse destructor at Derby, built 1969.

successful designs all incorporated the main features of Fryer's destructor. Additional developments were:

(1) the recognition that even higher temperatures were needed to destroy the refuse and provide suitable heating for steam-raising; thus forced blast was used, either by steam-jet or by fans. Temperatures up to 2,000 °F were claimed for the Horsfall destructor; (fig. 1)

(2) the hot gases from the furnace had to be allowed further combustion if all noxious fumes were to be avoided, and thus the flue led into a combustion chamber where either the gases burnt further by their own heat, or could be assisted to burn by additional heating;

(3) for steam-raising, a water-tube boiler was often best, it being possible to arrange for the hot gases to pass through the cluster of tubes two or three times; however, Lancashire and other flue-type boilers were often used;

(4) semi-automatic feeding of the refuse was common.

By the time refuse destructors came to be used in association with electricity generation, a fair degree of perfection had been attained.[12] Their use had spread widely. Beginning in 1877-8 with the three we have already mentioned, their numbers increased by about three per annum to a total of 47 in 1892,[13] then to 88 in 1900[14] and to about 350 in 1912. Many descriptions of individual installations were published.[15] Brief particulars of fifty destructors in use in Britain in 1893 were given by Jones,[16] and of those in use in 241 towns in Great Britain and Ireland in 1912 by Goodrich.[17]

When the idea of adding a steam boiler to a destructor was first put into practice I have been unable to determine. It was probably in the early 1880s. As forced blast was introduced, some steam was needed for this, either directly for jets or to drive an engine for fans. Other steam engines could be used to help in handling the materials. However, there was a great surplus of steam, and this began to be used for heating water for public baths. It became a common practice to build bath-houses in association with destructors. Other uses for the steam included the pumping of water and sewage. It soon became customary to consider the economics of refuse destruction, and to think in terms of making a profit out of what was undoubtedly a sanitary necessity. Two examples from 1892 will illustrate this.

(1) *Oldham.* Tests of the performance of the destructor at Oldham were made by Watson.[18] He measured the amount of steam at a given pressure produced by burning a suitable amount of refuse at what was thought to be the best temperature. The steam used for the forced draught was then deducted, and the remaining steam expressed as horse-power-hours per ton of refuse. Valuing this at 1*d.* per hp-hour, he found the value of available power as 5*s.* per ton of refuse. The inclusive cost ('including all charges') of burning worked out at 1*s.* 10*d.* per ton and the cost of collection at 2*s.* 0*d.* per ton. There was thus a profit of 1*s.* 2*d.* per ton plus whatever could be obtained for the clinker.

(2) *Southampton.* Here there was a well-designed destructor plant and a separate sewage disposal plant.[19] The steam generated at the destructor was used primarily for compressing air, although some electricity was generated as well for providing light in the plant and its immediate neighbourhood. The compressed air was used for a variety of purposes, but mainly for pumping sludge, not only at the Southampton works, but also, by means of a $2\frac{1}{2}$-mile pipe line, at the works of a neighbouring authority. The account worked out as follows:

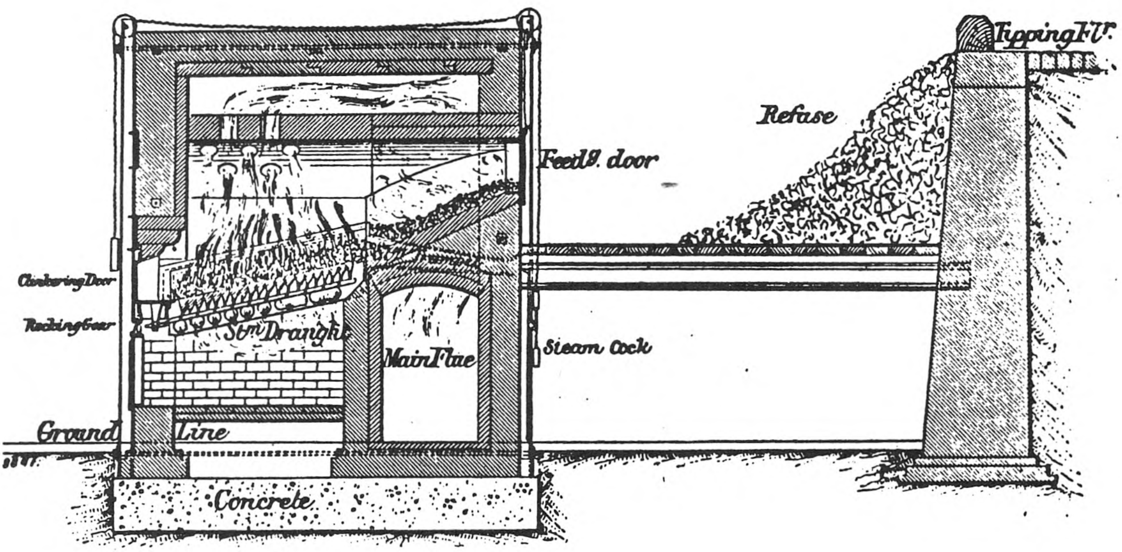
Destructor: wages, 4 men .. £251 p.a.
Sewage works: mainly wages .. £322 p.a.

The capital investment was £3,723 for the destructor and £3,000 for the sewage works, i.e. about £6,700 in all. Interest and depreciation were not stated, but allowing for these at say 3 per cent each, we have charges of £400 p.a.

Thus total outgoings .. about £970 p.a.
Revenue: sales of manure and compressed air .. £600 p.a.
sales of clinker .. £300 p.a.

The total revenue thus almost balanced the outgoings even when all interest and depreciation charges were allowed for.

Fig. 1 Cross-sectional diagram of the Horsfall Refuse Furnace (from *Engineering,* **63** (1897), 122).



It should be noted that in both these examples no account has been taken of what it would have cost the authority to dispose of its refuse by carting and dumping. This was commonly said to cost, in an average case, about 2*s*. per ton more than carting it to the destructor. In the case of Southampton, the refuse handled for its population of about 13,000 was about 3,000 tons p.a. giving a saving of carting of about £300 p.a. Thus destructors seemed to make a virtue out of necessity.

A feature of the design of almost all the destructor furnaces was that they were composed of several 'cells', each cell being an independently-fired furnace unit, but linked up to a flue and boiler system that was common to two, four, or even more cells. Large destructors might have up to twelve cells and several boilers. This feature was to prove of very great importance when destructors came to be used for electricity generation, for a varying number of cells could be fired at different times to match the fluctuating electrical load of the station.

It is necessary to point out that the nature and composition of refuse varied very much from one place to another and also from one time of the year to another. Up to about the turn of the century, hand-picking of the refuse to extract valuable components such as iron, bones, rags, etc., was used by some authorities, but disgust at this revolting use of human beings eventually led to its abandonment. The proportion of burnable cinder obviously was greater in the winter than in the summer. The method of collecting sewage also varied, and in many places it was included in the general refuse. But with all these variations, it was fairly generally agreed that a typical figure for the amount of refuse was about 250 tons per year per 1,000 people. Analyses of refuse and of its calorific value were published.[20] Later, by the turn of the century, enough data had been collected to permit the tabulation of the steam-raising value of refuse in different places, based on the actual performance of the furnaces installed. Expressed as pounds of steam per pound of refuse from and at 212 °F (100 °C), the figure varied from about 0.6 to 1.6, with lower values in summer than in winter.[21] For design purposes, a figure of 1.0 was evidently a reasonable assumption.

Electricity from refuse

The idea of using some of the steam generated in a refuse destructor for driving a dynamo to provide a supply of electricity was a rather obvious one, especially after electricity began to be generated for public supply, from 1882 onwards. Yet it seems to have been taken up only very tentatively. One or two destructor works used small dynamos to provide some internal lighting in the works (it was claimed that this was done at Nottingham as early as 1882)[22] and, as we have seen, the Southampton works extended such lighting to a few streets in the immediate vicinity, probably in about 1890; but this extension was withdrawn quite soon to allow a private lighting company to include those streets in its system.[23] A public demonstration of electric lighting from the burning of town refuse was given in Halifax at the end of 1893, using a refuse destructor and a special kind of boiler, rather similar to what was known as an 'elephant' boiler, constructed according to the patents of a Frenchman called Livèt.[24] The steam powered a Parsons turbo-electric generator, and the electricity energized a 25,000 candlepower searchlight and a number of ordinary arc lights.[25] It is believed that the Livèt boiler did not come into general use, but the demonstration did attract notice.

In spite of the fact that in all the reports and articles of the 1890s and early 1900s credit is given to Oldham for having the first public electricity supply generated from refuse (opened in March 1896)[26] this is not the case. Both Ealing and Cheltenham preceded Oldham. All three utilized existing refuse destructors, attaching electricity works to them. Since the destructors were necessarily remote from the centre of the towns, this meant longer cables than would have been necessary for ordinary generating stations, and the extra cost of these was consciously set off against the saving of using cheap steam. Ealing's refuse-generated electrical supply was started on 3 October 1894, the station having a total capacity of about 250 kW, of which about 35 kW could be provided by the steam from the destructor.[27] The electrical works at Cheltenham were opened in May 1895 with 176 kW capacity, of which about 50 kW could be provided by the steam from the destructor.[28] The point was made in reports that the steam from the destructors would be sufficient to meet the daytime demand, and that ordinary coal-fired boilers would only need to be used in the evenings to meet the peak lighting load. Thus considerable savings were expected. At Cheltenham, at any rate, the scheme gave satisfaction and was reported to be a success both technically and economically.[29] It is believed that combined working was abandoned at Ealing after only a short time.[30]

The first detailed plan for a new destructor and electricity works to be constructed together for combined working was probably that for King's Road, St Pancras, London, in mid-1893.[31] The plant was brought into use in August 1895, but as a combined station was a complete failure. The technical press was almost completely silent on the matter, but the whole sorry story can be found in the minutes of the St Pancras Vestry,[32] especially if one is prepared to read between the lines. The design of the destructor cells was faulty and enough steam could not be raised to drive even the fans for the forced draught. The excuse was made that the St Pancras refuse was of low calorific value until tests made with it in the refuse destructor at Leyton showed that there it could be burnt at the rate of 15 tons per cell per day as compared with the 4 tons achieved at St Pancras. In spite of very reasonable tenders from reputable destructor manufacturers for the complete reconstruction of the furnaces, the St Pancras Vestry decided merely to modify them according to the recommendations of their own manager. Thus the destructor never was satisfactory and never (except for short unsatisfactory trials) supplied steam to the electricity generating plant.

The first successful combined works designed as such was that opened at Shoreditch, London, in June 1897.[33] There was thereafter a rush of other combined stations, over forty having been opened by the end of 1905. As there were then a total of 384 electricity generating stations,[34] excluding the few operated by the bulk suppliers, this meant that more than 10 per cent of the stations were partly or wholly operated from refuse. In the following five years, a period of reduced expansion of demand for electric lighting probably caused by improvements in gas lighting, there was an increase of only thirty-four in the total number of stations,[35] but a rise to almost 20 per cent in the proportion which were combined stations.

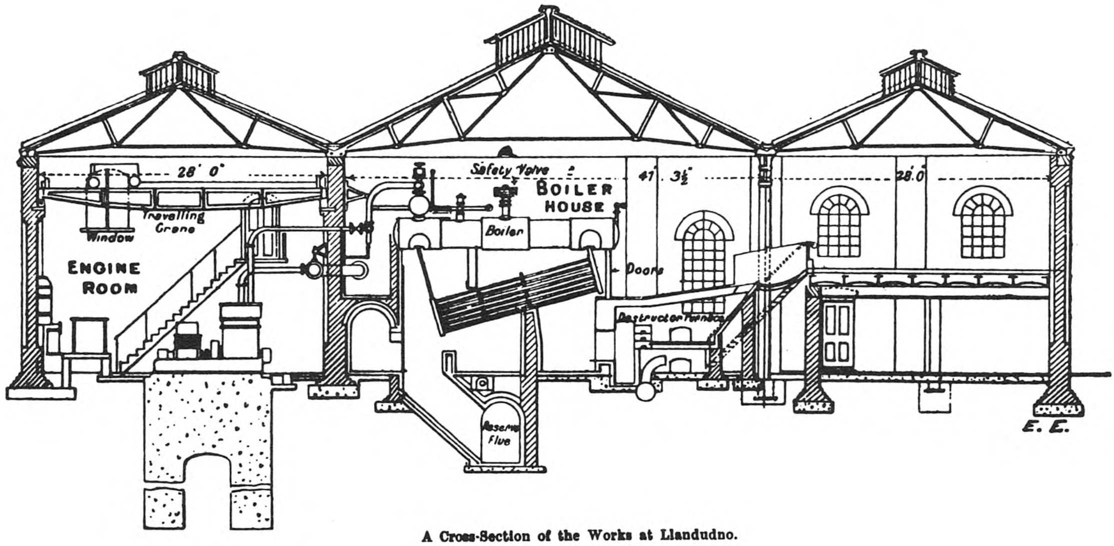
The First World War of 1914-18, of course, halted this development, and afterwards a new approach to electricity supply, based on larger stations and larger supply areas, began to emerge. Moreover, the demand for electricity was such that no longer could refuse supply a significant proportion of the steam required for electricity generation. Many of the combined stations, however, continued in use for a long time. The Shoreditch combined station did not cease regular operation until 1940 and was still occasionally used until it was dismantled in 1948.[36] Even then, the destructor part continued to operate until the early 1960s, supplying steam for heating the adjacent public baths, which had been part of the original installation using the exhaust steam from the engines of the electricity-generating part of the works. Extracts relating to this station from a letter from Mr R. H. Rawll, former Borough Electrical Engineer and Manager at Shoreditch, are given in Appendix 2.

Details of many of the early combined stations were published, and as there were so many variations in design, a selection of references is given.[37] A transverse sectional elevation of the Llandudno station is given in Fig. 2, as it was a neat 3-bay design, typical of many of the smaller stations; it had only four destructor cells, of Beaman and Deas type.

Appendix 1 lists 338 refuse destructors in the United Kingdom, known to have existed in 1912, with those used as combined stations to generate a public electricity supply shown in capital letters. The main source for this list is Goodrich,[38] but some of his errors have been corrected, and additional information given from such sources as the *Electrician* tables of generating stations. There must have been other cases where the combined use of a refuse destructor with a generating station was not recorded in published information. Indeed, Adams[39] stated in 1904 that there were already forty combined stations in operation, with another twenty under construction; and Robertson[40] stated in 1909 that 'combined stations are now increasing at the rate of about 20 per annum'. If this last statement was true, the only interpretation possible is that many existing generating stations were having refuse destructors built to work with them. It is, however, evident that my list cannot be complete. Another type of case which is not indicated in my list as a combined station is that where a small amount of electricity was generated for lighting perhaps only the works and the streets in the vicinity, as exemplified by Torquay, where 9 kW was available.[41]

Operation of combined stations

We have already discussed some of the requirements of refuse destructors in relation to the proper destruction of refuse and the raising of steam. When the destructor was to be used to supply steam for the generation of a public electricity supply, additional requirements were introduced. These related mainly to the variable nature of the electrical load. Even today there is a considerable fluctuation of load on the country's electrical supply, the ratio between maximum and minimum



A Cross-Section of the Works at Llandudno.

Fig. 2 Cross-sectional elevation of the Llandudno combined refuse destructor and electricity generating station. Refuse carts enter at first-floor level on the right; the refuse is tipped into the destructor furnace (4 cells). The hot gases heat two of the three water-tube boilers, which provide steam for the three Belliss reciprocating engines which drive the dynamos on the left. The centre boiler of the three is separately coal-fired. Total generating capacity 250 kW (From *Electrical Engineer,* **22** (1898), 647).

demand each day being sufficient to introduce a serious loss of economic efficiency in the generating plant; but around the turn of the century the fluctuation was extreme. Since the load on many stations was almost entirely due to lighting—for the country as a whole, power represented a very small fraction of the electricity demand, not reaching 50 per cent until about 1910—there was an enormous peak demand in the later evening, a much smaller demand in the early morning and early evening, and hardly any demand during the day. The earlier practice of closing down the electricity supply during the day was no longer acceptable, and the problem was how to meet this varying demand with reasonable efficiency.

The combination with refuse destructors was evidently attractive in this situation, for the steam from the destructor could be expected to be sufficient to meet the daytime demand without the need to use expensive coal. In the evenings, coal grates could be brought into use. This leads to one of the special requirements of design for combined working: the need to provide grates for burning coal as well as refuse. The burning of refuse needed a very large grate working at a very high temperature with forced blast; coal-burning grates had to be much smaller and did not usually have forced blast. So a number of stations used entirely separate boilers for coal firing. Most found a means of using the same boilers for coal as well as refuse by the simple expedient of using a more-or-less standard boiler and grate with its flues connected to the flue from the destructor grates.

For the proper burning of refuse it was desirable to maintain each destructor cell at fairly constant rate of consumption, and if all cells were fired all day, this meant that for much of the day an excess of steam would be produced. Firing a variable number of cells coped with the grosser and predictable slow changes of load to a certain extent, but time was required to bring in additional cells, and this process evidently could not cope with rapid and/or unexpected changes. Consequently, a system of storage was necessary to absorb energy during slack periods and to give it out again at times of large demand. Such was the thermal storage system of Druett Halpin,[42] although a somewhat similar arrangement had been proposed by Baker as early as 1894.[43] Its principle was to use surplus steam to heat up water in a tank, which could be closed and under pressure in order to attain a higher temperature; when extra demand arose, this stored heat could be used in a number of ways, but the most obvious and most generally-used procedure was to take the water from the storage tank as superheated feed water for the boilers.

This thermal storage system was incorporated in the Shoreditch combined station and, probably, in some others. It was at first thought sufficiently attractive to be used in ordinary generating stations too, so that even coal-burning grates could be fired at high efficiency all day. Examples of this are Hampstead, where six boilers were provided with Halpin's thermal storage, Dudley in the West Midlands with two storage tanks, and the Kensington and Knightsbridge Co with seven; the last two stations, at least, were recorded as still using storage in 1910,[44] although an adverse report had been given by the Shoreditch engineer in November 1898.[45]

Most stations generating direct current (d.c.) supplies used secondary batteries or accumulators for the storage of electricity as such, the idea being partly the same as for the thermal storage scheme, i.e. to take energy in at slack times and give it out to help meet peak demand, but with the additional advantage of ensuring continuity of supply in the event of a temporary breakdown of the generating plant. It was a common practice to close down the generators in these d.c. stations during some hours in the morning and to supply the very modest load entirely from the battery. Stations supplying alternating current (a.c.) could not do this, of course, and for them one would have thought that thermal storage would have proved attractive. There is no evidence that this was so. Clearly, for combined stations supplying d.c., an alternative to the use of thermal storage was to use adequate batteries. This seems quite rapidly to have become the standard practice.

We shall now show the way in which combined stations were operated in respect to the varying load by taking three examples.

(1) *Shoreditch.* Russell, who was the first engineer of the Shoreditch undertaking, took some careful measurements of load, refuse and coal consumption, and other factors, over several normal working days.[46] One of his records is shown in Fig. 3. At Shoreditch there was a substantial load during the morning due to electric motors; as we have indicated, this was not typical of most stations. Thus the morning load was about 200 kW, twice that of

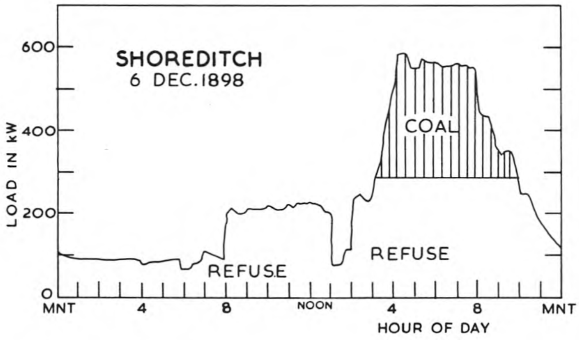


Fig. 3 Operating record for Shoreditch combined station, 6 Dec. 1898.

the night, but only about one-third of the evening peak load. As can be seen, the steam from the refuse destructor was able to supply all the load except for seven hours—it should be noted that the day concerned was in mid-winter—and even then it coped with more than half of the energy demanded. The variation of load during the day was coped with by a combination of heat storage and variation of the number of destructor cells in operation. From 11 p.m. one night until 6.30 the next morning, eight cells were in use, then ten for the rest of the day. The temperature of the water stored rose to a peak of 280 °F in the early hours of the morning, then fell as the motor load came on to around 245, and had fallen to 200 °F by the end of the evening peak. The amount of electrical energy supplied during the twenty-four hours by refuse was 4,350 units (unit=kWh), and by coal 1,321 units, and to produce this 123 tons of refuse and 4.15 tons of coal were burnt. The refuse was ordinary domestic refuse, trade refuse, and shop sweepings.

(2) *Gloucester.* Adams[47] gives an interesting set of figures for the station at Gloucester, which, although opened for the generation of electricity in 1900, did not have the associated refuse destructor brought into use until 1902. The measured recordings are shown in Fig. 4. It was a comparatively small station, and the city not having many factories, did not have a substantial morning motor load. Thus the night load of just over 40 kW fell to only about 25 kW during the day, and the evening peak of 165 kW was over six times the day load. The destructor had only two cells, so there was no flexibility there, and there was no thermal storage, although there was a small storage battery. There are no data on how the battery was used. It is fairly evident that the destructor was not used at top effi-

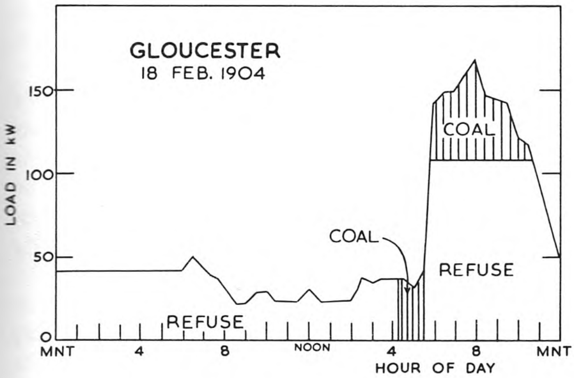


Fig. 4 Operating record for Gloucester combined station, 18 Feb. 1904.

ciency all day, since 107 kW was generated from it in the evening. The destructor was closed down for an hour just before the evening load came on for ashpit cleaning, and this would no doubt have been a factor in enabling it to meet the high demand. During the twenty-four hours there were 1,172 units generated from twenty tons of refuse, and 218 units from 0.875 tons of coal.

(3) *Hackney*. Adams gives a detailed analysis of the performance of the combined station at Hackney, but the most interesting features are included in the example shown in Fig. 5. Once again this was for a day in mid-winter. Hackney had an unusually large battery which, with 304 cells of 2,400 ampere-hours capacity, could store over 1,200 units of electricity. The diagram shows how this battery was used.

There was little day load at Hackney, as at Gloucester, and because the surplus electricity from the night-time operation of the destructor had left the battery fully charged, it was usual to close down the destructor as well as the generators during the morning; this gave a very good opportunity for cleaning and maintenance. The morning load used less than half the capacity of the battery. During the afternoon the battery was fully charged again ready for the evening peak. On some weekdays, e.g. some Thursdays, which were early closing days, it was unnecessary to use any coal at all, but on the day illustrated (which was actually a Thursday) some coal was used. It is interesting to observe that the energy taken from the battery was only about 600 units—half its total stored charge—and that if it had been almost completely discharged, no coal need have been used on this occasion; but it was the declared policy of the management to hold a

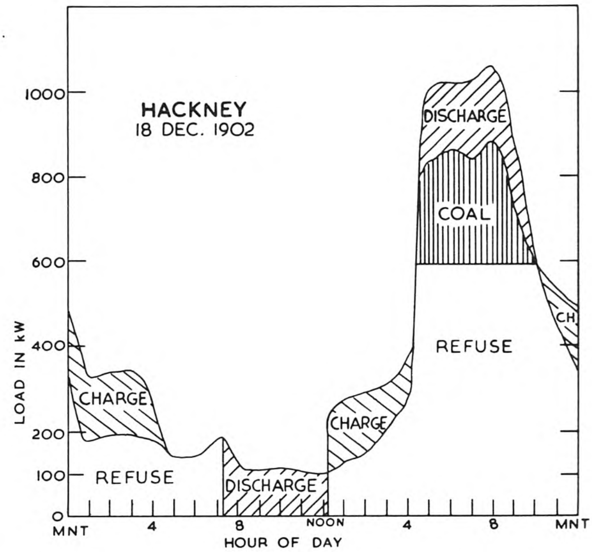


Fig. 5 Operating record for Hackney combined station, 18 Dec. 1902.

reserve against emergencies: 'we think a great deal more of the continuity of our electricity supply than of squeezing a few extra units per ton out of the refuse'.[48]

On the day concerned there were 8,033 units generated from refuse, and 1,165 from coal; consumption was 144 and 2.6 tons respectively.

Economics of combined stations

This is a most difficult subject, and its consideration gave rise to a vast amount of controversy in the 1890s and the early 1900s, some of which appeared in the papers we refer to and in those in the supplementary bibliography appended. One of the difficulties was that each authority operating a station had its own system of accounting. Sometimes the destructor and electricity-generating costs were not separated, sometimes the steam from the destructor was charged to the electricity account at a nominal rate, and sometimes it was charged at a calculated rate based on all sorts of assumptions. Occasionally true costs were worked out, and one such case appears to be the account for the station at Greenock for the year ended 31 January 1909.[49] It will probably be helpful to set out and discuss this case first.

Greenock, year ended 31 January 1909. One feature which makes this case more convincing than most is the fact that the working of the generating part of the station was studied for three months using coal fuel alone, while completion of the destructor was awaited. The true value of the steam supplied by the destructor could thus be accurately assessed, and a realistic price charged for it in the accounts. The analysis was as follows:

Coal burnt per unit of electricity generated . . . 4.5 lb
Price of coal—10*s.* per ton = 0.0536*d.*/lb
Cost of coal per unit generated . . . 0.24*d.*

The capital charges on the coal-fired boilers and auxiliary plant were then added; specific figures were not stated, but they may be taken as 3.5 per cent interest and 3.33 per cent depreciation on about £8,000; so say

Capital charges . . . £530 per annum
Units generated by coal in year . . . approx. 1.25 million
Capital charges per unit generated . . . 0.11*d.*

Thus the total cost figure was 0.35*d.* per unit generated. This was the figure used in the accounts. Why wages were not allowed for is not clear, but they would probably have added no more than about 0.03*d.*/unit.

The destructor had to be supplied with electricity for the fan motors and lighting, and since generating costs were now involved in addition to steam-raising costs, this was charged at 0.6*d.*/unit.

The overall performance of the destructor could now be assessed. The official statement amounted to this:

Expenditure	£
Labour for operating destructor	936
Labour for treating residue	134
Repairs to building and plant	160
Disposal of unsaleable residue	135
Electricity used in destructor, 132,006 units at 0.6*d.*/unit	330
Rates, taxes, insurance	83
Management	65
Interest on capital cost of £19,800 at $3\frac{1}{2}$%	696
Sinking fund, one-thirtieth of capital	663
Total expenditure	3,202
Receipts	
Sale of steam for electricity generation, 1,142,064 units at 0.35*d.*/unit	1,665
Sale of clinker	65
Total receipts	1,730
Net cost of refuse disposal	1,472

The net cost of refuse disposal works out at 1*s.* $8\frac{3}{4}$*d.* per ton. Previously the refuse had been carted two miles out of town and tipped for 1*s.* $3\frac{1}{2}$*d.* per ton.

Discussion. It must be emphasized that the case of Greenock has been presented not because it was typical but because it was the only case I know where a sound scientific basis has been used for the accounting. At Greenock the destructor did not show a profit. By far the greatest factor in reaching this conclusion was the very low cost quoted for carting and tipping the refuse when it was not burnt in the destructor. The figure of 1*s.* $3\frac{1}{2}$*d.* per ton may have been correct for Greenock, but it was not typical. Data on this matter are extremely sparse, and in his detailed study of costs of destructor working, Adams[50] was able to give figures for 'alternative method of disposal' in only three cases, and they were unfortunately London boroughs where barging and dumping were used. In these three cases—Shoreditch, Fulham, and Bermondsey—the costs were respectively 4*s.* 0*d.*, 2*s.* 3*d.*, and 4*s.* 9*d.* per ton. Had these costs been involved at Greenock, the *profit* attributable to the destructor would have been large.

Another important factor is the cost per ton of coal. At Greenock this was very low. Obviously the cost varied with the quality of the coal, but it varied even more from place to place. Gloucester paid only 10*s.* for slack in 1902, but the London stations had to pay from about 13*s.* to about 21*s.* for differing grades of coal. Had the cost at Greenock been 20*s.* per ton, the valuation of steam from the destructor would have been 0.59*d.* per unit generated, and the net cost of refuse disposal would have been halved.

Beside these considerations of alternative disposal and cost of coal, all other factors affecting the accounts are small. But the decision to build a destructor was not—or, at any rate, should not have been—based on profit but rather on sanitary grounds. The real question was, if a destructor was to be built, would it be worth while to couple it to the electricity generating station? The answer to this at Greenock was clearly that it paid to the extent of £1,665 per annum, i.e. the amount in effect paid by the electricity department for the steam from the destructor, minus the extra labour and capital charges due to having separate boilers at the destructor (again, Greenock was not typical in this since most stations had common boilers). These charges could not have amounted to more than about £600 per annum, so that there was a clear £1,000 benefit from combined operation.

Another factor which ought to have been, but never was, brought into consideration is the cost of energy storage, for we have seen that storage was necessary for the efficient operation of a combined station. Stations generating d.c. almost always had batteries as a matter of course, and in such cases it was usually thought that they also provided what storage was needed for the efficient use of the refuse destructor. Stations generating a.c. could not conveniently use battery storage. That storage *was* considered desirable seems indicated by the fact that a much higher proportion of combined stations generated d.c. than of stations generally. But a statistical analysis I made of the ratio of storage capacity to generating capacity in a random sample of forty-six combined stations and forty-eight non-combined stations (as recorded in 1906) showed no evidence that any *additional* storage was provided in combined stations. Thus it is probable that few combined stations worked at highest efficiency.

Other cost benefits of combined working. It was often possible to get some other benefits from combined working. One example of this is the case of Shoreditch, where the exhaust steam from the engines was used to heat the public baths and the 'free' or public library, which were both on the same site as the station, and, moreover, also for pumping and for boiling clothes in the wash-houses. The engineers valued this steam at about £750 per annum, although only about one-third of that sum was actually allowed in the accounts. Of course, it could be argued that if this steam had not been taken, the engines could have had condensers which would have raised their efficiency considerably. In tests at Mansfield[51] it was shown that the use of condensers increased the number of units generated per ton of fuel by 22 per cent. The real value of exhaust steam services, therefore, seems questionable.

The question of the sale of clinker is interesting, although not strictly relevant to the economics of combined working. In the earlier days it was possible either to sell the clinker, or, better, to make it into a saleable product. We saw that at Greenock in 1909 only £65 was obtained by the sale of clinker. Actually, only 1,286 tons were sold out of the 5,338 tons produced, and £135 had to be paid out for the disposal of the unsaleable stuff. It is fairly clear that the early expectations of good receipts from the sale of clinker or clinker products were not always fulfilled, although some towns were very successful and by careful processing able to sell 10,000 tons or more each year.

Another item in which there should have been a saving from combined working is labour. Since little or no steam has to be raised in the electricity station itself for much of the day, there should be a saving in stokers' wages. When the two council departments concerned could agree, there should be a saving in supervisory costs. Data on actual cases are practically non-existent, but Adams[52] does give estimated savings for three London stations, varying between £200 and £750 per annum. So this might well have been a significant factor.

Productivity of stations in units per ton. An interesting and useful index of the performance of stations is their productivity measured by the number of units of electricity generated per ton of fuel consumed. This index was a function of many separate factors, the main ones being (a) the quality of the fuel, (b) the design of the furnaces and boilers, (c) the efficiency of the generating plant, (d) the use of storage tanks and batteries, and (e) management. For a given station, however, it permitted an accurate assessment of the value of the refuse as compared with coal. A selection of figures for various stations is given in Table 1.

We have included information in Table 1 which indicates the variability of refuse over the year, and this is one of the main factors causing the average units/ton on refuse to be so far below the peak. The other main factor is the fact that the output of the destructor is not utilized fully all through the day and that the thermal or electrical storage is inadequate. The value of refuse as fuel evidently varies from less than one-tenth to nearly one-third of that of coal. The variability of performance from one station to another is also evident; an improvement over the decade between the opening of Shoreditch and that of Greenock was, of course, to be expected. The exceptionally high figure of 105 units/ton for refuse at Pontypridd was attributed to an exceptional quality of refuse.

It is obvious from Table 1, and we have also commented, that Hackney was a particularly efficient station. We have already mentioned the large battery as one reason. Other reasons given by Robinson[53] were the use of large triple-expansion engines, of condensers and superheaters, of mechanical stoking, and of electrical drive for all auxiliary plant.

Conclusions to the historical study

The concept of destroying town refuse by incineration in properly designed furnaces arose in the 1870s, and the idea of using the heat produced for the production of steam which could be used in

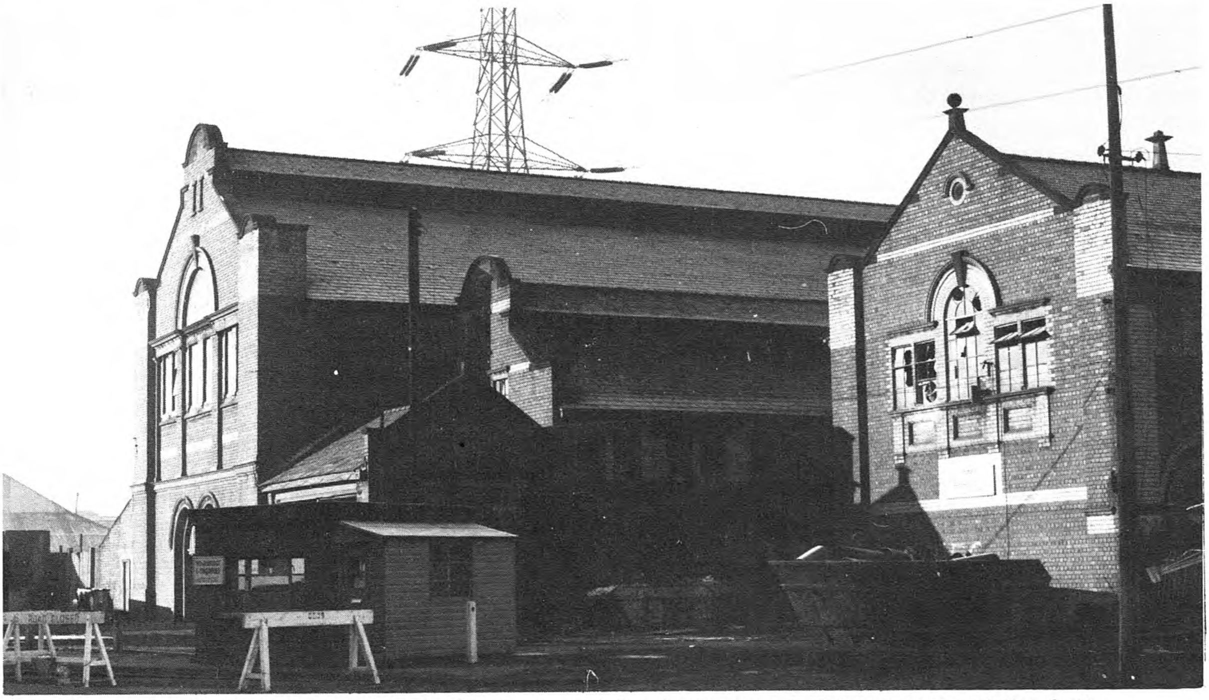


Plate 2 Two views of the Nechells (Birmingham) refuse destructor, believed to have been built in two stages in 1892 and 1901
(A) View from north-east.

(B) East end of large block, which has a ramp-road up to first-floor level on its south side.

Table 1 Productivity at various combined stations

Station	*Units/ton on refuse*		*Units/ton on coal*	*Grade of coal*	*Cost of coal per ton*	*Year*
	Peak	*Average over year*				
Shoreditch[1]	55	21	280	Welsh smokeless	21*s*. 8*d*.	1899
Fulham[1]	92	30	300	Derbyshire	13*s*. 5*d*.	1902/3
Hackney[1]	105	40	448	Scotch	14*s*. 0*d*.	1902/3
Partick[1]	—	30*	247	Scotch bitumen	8*s*. 0*d*.	1902/3
Gloucester[1]	59†	15	200	Slack	10*s*. 0*d*.	1902/3
Mansfield[2]	88‡ 72§	—	—	—	—	1902
Liverpool[3]	—	45	—	—	—	1909
Greenock[3]	97†	67**	500	—	10*s*. 0*d*.	1909
Pontypridd[4]	—	105††	352	—	—	1909

Notes:
* about 60 averaged over a winter month in 1904
† on special test
‡ with engines condensing
§ with engines non-condensing
** 86 for October, 24 for June, indicating seasonal variation in refuse quality
†† averaged over winter months only
References to sources of data: (1) Adams; (2) Leask; (3) Robertson; (4) Goodrich

other council works was taken up in the 1880s. The idea that refuse destructor works could or should be made profitable followed from this, and we have indicated by examples that their use, in addition to improving sanitation and hygiene, would also have proved cheaper in most cases than the older methods of refuse disposal. It is therefore not surprising that the number of destructors increased quite rapidly.

A more interesting and much more difficult question was raised by the association of destructors with electricity generating stations which began in 1894. There were two aspects of this. Firstly, if it had already been decided to instal a refuse destructor anyway, was it cheaper for the electricity station to take some of its steam from the destructor or to produce all its steam itself? Superficially, it seemed that to use steam produced from refuse—which had to be burnt anyway—must be cheaper, but technical considerations showed that this was not necessarily so, and controversy raged for years. Secondly, if the decision to instal a refuse destructor had not been made, and the alternative of continued tipping was still open, was it cheaper to provide a combined destructor/electricity station than to operate the electricity station entirely on its own? As hardly any operating authority had a suitable system of accounting or kept appropriate records, the matter was never really settled. Nevertheless, combined stations became very numerous, exceeding 10 per cent of the total number of electricity generating stations around 1905, and approaching 20 per cent by 1910.

One reason why the economy of combined working was not obvious was the fact that the load on electricity generating stations fluctuated wildly during the 24 hours of each day, and that therefore the steam from a destructor could only be efficiently used if some form of storage of energy were provided. Thermal storage was sometimes used, but more often electrical storage in secondary batteries was employed, and it was rarely adequate. Another reason was that the most economical site for the electricity station was not usually the most economical site for the destructor.

The detailed analysis by Adams, to which we have frequently referred, was made in 1902/3 and represented a very considerable achievement; nevertheless, we cannot use his figures with any real confidence because they are generally based on special test observations and several assumptions about the working, rather than on careful records over a long period. However, there is now very little reason to doubt his main conclusion that there was, in general, a substantial saving from combined operation.

As the consumption of electricity per head of population has increased much faster over the years than the production of refuse per head, the electricity which could be generated from the burning of refuse became a negligible proportion of the total amount generated, and combined destructor/electricity generating stations went out of use. In the present decade some new attempts to use refuse in this way have been made, at Edmonton (London) and Nottingham, and it will be interesting to see if other schemes follow. One of the important differences between the early days and the present is that around 1900 there was little economy to be gained from large-scale electricity generation; the engine units were all small anyway. But now the economy of scale is all-important; to achieve low cost per kWh, turbo-alternators of 500 MW capacity are being used in the latest generating stations. Refuse destructors, however, cannot work on anything like this scale; 20 MW is about the most that has so far been considered practicable. Thus the economic case is now quite weak. On the other hand, energy conservation has become a major consideration, and fuel costs are rising rapidly. It is thus hard to predict how things will develop.

Industrial archaeology of refuse destructors and combined stations

It is certain that many refuse destructors were built after 1912, the date at which my list in Appendix 1 closes. It is therefore probable that there were over 500 destructors and over 100 combined destructor/electricity generating stations in Britain. The architecture of these establishments was very varied, according to the tastes of the municipal authorities concerned and, no doubt, also according to the class of district in which they were built. Some were—and are—very handsome buildings, and a good example of one such is that at Nechells, Birmingham, shown in Plate 2. Some small ones, while plain, were attractive in their functional simplicity—an example is that at West Bromwich, in the West Midlands, shown in Plate 3. Some others which were plain look very gaunt, as at Ipswich, Plate 4 (although the generating station and other buildings were handsome, Plate 5), and Malvern, Plate 6. Many of the destructors had office blocks, and these could be interesting too; an example is at Montague Street in Birmingham, Plate 7.

Little information is available on this subject.

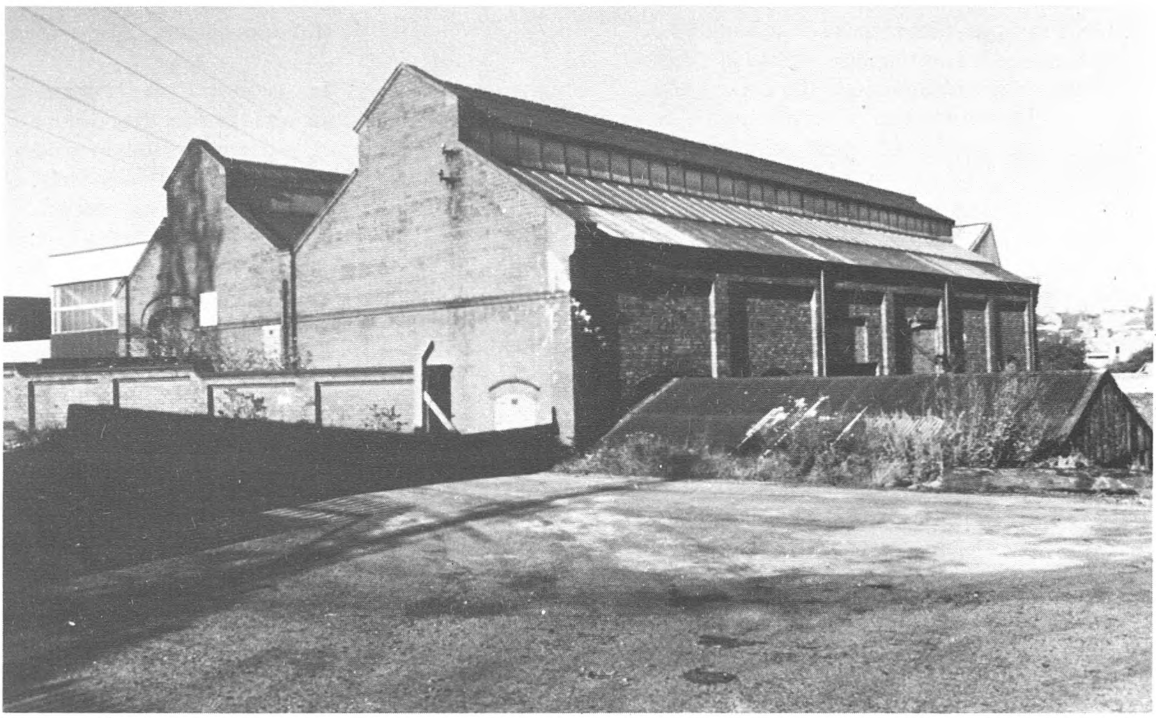


Plate 3 Refuse destructor at West Bromwich, which fed steam to an adjacent electricity-generating station. Refuse carts entered at first-floor level by raised roadway to entrance in left-hand bay. Built 1910.

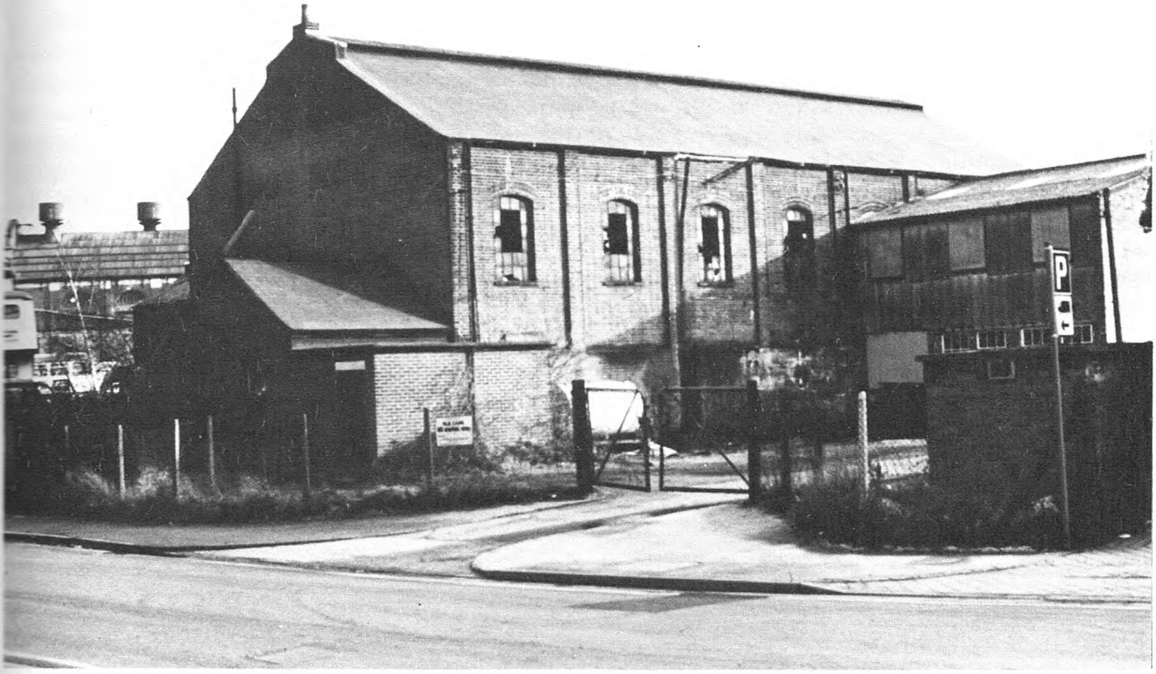


Plate 4 Refuse destructor at Ipswich. Steam was fed by an external steam pipe to the electricity generating station, seen behind on the left. Built 1903.

Plate 5 Ipswich generating station behind the offices of the old Electricity and Tramways Departments, with the old tram sheds in the foreground. With the refuse destructor, which stands well to the right of the tram sheds (see Plate 4), the whole made a very extensive municipal complex. Built 1903.

Books on industrial archaeology rarely mention it. Buchanan[54] does not, while Cossons[55] gives it a fraction of a paragraph; I believe that none of the regional books on industrial archaeology mention it, although John Hume's excellent and more concentrated book on Glasgow[56] lists six pre-1914 destructors still standing. It is indeed remarkably difficult to find the locations of the sites of destructors, as large-scale maps rarely indicate them as such, and the buildings, even if still extant, are often now used for a quite different purpose and are not easily recognized for what they were. Some are now in private hands, but most of the sites remain in public ownership, often being still used by the salvage department or the cleansing department of a local authority. Those which were associated with electricity generation could have passed to the Central Electricity Generating Board, or more usually, to the regional Electricity Board.

In view of these difficulties, I am making a starting point for those wishing to pursue the study, by listing the locations of the pre-1912 sites which I know in Table 2. In Table 3 I have listed the six Glasgow sites given by Hume, in the form in which he describes and locates them; I have been unable to identify three of these sites with those listed by Goodrich[57] in 1912 and there is poor correlation between the dates of erection given by Hume and those given by Goodrich, supported by contemporary articles, etc. Nevertheless, as Hume's locations are definite and unambiguous, they are important and provide a base for further research. Doubtless, industrial archaeologists will also be interested to look at some modern (post-1969) destructors to make comparisons. Table 4 therefore lists a few of these.

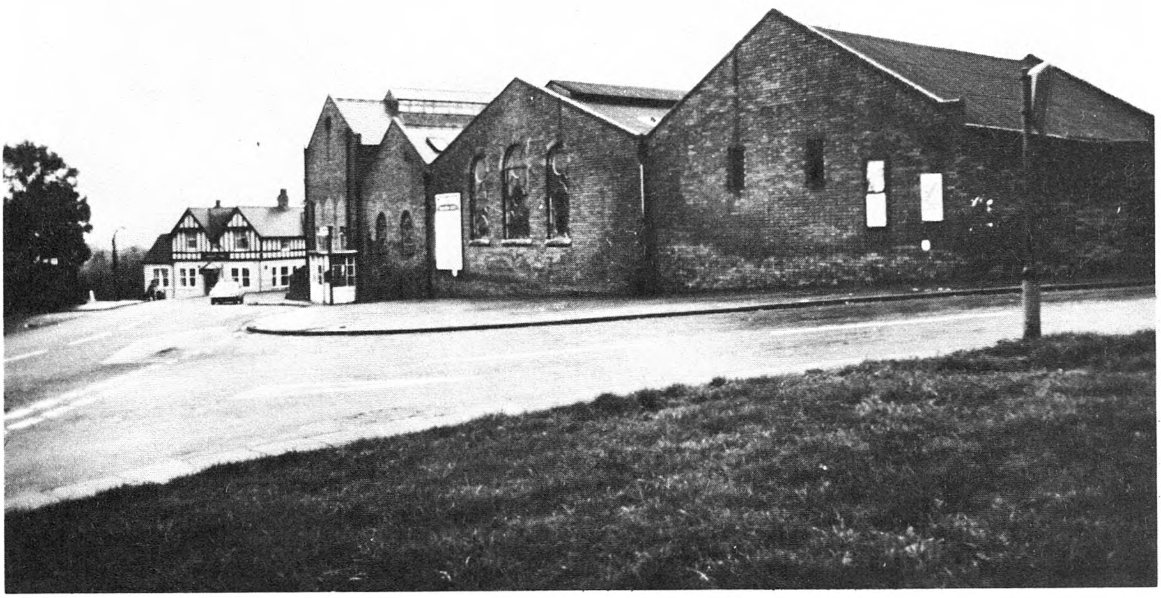


Plate 6 Combined refuse destructor and electricity generating station at Malvern. Built 1904.

Table 2 Some sites of refuse destructors (all pre-1912)

C=combined destructor/electricity station
* not inspected personally by author

Place	*Grid reference*	*Remarks*
West Midlands:		
Birmingham:		
Rotton Park St, Edgbaston	SP048871	Office building carrying date 1903 and more modern buildings still standing, in use by Corporation Salvage Dept.
Piers Rd, Handsworth	SP051893	Probable site; still used as Corporation Depot.
Lifford, Kings Norton	SP057800	Now only modern buildings, still Salvage Dept.
Holliday St	SP064865	Probable site; still Corporation Depot.
Shadwell St	SP070876	Site cleared; now car park.
Montague St	SP082867	Office block carrying date 1883 and other buildings stand, still Salvage Dept.
Montgomery St, Small Heath	SP094852	Destructor cleared, but some old buildings remain; Corporation Depot.
Aston Church Rd, Nechells	SP097892	Building almost intact, private occupation.
Wolverhampton:		
Crown St (C)	SO916999	Old combined station cleared; modern destructor on same site.
West Bromwich:		
Black Lake (C)	SO996926	Destructor building stands, old generating station gone. Still Council Depot.
Redditch:		
Summer St (C)	SP043673	Shell of generating station stands, destructor gone. Still Council Depot.
Malvern:		
Pickersleigh Rd (C)	SO789462	Buildings of combined station still stand, still Council Depot.
Gloucester:		
Ladybellegate St (C)	SO829185	Most of combined station still standing—some in private occupation—refuse destructor closed in 1923.
Cheltenham:		
off Sandfield Rd (C)	SO935233	Site cleared except for weighbridge platform.
London:		
Ealing:		
South Ealing Rd (C)	TQ180787	* No trace of old combined station.
Fulham:		
Townmead (C)	TQ261759	* No trace of old combined station.
St Pancras:		
Pratt St (C)	TQ294840	Only some walls remain.
Shoreditch:		
Coronet St	TQ332828	Buildings of combined station and offices still stand; Council Depot.
Bermondsey:		
behind Town Hall (C)	TQ338793	* No trace of old combined station.
Stepney (C)		
Osborn St, Whitechapel Rd	TQ340815	Buildings of combined station and offices still stand; Council Depot.
Tottenham:		
Park View Road	TQ346901	*
Hackney:		
Millfields Rd (C)	TQ360863	* No trace of old combined station.
Leyton:		
Ruckholt Rd	TQ377862	*
Croydon:		
Albert Rd, South Norwood	TQ351680	Site now levelled rubbish tip; no signs of refuse destructor.
Beckenham:		
Churchfields Rd (C) (formerly Arthur Rd)	TQ361690	Old generating station building remains with other miscellaneous buildings. L.E.B. occupation.
Miscellaneous		
Southampton:		
Chapel Wharf	SU430114	* This is the 1887 destructor.
Weymouth:		
Westwey Road	SY675792	* Buildings of combined destructor and sewage works still stand.

Ipswich:		
Constantine Rd/Portmans Walk (C)	TM154443	Refuse destructor derelict but complete shell; generating station (extended) still standing, tram shed in use as bus depot. Occupiers: Eastern Elect. Bd., C.E.G.B., Council.
Leeds:		
Meanwood Rd	SE295360	* Probable site of 1895 destructor (refuse destructor still shown on modern street map).
Llandudno (C)	SH785814	* Buildings of combined station still stand.
Partick, Glasgow (C)		
Maudslie St, Dumbarton Rd	NS552665	* Presumably same as Hume's ref. L.21 (Table 3).

Table 3 Remaining refuse destructors in Glasgow (all pre-1914)

Hume's Gazetteer Reference	*Address*	*Remarks*
B8	201 Shuna St (Maryhill area)	Destructor now incorporated into Bryant & May's Empire Match Factory.
C77	113 Charles St (Port Dundas)	Destructor and workshops.
E2	16 Haghill Rd (Parkhead area)	Destructor.
H222	55 Kilbirnie St	Refuse disposal works including a destructor.
K8	Gilbert St, Kelvinhaugh	'Refuse disposal works', but Goodrich shows a destructor at Kelvinhaugh erected in 1894.
L21	15 Meadow Rd, Partick	Electricity generating station, incorporating refuse destructor.

Table 4 Some modern refuse destructors

Place	*Grid reference*
Edmonton, London (generates electricity for Grid)	TQ 36 93
Avonmouth	ST 535795
Leamington Spa (Prince's Drive)	SP 309654
Coventry	SP 345778
Castle Bromwich	SP 146905
Coleshill, near Birmingham	SP 193916
Wolverhampton (Crown Street)	SO 916999
Derby (Raynes Way)	SK 384344
Nottingham (Eastcroft) (provides district heating)	SK 580391

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2 F. T. F. Wiggin, *Proc. Inst. Elect. Engrs.* (in press).

3 A. W. Neal, *Refuse Destructors and Separation* (1938).

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7 Goodrich lists thirty-two such overseas installations in 1904. The ubiquity of British destructor designs was still apparent in Europe in 1952; see the O.E.E.C. Report, *Collection and Disposal of Town Refuse* (1953).

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9 According to D. J. Hagerty, J. L. Pavoni and J. E. Heer, *Solid Waste Management* (New York, 1973).

10 'Drying Sewage', *Engineering*, **14** (1872), 261.

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15 W. B. G. Bennett, 'The Southampton Sewage Precipitation Works and Refuse Destructor', ibid., **54** (1892), 395-7; 'Refuse Destructor at Leyton', ibid., **62** (1896), 670-1.

16 C. Jones, *Refuse Destructors* (1894).

17 W. F. Goodrich, *Modern Destructor Practice* (1912), chap. 5.

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28 'The Cheltenham Electricity Works', *Elect. Engr.*, **15** (1895), 553-63 and 566-7.

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30 Mr. G. C. Morgan has searched the Ealing Council minutes and found no reference to combined working after 1895. Moreover, combined working at Ealing is not shown in tables of generating stations after the first year or two.

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54 R. A. Buchanan, *Industrial Archaeology in Britain* (1972).

55 N. Cossons, *Industrial Archaeology* (Newton Abbot, 1975).

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8 'The Cremation of Dust-bin Refuse', ibid., **65** (1898), 179-90, 212-13, 217.

9 'The Horsfall Destructor', ibid., **66** (1898), 200-2.

10 F. L. Watson, 'The Designing and Construction of Refuse Destructors', ibid., **66** (1898), 342-4.

11 'Refuse Destruction', ibid., **67** (1899), 458-9.

12 'Refuse Destruction', ibid., **69** (1900), 653-4.

13 'Combined Destructor Stations', *Electrician*, **63** (1909), 56-7.

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Plate 7 Office building associated with the refuse destructor at Montague Street, Birmingham. Decorated gable with date 1883.

Appendix 1 List of Refuse Destructors in UK in 1912

Those which were associated with electricity generating stations are shown in capitals. Dates shown are dates of erection. Numbers in brackets are the number of separate destructors in the town shown.

ABERDARE (1) 1900
ACCRINGTON (1) 1901
Aldershot (2) 1901 and 1910
Ardrossan (1) 1904
ASHTON UNDER LYNE (1) 1901
Atherton (1) 1901
AYR (1) 1905
BANGOR (1) 1900
BARNSLEY (1) ?
BARROW IN FURNESS (1) 1903
Barry[1] (1) 1901
Basingstoke (1) 1911
Bath (1) 1895
Batley (1) 1887 } two separate destructors
BATLEY (1) 1904 }
Battersea (1) 1888
BECKENHAM (1) 1900
Bedford (1) 1911
Belfast (1) 1901
Bellshill[2] (Lanarks) (1) 1910
Bermondsey (1) 1899 } two separate destructors
BERMONDSEY (1) 1901 }
Birkenhead (2) 1894 and 1896
Birmingham (11) 1877-1905
Blackburn (4) 1882, 1900, 1901, 1902
Blackpool (4) 1891, 1896, 1899, 1902
Blantyre (1) 1910
Bognor (1) 1912
Bolton (4) 1881, 1888, 1901, 1902
Bootle (1) 1894
Bournemouth (3) 1887, 1891, 1911
Bradford (3) 1891, 1897, 1902 } four separate destructors
BRADFORD (1) 1904 }
Brentford (1) 1900
Bridport (1) 1904
Brighton (1) 1896
Bristol (2) 1892 and ?
Bromley (1) 1904
Burnley (1) 1898 } two separate destructors
BURNLEY (1) 1902 }
Burton on Trent (2) 1890 and 1899
Bury (3) 1880, 1897, 1901
BURY ST EDMUNDS (1) 1908
Buxton (1) ? } two separate destructors
BUXTON[3] (1) 1908 }
Cambridge (1) 1899
CAMBUSLANG (1) 1905
CANTERBURY (1) 1901
Cardiff (1) 1907
Chadderton (1) ?
CHELTENHAM[4] (2) 1890 and 1910
Chester (1) 1912
Chesterfield (1) 1901
Chiswick (1) 1904
Chorley (1) ?
CLECKHEATON (1) 1902
Clydebank (1) 1907
COLNE (1) 1899
COVENTRY (1) 1910
Croydon (1) 1905
DARTFORD (1) 1903
DARWEN (1) 1899
Derby (2) 1882 and 1898
Dewsbury (1) 1895
DORKING (1) 1910
Droylsden (1) 1910
Dublin (2) 1894 and 1907
Dudley (1) 1909
Dunoon (1) 1907
EALING[5] (1) 1883
Eastbourne (2) 1890 and 1904
East Ham (1) 1903
Eccles (1) 1904
Edinburgh (2) 1893 and 1897
ELLAND (1) 1903
Epsom (1) 1904
Exmouth (1) 1908
FALMOUTH (1) 1906
FARNWORTH (1) 1909.
Featherstone (1) 1907 (presumably the Featherstone in the West Riding of Yorkshire)
Felixstowe (1) 1907
Felling (1) 1906
Finsbury (3) 1895 and 2 in 1899
Fleetwood (1) 1900 } two separate destructors
FLEETWOOD (1) 1909 }
Folkestone (1) 1904
FULHAM (1) 1901
Gainsborough (1) 1909
Galashiels (1) 1910
Glasgow (7) 1881-1903
GLOUCESTER (1) 1902
Gosport (2) 1905 and 1910
Gourock (1) 1901
Govan (1) 1893
Grantham (1) 1903
GRAVESEND[6] (1) 1903
GRAYS (1) 1901
GREENOCK (1) 1908
GRIMSBY (1) 1903
GUERNSEY[7] (1) 1904
Guildford (1) 1910
HACKNEY (1) 1902
Hampstead (1) 1888
Hampton (1) 1908
Hartlepool (1) 1901
Haslingden (1) 1909
Hastings (1) 1899
Heckmondwike (2) ? and 1900
Hereford (1) 1897
HERTFORD (1) 1910
HESTON & ISLEWORTH (1) 1904
Heywood (1) 1902
Hoddesdon (1) 1910
HOLYHEAD (1) 1905
Hornsey (1) 1889
Huddersfield (2) 1891 and 1898 } three separate destructors
HUDDERSFIELD (1) 1910 }
Hull (2) 1882 and 1902
Hunstanton (1) 1899
Hyde (2) 1893 and 1903
Ilkley (1) 1905
IPSWICH (1) 1903
Jersey (St Helier) (1) 1899
Kensington (1) 1905

KETTERING (1) 1905
Kings Norton (1) 1905
Kingston-on-Thames (1) 1903
Kingstown (1) 1907
LANCASTER (1) 1901
Leamington (1) 1903
Leeds (4) 1876-1906
Leicester (4) 1890-1902
Leigh (1) 1904
Leyton (1) 1898
Littlehampton (1) 1912
LIVERPOOL (5) 1891-1901 } six separate destructors
Liverpool (1) 1893
Liversedge (1) 1900
Llandrindod Wells (1) 1906
LLANDUDNO (1) 1898
Loughborough (1) ?
Lowestoft (1) 1900
Luton (1) 1904
Lytham (1) 1902
MALVERN[8] (1) 1904
Manchester (5) 1876-1904
MANSFIELD (1) 1903
MEXBOROUGH (1) 1902
MIDDLETON (1) 1905
Morecambe (1) 1902
NELSON (1) 1900
Newcastle upon Tyne (4) 1885-1907
Newmarket (1) 1893
Newtown (1) 1911
NORTHAMPTON (1) 1903
Norwich (1) 1898
Nottingham (2) 1882 and 1904 } three separate destructors
NOTTINGHAM (1) 1903
Nuneaton (1) 1901
Oldham[9] (3) 1891-1901
Ormskirk (1) 1910
Ossett (1) 1906
Padiham (1) 1901
Paignton (1) 1909
Paisley (1) 1900
PARTICK (1) 1902
PEMBROKE (DUBLIN) (1) 1900
Plymouth (1) 1901
Pontefract (1) 1906
PONTYPRIDD (1) 1909
Poplar (1) 1898 } two separate destructors
POPLAR (1) 1909
Port Glasgow (1) 1903
Portsmouth (2) 1910 and 1911
Preston (2) 1885, 1892 } three separate destructors
PRESTON (1) 1905
Radcliffe (1) 1902
Ramsgate (1) 1899
RATHMINES (DUBLIN) (1) 1905
Rawtenstall (1) 1902
REDDITCH (1) 1908
Rhondda (1) 1900
RHYL (1) 1902
Rochdale (1) 1894
Rotherham (1) 1892 } two separate destructors
ROTHERHAM (1) 1909
Royton (1) 1893
Rugby (1) 1905
ST ALBANS (1) 1908
St Annes (1) 1900
ST HELENS (1) 1899
St Pancras[10] (1) 1894
Salford (5) 1883-1902
Salisbury (1) 1902
Seaford (1) 1912
Sheerness (1) 1903
Sheffield (2) 1897 and 1903
Shettleston (1) 1907
SHILDON (1) 1905
SHIPLEY (1) 1903
SHOREDITCH (1) 1897
Skegness (1) 1910
Smethwick (1) 1905
Southampton (3) 1887, 1901, and 1910
Southgate (1) 1909
Southport (2) 1901 and 1905
Sowerby Bridge (1) 1910
Stafford (1) 1898
Stalybridge (1) 1906
STEPNEY (1) 1900
Stockton-on-Tees (1) 1901
STOKE NEWINGTON (1) 1907
Stoke-on-Trent (3) ? } five separate destructors
STOKE-ON-TRENT (2)[11]
Stourbridge (1) 1904
Stratford and Wolverton (1) 1906
Stretford (1) 1901
Stroud (1) 1912
Sudbury (1) 1903
Surbiton (1) 1912
SWANSEA (1) 1904
Swinton and Pendlebury (1) 1912
Taunton (1) 1903
TODMORDEN (1) 1905
Torquay (1) 1899
Tottenham (1) 1903
Tredegar (1) 1908
Troon (1) 1911
Twickenham (1) 1907
Uddingston (1) 1898
WAKEFIELD[12] (1) 1903
Wallasey (2) 1896 and 1910
Walthamstow (1) 1905
Wandsworth (1) 1899
Warrington (2) ? and 1896 } three separate destructors
WARRINGTON (1) 1901
Watford (1) 1904
West Bridgford (1) 1903
WEST BROMWICH (1) 1910
West Hartlepool (1) 1901
Westminster (1) 1900
Weymouth (1) 1903
WIMBLEDON[13] (1) 1899 } two separate destructors
Wimbledon[13] (1) 1909
Winchester (2) ? and 1907
Windsor (1) 1904
WOLVERHAMPTON (1) 1904
Wood Green (1) 1908
Woolwich (1) 1893 } two separate destructors
WOOLWICH (1) 1903
Worthing (1) 1905
WREXHAM (1) 1900
Yarmouth (1) 1902
Yeovil (1) 1911
YORK (1) 1898

References

1 Entered as Bary by Goodrich, but no place of this spelling known.

2 Presumed to be the Bellshill in Lanarkshire.

3 Not shown as combined station by Goodrich, but in *Electrician* list for 1910.

4 The earlier destructor at Cheltenham had evidently ceased to be used in conjunction with the generating station by 1912 as Goodrich shows it to provide power only for works purposes.

5 Combined working at Ealing started 1894 and later discontinued.

6 Not shown as combined station by Goodrich 1912.

7 Goodrich shows Guernsey Railway Co as operating a combined station in 1912 in his Table 4, but does not show combined working in his Table 10.

8 Goodrich 1912 does not show destructor at Malvern; existence proved by other references.

9 Combined working at Oldham in 1890s (see text).

10 Originally designed for combined working (see text).

11 Combined stations at Stoke (Central) and Burslem.

12 Shown as 2 destructors in Goodrich's Table 10 with no indication of combined working, but as one combined station in his Table 4 and in *Electrician* tables.

13 Neither destructor at Wimbledon was shown as a combined station by Goodrich 1912.

Appendix 2 The Handling of Refuse at the Shoreditch Combined Station

(N.B. Many refuse destructors used top-fed furnaces, and the methods used to get the refuse to first-floor level were varied; some destructors were built against a bank so that dust-carts could enter directly to the first floor—West Bromwich is an example of this. Others had a ramp up to first-floor level—Nechells and Llandudno are examples. Shoreditch unloaded the carts on the ground floor; the subsequent procedure is vividly described in the following extract from a letter to the author from Mr R. H. Rawll.)

During the period I was the borough electrical engineer and manager at Shoreditch prior to nationalization of the electricity supply industry, although the borough surveyor was responsible for collecting the refuse in the borough, it was unfortunately my responsibility to burn it in the old refuse destructor in Coronet Street, the steam raised from which was still passed directly to the adjoining Pitfield Street Public Baths. The original handling plant was still utilized and was of a most primitive character. On elevating the refuse to the top of the boilers, it was there transferred to skips running on rails over the various manholes through which it was discharged into the various furnaces below. Each skip was propelled by a direct-current motor, which was connected to two external bare metal 'horns'. The operator had two flexible conductors, supplied from an overhead trolley system, which he plugged on to the horns in order to move the skip. You can imagine the arc when he withdrew the plugs on stopping the skip! This extraordinary arrangement was often adversely criticized by the Factory Inspector, but apparently he had no jurisdiction over this, because legally it was not a 'manufacturing process'.