The Capacity and Principal Dimensions of Refuse Storage Bunkers in Modern Incineration Plant

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INTRODUCTION

The authors have been aware of a lack of a consensus of opinion upon design parameters appropriate for refuse storage bunkers. Decisions on bunker size in the many plants which have been constructed in recent years would seem to have been made on the personal and subjective opinion of the designer.

It was felt that it would be useful to collect and collate information from a broad sample of plants completed over the last ten years, and the collated information might indicate some general rules which were arising fortuitously from the various subjective solutions. A questionnaire related to various factors associated with refuse bunkers was sent to 130 plant operators throughout the world. A very satisfactory response was achieved and information has been made available concerning 89 plants. A good response was obtained from Australia, Austria, Brazil, Canada, Denmark, Finland, France, Germany, Norway, Sweden, Switzerland, the United Kingdom and the United States. Some information was forthcoming from Japan, but, regrettably, no replies were received from those approached in Hong Kong, Thailand or the U.S.S.R.

The information provided for the questionnaire is very extensive and, after full collation, could serve as the basis of a number of papers on the design of bunkers and associated facilities. This paper assesses the information which is given on the more fundamental design aspects.

FUNCTION OF THE REFUSE BUNKER

As a first step, we should perhaps define what we mean by a “refuse bunker.” It is taken to mean a containing structure for the storage of untreated, or partially treated, refuse. It is the point at which the refuse is received and discharged from the transportation and where it is held prior to introduction into the incinerator furnaces. It acts as an inertial device to equalize the competing requirements of a random and irregular delivery of refuse and the steady feeding rate demanded by the incinerator furnace. The availability of storage capacity provides a safeguarding time period for the collection system in the event of mechanical breakdown of the furnace equipment. The available storage provides a buffer to allow repairs to be carried out and delaying the time when diversion to another point of disposal becomes necessary. The bunker also provides the storage necessary to allow combustion of refuse to be carried on over a 6 or 7 day working week when the delivery of refuse is limited to 5 days in each week.

The bunker may be said to play two roles:
1. It protects the refuse incineration plant against interruption of combustion, due to shortage of refuse fuel.
2. It protects the refuse collection service from disruption, due to short-term mechanical faults in the incinerator plant.

The first role will be the dominant concern of the designer of plants where heat recovery relates to a heat or power export scheme. The contractual obligations of plant operators in such installations in respect of heat or power supply to their clients will emphasise the need for substantial storage capacity in order that the heat supply may be more satisfactorily guaranteed against interruptions in the refuse delivery service. Storage requirements for this role would appear to be more easily quantified than for the second role.
Designers who are not concerned with heat export will be likely to give more weight to the second role and will be more concerned with the speedy and convenient discharge of transportation and in preventing delays and inconvenience to the collection service. The nature of collection services is very diverse and hence there is greater difficulty in establishing any pattern in the quantifying of storage requirements for such installations.

The questionnaires suggest that the selection of dominant role is a matter of national or regional philosophy, as related to solid waste disposal.

**PRINCIPAL FEATURES OF REFUSE BUNKERS**

The questionnaires reveal that, with a very few exceptions, the approach to bunker design is generally similar throughout the world. They consist of a rectangular concrete box, all or partially below ground level, with a superstructure supporting the furnace feed chutes and, above them, the refuse grabbing cranes, which transfer the refuse from the lower storage area to the feed chute.

There are doors or tipping openings along one long side at tipping level. Refuse tipped from vehicles falls into the lower part of the bunker, from where it may be lifted directly to the furnaces, or may be restacked in the part of the bunker not immediately adjacent to the tipping face. A typical bunker cross section is shown in Fig. 1.

Bunkers may be sectionalized or compartmented on plan and are, in some cases, provided with facilities for the pre-treatment and size reduction of bulky objects. The furnace feed chutes are usually located immediately opposite the tipping beam but are, in some instances, located on the short side of the bunker.

**STORAGE CAPACITY OF BUNKER**

For the purpose of this study, two filling conditions for bunkers have been considered —

1. A lower filling condition, which is that condition applying when the bunker is filled to the level of the tipping beam throughout its whole area. This gives a contained value of

   \[ 1 \times w \times d_1 \text{ cubic metres} \]

2. A maximum filling condition where the bunker is filled beyond the condition 1 by the stacking of refuse in parts of the bunker up to furnace feed chute level but in such a manner as to keep at least 50 percent of the tipping positions still in operation.

   This condition gives a contained value of —

   \[ 1 \times w \times (d_2 - d_1) + \frac{1 \times w \times (d_2 - d_1)}{2} \text{ cubic metres} \]

From the information contained within the questionnaires, the contained value of refuse for both filling conditions has been calculated for every plant in the sample.

**BUNKER STORAGE CAPACITY RELATED TO FURNACE BURNING CAPACITY**

As a further step, each of the bunker capacities has been divided by the rated burning capacity of the furnaces within the plant. This has resulted in two coefficients for each plant examined.

- **Coefficient A** relating storage capacity to tipping level with furnace capacity.
- **Coefficient B** relating maximum storage capacity with furnace capacity.

The coefficients for the plants are shown diagrammatically in Figs. 2A and 2B, and Fig. 2C is a histogram showing the distribution of values for coefficient A. It will be seen that there is a degree of consistency for stored volumes of refuse in particular geographic regions.
UNITED KINGDOM

REFUSE STORAGE BUNKER VOLUME TO TIPPING LEVEL
EXPRESSED AS M3 INSTALLED TONNAGE

HIGHEST FREQUENCY 90 - 150 m3/tonne

FIG. 2A(ii)
CONTINENTAL AMERICA
AUSTRALIA & JAPAN

REFUSE STORAGE BUNKER
VOLUME TO TIPPING LEVEL
EXPRESSED AS M$^3$ INSTALLED TONNAGE

FIG. 2A(ii)

HIGHEST FREQUENCY 100-120 m$^3$/tonne
GERMANY, AUSTRIA, SWITZERLAND & FRANCE

REFUSE STORE BUNKER VOLUME TO TIPPING LEVEL EXPRESSED AS M³/INSTALLED TONNAGE

HIGHEST FREQUENCY 120-140 m³/tonne

FIG. 2A(iii)
SCANDANAVIA

REFUSE STORAGE
BUNKER VOLUME TO TIPPING LEVEL
EXPRESSED AS % INSTALLED TONNAGE

HIGHEST FREQUENCY 120-140 m³/tonne

225 m³/tonne

177 m³/tonne

(DESCENDING EXTREME READINGS)

FIG. 2A(iv)
UNITED KINGDOM

PRACTICAL MAXIMUM STORAGE VOLUME
VOLUME TO TIPPING LEVEL + 50% OF
SURCHARGE VOLUME
EXPRESSED AS m³ INSTALLED TONNAGE

HIGHEST FREQUENCY 160-180 m³/tonne

FIG. 280
PRACTICAL MAXIMUM STORAGE VOLUME
VOLUME TO TIPPING LEVEL -50% OF
SURCHARGE VOLUME
EXPRESSED AS M$^3$/INSTALLED TONNAGE
HIGHEST FREQUENCY 160-180 M$^3$/Tonne

FIG. 2B(ii)
FIG. 2B(iii)

GERMANY, AUSTRIA, SWITZERLAND & FRANCE

REFUSE STORAGE MAXIMUM PRACTICAL
STORAGE VOLUME
(VOLUME TO TIPPING LEVEL + 50% OF SURCHARGE VOLUME)
EXPRESSED AS M³ INSTALLED TONNAGE

HIGHEST FREQUENCY 180-200 M³/TONNE

271 M³/TONNE
DISREGARDING EXTREME SAMPLES

308 M³/TONNE

GERMANY
AUSTRIA
SWITZERLAND
FRANCE
SCANDANAVIA
PRACTICAL MAXIMUM STORAGE VOLUME
VOLUME TO TIPPING LEVEL + 50% OF
VOLUME BETWEEN TIPPING LEVEL &
FURNACE FEED HOPPERS
EXPRESSED AS M³/INSTALLED TONNAGE

HIGHEST FREQUENCY 200-250 M³/tonne

350 M³/tonne

295 M³/tonne

(DISSREGARDING EXTREME
SAMPLE 0)

FIG. 2B(iv)
FIG. 2C(ii)

HIGHEST FREQUENCY OF REFUSE STORAGE TO TIPPING LEVEL 100-120 m³/tonne
EQUIVALENT TO 25-30 HRS @ 250 kg/m³
OR 20-24 HRS @ 200 kg/m³
REST OF THE SAMPLE (excluding the UK)

FREQUENCY DIAGRAM OF REFUSE STORAGE TO TIPPING LEVEL EXPRESSED AS M³/TONNE OF INSTALLED CAPACITY.

- HIGHEST FREQUENCY OF REFUSE STORAGE TO TIPPING LEVEL - 100 – 140 M³/Tonne
- EQUIVALENT TO: 25 – 35 hrs @ 250 kg/m³
  20 – 28 hrs @ 200 kg/m³

FIG. 2C(ii)
Mean figures, disregarding exceptional cases, are as follow:

<table>
<thead>
<tr>
<th>Country</th>
<th>Coefficient A</th>
<th>Coefficient B</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>126</td>
<td>215</td>
</tr>
<tr>
<td>Continental America, Australia &amp; Japan</td>
<td>145</td>
<td>214</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>180</td>
<td>280</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>177</td>
<td>295</td>
</tr>
</tbody>
</table>

(coefficients express cu. metres of bunker storage per installed hourly tonne of furnace capacity).

The consistency of results, as between United Kingdom, United States, Canada, etc., can be attributed to the relatively low number of heat recovery plants in those areas. Continental Europe and Scandinavia, with almost universal heat recovery, are again consistent, but at a higher level.

DENSITY OF REFUSE AND STORED TONNAGE

The information given in the questionnaires on refuse density was found to be unreliable and, for the purpose of further analysis, certain arbitrary assumptions have been made. Experimental work carried out by the Greater London Council, on compaction of refuse in bunkers, has produced a curve for density, which is shown in Fig. 3. For the bunker depths, which are general through the sample, it can be assumed that the average density of refuse in store in the bunkers will be in the range of 200-250 kg/m³.

Figure 4 shows the conversion of volumetric measurement to tonnes stored per tonne of furnace capacity. This factor is a direct indication of the number of hours which the furnace can operate for the given stored volume.

The mean figures, by geographic locations, are as follow:

1. If average density is 250 kg/m³.

<table>
<thead>
<tr>
<th>Equivalent Furnace Running Hours</th>
<th>(a) Storage to Tipping Level</th>
<th>(b) Maximum Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>31</td>
<td>54</td>
</tr>
<tr>
<td>Continental America, Australia &amp; Japan</td>
<td>36</td>
<td>54</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>44</td>
<td>74</td>
</tr>
</tbody>
</table>
EXPERIMENTAL REFUSE COMPACTION CURVES
DERIVED BY GREATER LONDON COUNCIL

EXPERIMENTAL CONSTANTS
Refuse density tipped from vehicles — 220 kg/m³
Refuse density prior to depositing into vehicles — 170 kg/m³
Test Duration — 21 days

CURVE A — INDICATES VARIATION OF REFUSE DENSITY WITH REFUSE DEPTH
CURVE B — INDICATES THE AVERAGE DENSITY OF REFUSE

FIG. 3
2. If average density is 200 kg/m³.

<table>
<thead>
<tr>
<th>Region</th>
<th>Storage Burner Capacity</th>
<th>Maximum Storage Burner Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>Continental America,</td>
<td>29</td>
<td>43</td>
</tr>
<tr>
<td>Australia &amp; Japan</td>
<td>35</td>
<td>59</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>25</td>
<td>43</td>
</tr>
</tbody>
</table>

The analysis indicates that, in the plants which have been considered, designers have provided storage bunkers which provide for storage to tipping level of 25-36 hours burning capacity in non-heat recovery areas and of 35-45 hours in heat recovery zones. The equivalent figures related to maximum refuse storage capacity are 43-54 hours in non-heat recovery zones and 56-74 hours in heat recovery regions.

The coefficients of storage volume, tonnage and hourly burning capacity have been derived on the basis of the installed incinerator capacity of plant. This has been done to allow a common basis of comparison. However, in multi-stream plant of 'n' streams the disposal function can in many cases be satisfactorily conducted by a lower number of furnaces in operation, commonly 'n-1' streams. Under these conditions a more generous situation applies and all the coefficients and derived constants can be uprated by the factor $\frac{n}{n-1}$.

**BUNKER STORAGE CAPACITY RELATED TO LIKELY DAILY REFUSE DELIVERIES**

As was stated in a previous section, one purpose of the bunker is to even out the irregular delivery of refuse and allow the constant burning rate furnaces to operate in their designed manner. It is not possible, of course, for the furnace or furnaces to operate at this rating for every hour throughout the year. It will be closed down at various times for maintenance, repair, breakdown or other reasons. The total availability of operable furnaces will be influenced by the number of separate operating streams within a given plant. It may, therefore, be said that a given plant will have a maximum practical annual capacity less than its theoretical maximum capacity, and it is felt that the following factors will be appropriate to show the proportion of theoretical maximum which is practically possible:

- One Stream Plant ............ 65%
- Two Stream Plant ............ 80%
- Three Stream Plant .......... 85%
- Four Stream Plant .......... 90%
Plate 4 Typical Photographic Section of Refuse Bunker and Tipping Doors in Medium Sized Plant.
(Winterthur, Switzerland)

Comparative Refuse Tonnages & Burning Hours per Tonne of Installed Furnace Capacity.

Fig. 4

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These factors have been applied to all of the plants with the sample and a maximum practical annual capacity obtained. It was found that very few plants were being asked to accept a throughput as high as this calculated figure. However, it is not unreasonable to assume that they might one day be asked to do so and, hence, to examine bunker storage capacity in terms related to the daily refuse deliveries which would be necessary to achieve such a level of utilization.

For the purpose of the study it has been assumed that the tonnage required for maximum practical capacity would be delivered to the plant in the course of 250 working days in any year and, hence, a theoretical maximum daily delivery has been calculated. Each bunker storage capacity has been examined against this theoretical delivery rate and storage capacity expressed in terms of “collection days of storage” for both capacity to tipping level and maximum capacity. These assessments are shown diagrammatically in Figs. 5A and 5B.

Differences are again apparent on a geographical basis, the mean storage available being as follows:

<table>
<thead>
<tr>
<th>Region</th>
<th>To Tipping Level</th>
<th>Maximum Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>1.30 days</td>
<td>2.21 days</td>
</tr>
<tr>
<td>Continental America,</td>
<td>1.32 days</td>
<td>2.00 days</td>
</tr>
<tr>
<td>Australia &amp; Japan</td>
<td>1.85 days</td>
<td>2.73 days</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>1.74 days</td>
<td>3.30 days</td>
</tr>
<tr>
<td>Scandinavia</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The evidence again confirms that storage in plants in areas with a heat recovery philosophy have greater storage capacity. The extent of divergence between areas of heat recovery and nonheat recovery is greater by this method of analysis and is felt to be more accurately expressed when measured, as in this analysis, against practical burning capacity of the plant, rather than against theoretical maximum burning capacity.
CONTINENTAL AMERICA

JAPAN, AUSTRALIA

BUNKER STORAGE TO TIPPING LEVEL
EXPRESSED IN TERMS OF
COLLECTION HOURS

ASSUMED REFUSE DENSITY
200 kg/m²

HIGHEST FREQUENCY
18 - 22 hours

24 HOURS MEAN
(IGNORING EXTREME SAMPLES)

FIG. 5A(ii)
GERMANY, AUSTRIA, SWITZERLAND & FRANCE
Bunker storage to Topping Level expressed in terms of collection hours.

ASSUMED METHOD
Density: 2256 kg/m³

HIGHEST FREQUENCY
15-31 hours

33 hours mean

30 descending extreme samples

FIG. 5A(iii)
SCANDINAVIA
BUNKER STORAGE TO TIPPEr LEVEL
EXPRESSED IN TERMS OF COLLECTION
HOURS.

FIG. 5A(iv)
UNITED KINGDOM
MAXIMUM BUNKER STORAGE EXPRESSED
IN TERMS OF COLLECTION HOURS

ASSUMED REFUSE DENSITY
250 kg/m³

HIGHEST FREQUENCY 48-52 HOURS

WEAK 55 HOURS
○ DISCARDING EXTREME SAMPLE

FIG. 5B(i)
CONTINENTAL AMERICA, AUSTRALIA & JAPAN

MAXIMUM BUNKER STORAGE EXPRESSED IN TERMS OF COLLECTION HOURS.

HIGHEST FREQUENCY
5.5 - 6.0 hours

FIG. 5B(ii)
MAXIMUM BUNKER STORAGE EXPRESSED
IN TERMS OF COLLECTION HOURS

FIG. 5B(iii)
FIG. 5B(iv)
FUTURE TRENDS IN BUNKER SIZING

It is only in the replies received from the United Kingdom, where an almost complete sample of plants built in recent years could be obtained, that it is possible to see any trends in the sizing of bunkers. Figure 6 shows the storage capacity provided in U.K. plants set out in date order of completion of the plant. It will be seen that, before mid 1972, plants were, in almost every case, restricted to a maximum storage capacity of two days' refuse. The mean storage capacity for 16 of the first 18 plants to be completed was 1.75 days. Plants completed since mid 1972 have an average storage of 3.01 days.

The earliest U.K. plants were designed in 1966 and 1967 and were strongly influenced by the financial implications of the change from low cost land fill disposal to the relatively high cost incineration method. The popular concern with environmental matters had then only just begun and no public support could be expected for better disposal methods per se. Hence, every effort was made to restrict capital and operating costs of plants to the minimum. One method of saving was restriction of the bunker size, and this was widely done.

Within a few months of commissioning of these early plants, it began to be apparent that such limitations represented a false economy. By late 1970 and 1971 designers had been able to secure approval of the additional expenditures that would be necessary to create greater storage and plants designed at that time came to completion after mid 1972. It is the view of the authors that a bunker of 3 days' storage capacity is about the right size for plants where no special considerations apply.

DEPTH OF BUNKERS

When refuse is delivered to a plant, it is usually deposited by backing the containing vehicle to the tipping beam and discharging by gravity into the vacant space in the bunker below. The tipped refuse will fall into a heap against the side of the bunker and will assume an angle of repose appropriate to the nature of the material tipped. No information is available upon the angles of repose which will obtain and, for the purpose of this study, it has been arbitrarily assumed to be 60° to the horizontal plane. It will be readily seen that the quantity of refuse which can be accommodated will vary with the square of the depth of the bunker. The volume of storage, available in a 1m length of bunker, for varying depths, has been shown in Fig. 7.

As soon as the volume within the angle of repose has been tipped to tipping beam level, it will be impossible to place further material until that previously placed has been transferred by the grab to another part of the bunker. The sample has been analyzed to determine what percentage of the theoretical maximum refuse delivery can be received into an empty bunker before the point is reached where all storage on the tipping face is filled and no more refuse could be received until material was transferred to another part of the bunker. The figures are:

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean Value</th>
<th>Most Common Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>27%</td>
<td>30%</td>
</tr>
<tr>
<td>Continental America, Australia &amp; Japan</td>
<td>33%</td>
<td>25%</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>48%</td>
<td>40%</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>47%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Clearly the greater proportion of daily maximum delivery which could be received without re-handling the better and it is, therefore, a generally desirable criteria that the depth of the bunker below tipping beam should be as great as other considerations will allow.

PLATE 6 REFUSE BUNKER IN LARGE PLANT SHOWING INTERNAL DIMENSIONS.
(BASEL, SWITZERLAND)
The sample reveals the following average bunker depths, which have been adopted by geographic distribution.

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>(a) Mean Depth</th>
<th>(b) Most Common Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>8.0m</td>
<td>6.0 - 7.0m</td>
</tr>
<tr>
<td>Continental America,</td>
<td>9.5m</td>
<td>8.5 - 9.5m</td>
</tr>
<tr>
<td>Australia &amp; Japan</td>
<td>10.0m</td>
<td>8.0 - 9.0m</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>9.5m</td>
<td>6.5 - 7.5m</td>
</tr>
</tbody>
</table>

**WIDTH OF BUNKERS**

There seems to be no consistent relationship between the depth and width of bunkers. In the sample, width is a very consistent feature, with very few bunkers more than 10 metres, or less than 7 metres, in width. The sample information, divided on a geographic basis, is as follows:

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>(a) Mean Width</th>
<th>(b) Most Common Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>8.3m</td>
<td>7 - 8m</td>
</tr>
<tr>
<td>Continental America,</td>
<td>9.5m</td>
<td>9 - 10m</td>
</tr>
<tr>
<td>Australia &amp; Japan</td>
<td>8.5m</td>
<td>9 - 10m</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>9.0m</td>
<td>8 - 9m</td>
</tr>
<tr>
<td>Scandinavia</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

While bunker width appears to have been arbitrarily selected, the authors feel that there is much to be said for the use of narrow, deep, configurations. If the width were to be only 1.5 or 2 times the fully open dimension of the refuse handling grab, this would be advantageous in reducing bunker trimming and re-positioning activities. Other considerations will militate against such a course but it is felt that the selection of a minimum bunker width consistent with these other considerations should be the aim.
LENGTH OF BUNKERS

There is no consistency and no pattern revealed in the lengths of bunkers, as revealed by the sample. It would seem that the length may be determined by any of the following factors:

(a) The residual dimension needed to produce a given stored volume where width and depth have been determined.

(b) The number of tipping positions which are needed to allow discharge of collection vehicles at peak periods.

(c) The configuration of equipment within the furnace hall constructed on one face of the bunker building.

The length of the bunker will, to some extent, determine the number of tipping positions which can be provided into the bunker. The sample provides useful information in this aspect, as follows:

<table>
<thead>
<tr>
<th>No. of Tipping Positions Provided</th>
<th>(a) Mean No.</th>
<th>(b) Most Common No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants up to 10t/hr.</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Plants up to 10 - 20t/hr.</td>
<td>7</td>
<td>8 - 9</td>
</tr>
<tr>
<td>20 - 30t/hr.</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Over 30t/hr.</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Continental America, Japan, Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants up to 10t/hr.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10 - 20t/hr.</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>20 - 30t/hr.</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Over 30t/hr.</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Continental Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants up to 10t/hr.</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>10 - 20t/hr.</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Over 30t/hr.</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Scandinavia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants up to 10t/hr.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10 - 20t/hr.</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>20 - 30t/hr.</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Over 30t/hr.</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

OTHER MATTERS REVEALED BY SURVEY

As was stated in the introduction to this paper, the information revealed by the questionnaire was very extensive and cannot be fully examined in one paper. There are, however, a number of points which can be briefly mentioned, although they may be more fully developed at some later date.

1) Vehicle Manoeuvring Area

It is usual to provide either an enclosed tipping hall or a canopy over the area from which the collecting vehicles tip refuse into the bunker. 50 of the plants in the sample had tipping halls, while 39 were provided with a canopy. Canopies are more usual in Continental Europe, United States and Japan, and enclosed tipping halls were usual in United Kingdom and Scandinavia.

2) Bunker Division

It is found that there has been a limited tendency in some geographic areas to provide compartmented bunkers. This has been done to allow separation of differing types of refuse, or to facilitate bunker cleansing or to limit fire hazard. It is a feature found in United Kingdom and Scandinavian plants but very rarely provided elsewhere. The number of compartments varies between 2 and 4 and enquiries made of some plant operators with such divided bunkers indicate that they do not have the
GRAPH OF EFFECTIVE STORAGE VOLUME ON BUNKER FRONT FACE IN RELATION TO BUNKER DEPTH (per M length of bunker)

FIG. 7

80
advantages hoped for. They have the major disadvantage of increasing accidental damage to crane grabs. In general it would seem that the division of any but the largest bunkers is not advisable.

3) Internal Angles and Drainage

It is usual for the internal angles at the bottom and sides of concrete bunkers to be splayed or radiused to make the removal of tipped refuse by grab more convenient and prevent dead areas where refuse might lie undisturbed by the grab. In plants constructed in the United Kingdom, United States, Japan, etc. it has been usual to provide some means of drainage from the base of refuse bunkers. In Continental Europe and Scandinavia such a facility is unusual.

4) Position of Furnace Feed Hoppers

The location of furnace feed hoppers within the bunker is predominantly that shown in Fig. 8A, lying directly opposite the tipping face. A proportion of smaller plants, particularly single stream plants do, however, have a different configuration. With only limited exceptions, the only alternative is that shown in Fig. 8B.

The proportion of plants within the sample adopting these configurations is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Configuration A</th>
<th>Configuration B</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Continental America, Australia, Japan</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>

5) Tipping Positions

It is most usual to arrange that delivery vehicles tip over the tipping beam directly into the bunker with the face of the bunker falling vertically below the tipping position. Some experiments have been carried out using an angled face beneath the tipping part. This would appear to have been done

(a) in order that the collection vehicle does not project into the bunker while tipping is in process avoiding possible damage to the vehicle by the crane grab
(b) in order that hinged doors would not, when open, project into the bunker and again be at hazard from the crane grab.

These experiments have, almost without exception, led to difficulties since the refuse has accumulated on the sloping surface which, since it is not beneath the crane path, cannot be easily cleansed of the adhering material. It would appear that the sloping tipping point, while excellent in concept, is subject to such practical difficulties that a vertical face is to be preferred.

The sample indicates the following incidence of these tipping arrangements.

<table>
<thead>
<tr>
<th></th>
<th>Vertical Face</th>
<th>Angled Face</th>
<th>Most Usual Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>28</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>Continental America, Canada, Japan, Australia, Brazil</td>
<td>18</td>
<td>3</td>
<td>35°</td>
</tr>
<tr>
<td>Continental Europe</td>
<td>19</td>
<td>7</td>
<td>50°</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>9</td>
<td>7</td>
<td>45°</td>
</tr>
</tbody>
</table>

A limited number of plants have adopted sophisticated mechanical feeding systems for the delivery into the bunker of refuse tipped into an external hopper. Notable examples are Paris (Ivry) and Dusseldorf. As far as is known, these systems work satisfactorily but are, of course, costly.

The provision of steel doors between tipping area and bunker is almost universal in the United Kingdom, Continental Europe and Japan, but is not done in the United States.

6) Bulky Waste Reduction Facilities

There is evidence of an increasing tendency to provide, particularly in larger plants, equipment for the reduction of particle sizes of large items of refuse delivered to the plant. Such equipment is for the purpose only of reducing to pieces which can conveniently be fed to the furnaces without likelihood of blockage. They do not serve to fragmentize to very small proportions such as would be required for experimental "combustion in suspension" systems. Three types of equipment are used in Europe for this purpose –

(a) The ‘scissor’ type shear
(b) The guillotine shear
(c) The rotary hammer mill

7) Refuse Grabbing Cranes

The survey has shown that the use of cranes with grab is the almost universal method of transfer of refuse from bunker to furnace. In multi-stream plants it is almost invariable to provide duplicated cranes, but in some smaller single stream plants only one crane may be provided.

It is becoming general practice in the whole of Europe to provide a separate control position remote from the crane and located at high level in the upper bunker. In the United States it remains current practice to operate cranes from a control position located upon the crane itself. Refuse grabs are of diverse type and the equipment chosen would seem to be largely a matter of national or regional preference. Thus, Swiss plants are almost all provided with four-rope clamshells, German and French plants incorporate a large number of four-rope polyps, while Scandinavian plants largely employ electrohydraulic polyps. The United States has mainly rope operated grapples, while the United Kingdom has examples of almost every type. The measurement of grab load weights during the furnace feeding cycle, by load cell or current transformer, is provided in only a minority of plants, but the authors welcome evidence that the number of plants so equipped is increasing.

8) Furnace Air Supply

It is almost universal to draw the furnace air from the bunker area, thereby creating negative pressure conditions and reducing the escape of dust and odours from the bunker area and from the plant generally. The evidence, suggests that the extraction points for this air are better located at high level in the bunker. Where they have been provided at low level considerable difficulty has been experienced due to blockage by flying paper and other light debris. In a limited number of United Kingdom plants a supplementary dust extraction system has been provided in order that dust may continue to be removed at times when the furnaces are not in operation. This can be considered an unusual facility.

9) Fire Fighting Equipment

The obvious fire hazard which must be present in a storage bunker for material such as refuse leads to a need for permanent fire detection and fighting equipment. No information was gathered in the survey regarding this aspect but supplementary enquiries suggest that this aspect is now receiving much greater attention than in earlier plants. The provision of efficient and safe fire protection systems in refuse bunkers must be considered as essential.

CONCLUSIONS

The nature of this paper is not such as to lead to conclusions. It is hoped that the assembly of information and its collation will be useful to designers, in allowing them to compare their own proposals with those of other workers in the same field and thereby to check some of their assumptions. The authors feel that it is essential that refuse bunkers should be sized in a manner which
allows both the incinerator plant and the refuse collection service to work at its maximum efficiency and that limitation of bunker size below the optimum is usually a false economy.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mr. N. Rayman, City Engineer and Surveyor, Coventry, for his assistance and advice in the preparation of this paper, and for the facilities made available for the collection and collation of the information. Also, they wish to express their appreciation to Mothwell Bridge Tacol, Ltd. of Croydon, England and Von Roll AG, Zurich, Switzerland for making available photographs used to illustrate the test.

They would further wish to thank all those plant operators who made the survey possible. A list of those plants which are included in the survey is given in Appendix 1.

REFERENCES


UNITS

This paper has been written in metric units, in accordance with current European practice. Refuse Densities have been expressed in tonnes/cubic metre ($t/m^3$) and refuse volume in cubic metres ($m^3$). For the purposes of this paper the following conversions will be satisfactory to accord with U.S. practice:

- U.S. ton/cubic yard = 0.7 tonnes/$m^3$.
- Cubic yard = 0.77 $m^3$. 

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## APPENDIX I

### PARTICIPANTS IN THE SURVEY

<table>
<thead>
<tr>
<th>United Kingdom</th>
<th>Rating</th>
<th>Manufacturer</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>2 x 15</td>
<td>Motherwell Br.</td>
<td>1972</td>
</tr>
<tr>
<td>Bolton</td>
<td>1 x 16</td>
<td>Heenan</td>
<td>1971</td>
</tr>
<tr>
<td>Blackburn</td>
<td>1 x 12</td>
<td>Heenan</td>
<td>1972</td>
</tr>
<tr>
<td>Exeter</td>
<td>1 x 8</td>
<td>Head Wrightson</td>
<td>1970</td>
</tr>
<tr>
<td>Gateshead</td>
<td>2 x 10</td>
<td>International</td>
<td>1973</td>
</tr>
<tr>
<td>Sunderland</td>
<td>2 x 10</td>
<td>International</td>
<td>1972</td>
</tr>
<tr>
<td>Derby</td>
<td>2 x 8</td>
<td>International</td>
<td>1969</td>
</tr>
<tr>
<td>Aitricham</td>
<td>2 x 4.5</td>
<td>Heenan</td>
<td>1972</td>
</tr>
<tr>
<td>Wolverhampton</td>
<td>2 x 10</td>
<td>Motherwell Br.</td>
<td>1972</td>
</tr>
<tr>
<td>Basingstoke</td>
<td>1 x 9</td>
<td>Heenan</td>
<td>1962</td>
</tr>
<tr>
<td>Folkstone</td>
<td>1 x 5</td>
<td>C.J.B.</td>
<td>1973</td>
</tr>
<tr>
<td>Sutton Coldfield</td>
<td>1 x 10</td>
<td>Heenan</td>
<td>1969</td>
</tr>
<tr>
<td>Swindon</td>
<td>1 x 12</td>
<td>C.J.B.</td>
<td>1973</td>
</tr>
<tr>
<td>Nottingham</td>
<td>2 x 12</td>
<td>Head Wrightson</td>
<td>1973</td>
</tr>
<tr>
<td>Salford</td>
<td>2 x 6.5</td>
<td>Heenan</td>
<td>1972</td>
</tr>
<tr>
<td>Rochdale</td>
<td>1 x 8</td>
<td>Heenan</td>
<td>1973</td>
</tr>
<tr>
<td>Havant</td>
<td>1 x 14</td>
<td>Thompson</td>
<td>1973</td>
</tr>
<tr>
<td>Blaby</td>
<td>2 x 10</td>
<td>Heenan</td>
<td>1973</td>
</tr>
<tr>
<td>Upton upon Severn</td>
<td>2 x 2</td>
<td>B &amp; Sorensen</td>
<td>1972</td>
</tr>
<tr>
<td>South Shields</td>
<td>2 x 10</td>
<td>International</td>
<td>1972</td>
</tr>
<tr>
<td>Tynemouth</td>
<td>2 x 10</td>
<td>Heenan</td>
<td>1972</td>
</tr>
<tr>
<td>Mansfield</td>
<td>1 x 5.6</td>
<td>B &amp; Sorensen</td>
<td>1972</td>
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<td>Middleton</td>
<td>1 x 8</td>
<td>Motherwell Br.</td>
<td>1968</td>
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<td>2 x 6.6</td>
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<td>Rhondda</td>
<td>1 x 9</td>
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<td>1974</td>
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<td>London</td>
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<td>Motherwell Br.</td>
<td>1971</td>
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<td>Edinburgh</td>
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<td>Heenan</td>
<td>1971</td>
</tr>
<tr>
<td>Glasgow</td>
<td>2 x 13</td>
<td>Motherwell Br.</td>
<td>1970</td>
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<td>Coventry</td>
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<td>Head Wrightson</td>
<td>1974</td>
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</table>

### Scandinavia (Cont.): Rating Manufacturer Commissioning

#### Denmark
- Copenhagen-West: 3 x 12, Volund, 1967
- Copenhagen-Amager: 3 x 12, Volund, 1970
- Korsor: 1 x 2, B & Sorensen, 1972
- Aalborg: 2 x 6.5, Volund, 1969
- Kolding: 2 x 3, B & Sorensen, 1969
- Frederikshavn: 2 x 3, B & Sorensen, 1965
- Helsingor: 1 x 4, Elsinore, 1967
- Roskilde: 2 x 3, Volund, 1965
- Fredericia: 2 x 2.3, Elsinore, 1966
- Sonderborg: 1 x 3, B & Sorensen, 1969

#### Sweden
- Stockholm-Lovsta: 4 x 5, Volund, 1938
  
- 1 x 15

### Continental Europe: Rating Manufacturer Commissioning

#### Germany
- Iserlohn: 2 x 8, Babcock, 1967
- Leverkusen: 2 x 10, Von Roll, 1970
- Nuremberg: 3 x 15, Von Roll, 1968
- Stuttgart: 3 x 20, V.K.W. & Martin, 1971
- Munich-South: 2 x 20, Martin, 1969
- Bonn: 2 x 6, Volund, 1965
- Hamburg-Stellinger: 2 x 20, Martin, 1972
- Solingen: 2 x 8.5, Von Roll, 1969
- Bremen: 3 x 15, V.K.W., 1970
- Rhein-Neckar: 2 x 10, E.V.T., 1 x 20, 1966

#### Austria
- Vienna: 3 x 8.5, Von Roll, 1963

#### Switzerland
- Lucerne: 2 x 5, Von Roll, 1968
- Basel: 2 x 12.5, Von Roll, 1968
- Lausanne: 2 x 4, Von Roll, 1958
- Limmat: 2 x 3, Martin, 1971
- Overland: 1 x 5, Martin, 1970
- Fribourg: 2 x 2.5, Von Roll, 1966
- Aarau-Lenzburg: 2 x 4, Soronno, 1973

#### France
- Angers: 3 x 5, Von Roll, 1974
- Blois: 2 x 3, Von Roll, 1971
- Cannes-Antibes: 1 x 5, Martin, 1971
- Rennes: 2 x 5, Martin, 1968
- Metz: 2 x 6, Martin, 1970
- Dieppe: 2 x 3, Von Roll, 1971
- Paris-Ivry: 2 x 40, Martin, 1970
- Paris-Issy: 4 x 15, Martin, 1966

#### Outside Europe: Rating Manufacturer Commissioning

#### United States
- Oyster Bay: 2 x 10, Morse Bulger, 1966
- Hempstead-N.Y.: 3 x 13, Flynn & Emerick, 1964
- Amarillo-Texas: 2 x 5, Affiliated Incin., 1965

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<table>
<thead>
<tr>
<th>Outside Europe (Cont.)</th>
<th>Rating</th>
<th>Manufacturer</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oshkosh-Wisc.</td>
<td>2 x 7.5</td>
<td>Affiliated Incin.</td>
<td>1968</td>
</tr>
<tr>
<td>Chicago-Northwest</td>
<td>4 x 16.7</td>
<td>I.B.W. Martin</td>
<td>1971</td>
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<tr>
<td>Houston-Texas</td>
<td>2 x 16.7</td>
<td>Combustion Eng.</td>
<td>1967</td>
</tr>
<tr>
<td>Tampa, Florida</td>
<td>3 x 10</td>
<td>Volund</td>
<td>1967</td>
</tr>
<tr>
<td>Braintree, Mass.</td>
<td>2 x 5</td>
<td>Riley</td>
<td>1971</td>
</tr>
<tr>
<td>Ft. Lauderdale-Fla.</td>
<td>2 x 9.4</td>
<td>Detroit Stoker</td>
<td>1966</td>
</tr>
</tbody>
</table>

**Canada**

| Montreal               | 4 x 12.5| Von Roll         | 1972          |
| Hamilton-Ontario       | 2 x 12.5| Detroit Stoker   | 1971          |

**Japan**

| Tokyo-Skakujii         | 2 x 12.5| Von Roll         | 1968          |
| Tokyo-Edogawa          | 3 x 8.3 | Takuma           | 1965          |
| Tokyo-Chitose          | 2 x 12.5| Takuma           | 1970          |
| Nishinomiya-West       | 2 x 6.3 | Mitsubishi       | 1967          |
| Kyoto-Kita             | 2 x 8.4 | Von Roll         | 1967          |

**Australia**

| Waverly-Woolahra       | 2 x 11  | Von Roll         | 1973          |

**Brazil**

| Sao Paulo-Pinheiros    | 2 x 4.5 | Nichols          | 1949          |
| Sao Paulo-Pont         | 2 x 6.5 | Martin           | 1959          |
| Pequena                |         |                  |               |
| Sao Paulo-Vergueiro    | 2 x 6.5 | Martin           | 1967          |