A Salvage Fuel Boiler Plant for Maximum Steam Production

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Abstract
Heat recovery from incinerator furnaces in this country has improved as the advances in the incineration process have taken place. A design to further improve this recovery has recently been made.

Features of the design, and the anticipated performance of an installation for maximum steam production using water walls in the incinerator furnace integral with a steam boiler, are explained and discussed. These relate to the project now under construction for the Navy Public Works Center, Norfolk, Virginia.

Introduction
The use of waste heat boilers to generate steam from the products of combustion at municipal incinerators is not new. A number of such installations have been made in this country. Most of these, however, have been of low efficiency due mainly to the fact that the limited need for steam did not economically justify more efficient and more expensive installations. The batch feeding of refuse with attendant furnace temperature variations contributed to poor efficiencies.

The trend toward continuous feed incinerator stokers which give more constant furnace temperatures, makes improved steam production feasible. Because of economic conditions that make high steam production rates desirable, Europe has used more efficient heat recovery methods for some time. In this country, increasing interest in fuel saving is directing attention toward incinerator waste heat for power generation, heating, water desalting, or other uses. Thus, the subject of maximum steam production from incinerators is a timely one.

The incinerator that will be discussed here offers the solution to both a refuse disposable problem and a need for steam.

Studies conducted under the auspices of the Atlantic Division, Bureau of Yards and Docks for the Navy Public Works Center at Norfolk, Virginia, indicated that an imminent refuse disposal problem was developing. Existing facilities included two small incinerator furnaces having a total rated capacity of 66 tons per day, and a fill area adjacent to the Naval Air Station at which open burning was taking place. Predictions indicated that the fill area would be completely exhausted by mid-1965, and that the existing incinerator capacity was already grossly inadequate. The City of Norfolk could offer no additional refuse disposal facilities and the only sanitary landfill area which could be developed was approximately 40 miles from the Base.

At about the same time it was revealed that additional steam-generating capacity was going to be required in the near future. An existing steam distribution system supplies steam to the various facilities around the Base from steam-generating plants. The capacity of these plants was rapidly becoming inadequate. If sanitary landfill were to be used for refuse disposal, an additional steam-generating plant would be required.

Therefore, these conditions afforded an excellent opportunity to design and erect facilities to provide maxi-
mum steam production from the burning of waste material.

After a thorough analysis of the quantity and nature of the refuse produced at the Base, the Bureau of Yards and Docks proposed a combination refuse incinerator and boiler plant having two furnaces, each to have a burning capacity of 180 tons of refuse per day, and capable of being fired with oil as well as refuse. This proposal was made with the advice and capable direction of Mr. Leroy F. Deming, former civilian consultant to the Bureau on power generation, and approved by Rear Admiral W. C. G. Church and later by his successor Rear Admiral N. J. Dustrup, Directors of the Atlantic Division.

A preliminary engineering report on the feasibility of the salvage fuel boiler plant was authorized in October 1962 and made by Metcalf & Eddy. Various incinerator furnace and boiler combinations were evaluated, and the preliminary report recommended a plant consisting of two 180-ton-per-day incinerator furnaces, each with a waste heat boiler capable of producing 50,000 lb of steam per hour, the boilers to be mounted above and integral with the incinerator furnace settings. Steam would be generated from the products of combustion of the refuse supplemented by oil firing as required.

Subsequent to this study, the advisability of using water-cooled furnace walls integral with the boiler was advanced. This led to investigation of the advantages of a water walled, steam producing, incinerator furnace compared with a refractory incinerator furnace joined to a steam boiler primarily utilizing convective heat. The water wall concept was adopted and final design was authorized.

The new facility will replace, and is being erected on the site of, the present incinerator at the Naval Base. Access to and egress from the tipping floor is from Admiral Taussig Boulevard. The plant is to serve the entire Sewell's Point Navy Complex including the ships berthed at the waterfront.

**Design Considerations**

The refuse consists of garbage from the cafeterias and large quantities of crates and packing materials in addition to the normal rubbish. The quality of this mixed refuse was considered to be slightly better than most municipal refuse, as regards non-combustibles and somewhat higher in heating value. Despite these factors, the design basis adopted was for refuse having a heating value of 5,000 Btu/lb as fired.

An economic study of costs of an installation with and without water walls indicated that an appreciable increase in steam production could be obtained economically from a given amount of refuse if water-wall furnaces were used.

In the conventional refractory furnace for burning typical modern refuse, large quantities of excess air are required to keep the temperatures down, prevent slagging of the residue, and spalling of refractory. If water walls are used to absorb much of the attendant heat, excess air can be greatly reduced while maintaining equivalent furnace temperatures.

There has not been experience in burning typical American municipal refuse in water-wall furnaces with integral boilers. European installations, burning refuse of much lower calorific value and utilizing supplementary oil burners, have proven successful. No data are available on the minimum amount of air required for good combustion of typical American municipal refuse. Figures from plants burning bagasse and similar waste fuel of more consistent quality than that of refuse, indicate that 30 to 35 per cent excess air is commonly used. European practice reports that about 50 per cent excess air is used in their refuse plants having water-wall furnaces. It may be that more air will be required for the satisfactory combustion of our refuse.

The amount of effective water-wall surface has a direct bearing on the problems of furnace exit temperatures being either too high or too low. If too much water-cooling surface is installed, the furnace temperatures will fall below deodorizing temperatures, especially at part loads. This must be avoided.

The heat transfer to water walls in a steam-generating furnace is almost entirely by radiation supplemented by some convection, the amount depending greatly on furnace design and the type of firing. Many factors are involved and the design engineer cannot approach the problem in a purely theoretical manner. This is especially true with refuse, due to the non-homogeneous nature of the fuel. The designer must, therefore, resort to comparable data collected from units utilizing similar fuels of similar design, and operating under similar conditions. Bagasse-burning or bark-burning boilers are examples of similar units. Theoretical heat transfer calculations are advantageously applied to data for conditions differing from actual test data.

In advance of actual operation, for example, prediction of the temperature of the gas leaving the furnace requires a background of accumulated data, experience and judgment, such as is possessed by boiler manufacturers. Different boilers have different arrangements of tubes for the water-wall surfaces, requiring that specifications be left open sufficiently to allow for these variations in tube arrangements, but at the same time maintaining the fundamental concepts and requirements to assure good performance.

Limited information on heat absorbed by water walls has been published in technical books and other publications based on conventional fuels [1], [2] and [3].

**Economic Considerations**

An investigation was made to determine the probable savings that might be obtained by the water-wall installation.
The primary purpose of the water walls is to absorb radiant heat from the fire. The result is to assist the waste-heat boiler in the formation of steam, and also benefit the operation in several aspects by the reduction of gas flow. Thus, the value of the additional steam plus the other benefits must be balanced against any increased costs involved.

Probable maintenance costs are difficult to evaluate because of insufficient experience with water walls and refuse burning. Experience with water-cooled walls in bagasse and bark furnaces has indicated that water-wall maintenance is negligible except for an occasional instance when appreciable quantities of sand became mixed with the fuel and caused some abrasion on the tubes when thrown against them with a spreader stoker. This should not happen in an incinerator furnace where refuse is burned on a grate.

Reports on maintenance of refractory walls of an incinerator furnace vary considerably, but it can be concluded that such maintenance would be greater than for water walls. However, no allowance was made for this in the cost comparison. It is also considered that the required operating personnel and labor costs would be the same for either type of installation, i.e. with or without water walls.

The cost comparison was for an installation with a refractory furnace enclosure having a convection-type waste-heat boiler mounted adjacent thereto, compared with an installation having water-cooled furnace walls integral with a convection type boiler, both having the same refuse burning capacity. Appurtenances were included for 200 per cent excess air with the refractory furnace and 100 per cent excess air with the water-wall furnace. The steaming capacity in both cases was sufficient for generating 50,000 lb of steam per hour using auxiliary oil fuel if needed.

The following conclusions were deduced from this comparison:

1. The steam production from refuse alone could be increased approximately 38 per cent by the use of water-wall furnaces.

2. The initial cost of the water-wall installation with fan and fly ash collection equipment capacities for 100 per cent excess air practically balanced the initial cost of the refractory furnace and boiler installation with auxiliaries based on 200 per cent excess air.

3. The principal saving in operating costs would be in cost of auxiliary fuel.

4. Based on a continuous boiler output of 50,000 lb steam per hour, 24 hours a day, the saving in fuel cost would amount to approximately $47,000 per year with oil at $2.81 per barrel. This is on the assumption that sufficient refuse is available to operate the refuse furnace continuously at rated capacity.

**Specification Details**

The major performance items required by the specifications are indicated in Table 1.

In addition, the specifications required that the overall design layout be integrated and the equipment provided by the boiler manufacturer who shall be responsible for the entire integrated system.

The contractor was allowed the choice of either a forced circulation boiler or a gravity circulation boiler, adapted with water walls for the furnaces. Specifications required that sides, rear walls and the roof arches of the furnace be provided with water-wall cooling. A choice from several makes of American-made stokers was allowed. The exact amount of equivalent projected radiant surface (EPRS) was not specified because of arrangements proposed by different boiler manufacturers, but the minimum gas temperature leaving the primary furnace at 50 per cent of rated load was set at 1,400 F.

**TABLE 1**

<table>
<thead>
<tr>
<th>SPECIFICATIONS FOR EACH BOILER-FURNACE UNIT</th>
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<tbody>
<tr>
<td>Mixed refuse, tons/day</td>
</tr>
<tr>
<td>Btu/lb as fired</td>
</tr>
<tr>
<td>Moisture, per cent</td>
</tr>
<tr>
<td>Noncombustible, per cent</td>
</tr>
<tr>
<td>Steam production</td>
</tr>
<tr>
<td>a. With refuse at 5,000 Btu/lb, lb/hr</td>
</tr>
<tr>
<td>b. With drier refuse or with refuse plus oil lb/hr</td>
</tr>
<tr>
<td>c. With oil only, lb/hr</td>
</tr>
<tr>
<td>Design stoker loading</td>
</tr>
<tr>
<td>Lb refuse/sq ft of effective grate surface/hr</td>
</tr>
<tr>
<td>Heat release</td>
</tr>
<tr>
<td>Btu/hr/sq ft effective grate surface</td>
</tr>
<tr>
<td>Btu/cu ft primary furnace volume (max)</td>
</tr>
<tr>
<td>Minimum gas temperature leaving primary furnace</td>
</tr>
<tr>
<td>at 50 per cent of rated load, degrees F</td>
</tr>
<tr>
<td>Steam pressure, psig</td>
</tr>
<tr>
<td>Steam quality</td>
</tr>
<tr>
<td>Feedwater temperature, degrees F</td>
</tr>
<tr>
<td>Exit gas temperature from boiler at design refuse capacity, degrees F</td>
</tr>
</tbody>
</table>

**Estimated Steam Production**

It is recognized that, in most cases, refuse does not have consistent characteristics. Heating values and moisture content change from day to day, and sometimes from hour to hour. Despite these recognized inconsistencies in the refuse, with constant feeding and close control of combustion air and furnace gases, uniform steam production is predicted.

A weight balance is shown in Appendix A and a heat balance is worked out in Appendix B for the rated design refuse load using 50 per cent excess air. These figures indicate that it can be reasonably expected to produce steam at a rate of 50,000 lb per hour from refuse having the characteristics previously established. This corresponds to 3.3 lb of steam per pound of refuse.
Heat balances have been worked out for other conditions in a similar manner, and the results shown graphically. Fig. 1 shows the expected steam production from refuse only, at loads from one-half to full rated refuse capacity using 50 per cent excess air.

Fig. 2 shows the expected variation in steam production at rated capacity of 180 tons per day with variation in heating values of the refuse from 4,000 to 6,000 Btu/lb with 50 per cent excess air, using refuse only.

Fig. 3 shows the expected steam production as the excess air is varied, assuming that complete combustion takes place at rated capacity with 5,000 Btu/lb refuse.

Description of Equipment and Layout

The boiler-furnace unit to be furnished was detailed and fabricated by Foster-Wheeler, Inc., with a three-section Detroit reciprocating stoker 10 ft wide by 36 ft long overall. The effective grate area is considered as 269 sq ft corresponding to a burning rate of 56 lb per hour of refuse per square foot of effective grate area.

Fig. 4 shows a longitudinal section through the boiler-furnace unit.
It should be noted that the arrangement consists of comparatively low arches over the front and rear sections of this refuse furnace and the main uptake to the convection boiler at approximately the center of the furnace. The arches and three walls including the boiler uptake section are water cooled. Tubes are 2½ in. nominal outside diameter on 3½ in. centers with headers at top and bottom with connections to the steam drum. The gross equivalent projected water-wall radiant surface is 1,350 sq ft. Of this total radiant surface, 900 sq ft is designed to receive the effective heat release from radiation.

Overfire air is supplied through the front arch of the furnace from a fan rated at 12,000 cfm at 70 F. Underfire air is supplied below the two long sections of grate from a fan rated at 30,000 cfm at 70 F. Both fan capacities can be regulated down to 30 per cent excess air by inlet damper controls.

No air is supplied to the feeding section of the stoker. A sifting hopper is supplied under this section from which siftings are removed manually. Siftings from the two burning sections of the stoker drop into the wind boxes from which they will be removed through access doors by hand tools.

The convection section of the boiler is a typical two-drum single-pass water-tube boiler. Tubes are 2½ in. in diameter, 7 in. center-to-center in a direction perpendicular to gas flow, and staggered in adjacent rows. Between adjacent rows, 5-in. center-to-center spacing is avoided. Soot blowers are provided for cleaning the outside of the tubes and two small hoppers are provided, one each side of the water drum, for collecting fly ash.

Other equipment in the plant mainly follows recent standard practice. Refuse is delivered by trucks and dumped into a receiving bin from which the furnaces are fed by a 3½ ton crane with a 2 cu yd clamshell bucket. The feed chute is water cooled in the lower section.

Gases leaving the boiler pass through fly ash removal equipment consisting of a battery of 24-in. diameter cyclone collectors for each unit. Water is introduced tangentially in the lower section of the cones to wash out collected fly ash, which is then discharged by gravity into the residue conveyor trough. The system has to guarantee a stack emission of not more than 0.85 lb per 1,000 lb gases corrected to 50 per cent excess air. Stack emission tests are required as part of the contract.

An induced-draft fan for each unit draws the gases through the furnace, boiler and fly ash removal equipment, and discharges to a short steel stub stack. Rated capacity is 54,500 cfm at 580 F corresponding to 13.8 lb of gas per pound of refuse. Each fan is motor driven through a magnetic coupling for variable speed control and is furnished with an inlet vane damper.

Boiler auxiliaries are all sized for steam production of 50,000 lb steam per hour per boiler. Feedwater is obtained from the Norfolk, Virginia, municipal water supply. Practically no condensate return is expected. Water-treatment equipment consists of a zeolite water-softening system followed by chemical treatment consisting of an acid-mixing system, degasifying and sodium sulfite systems. Chemical pumps, mixing tanks and other appurtenant equipment are included. The treated water then passes through a deaerating feedwater heater using 5 psig steam for heating the feedwater to approximately 228 F before being pumped to the boilers.

Two boiler feed pumps with motor drives, each having the capacity for one boiler, and one steam-turbine-driven pump having sufficient capacity for both boilers are supplied. Exhaust steam from the turbine is used in the feedwater heater.

A steam-atomizing oil burner for heavy oil and having capacity to generate 50,000 lb of steam per hour with oil only is installed in each unit. These can also be used to augment the steam production from refuse when and if required. Oil storage facilities, heaters and transfer pumps are included.

The residue drops from the stoker through a bifurcated chute into either one of two conveyor troughs filled with water. Flight conveyors remove the residue and elevate it in an inclined section so that it can be discharged directly into a waiting truck. The underground conveyor tanks are of concrete with metal wearing plates on the bottom. The collected fly ash is removed along with the residue.

Due to the limited funds available, the building was designed as a strictly utilitarian structure with concrete foundations and corrugated metal siding on structural steel framework. The building is supported entirely on concrete pile foundations.

The total contract price was $2,135,000, of which approximately $150,000 was for demolition of existing structures and site preparation, and $1,100,000 was for incineration equipment and appurtenances.

**Boiler Controls**

The automatic combustion controls employ a pneumatic system with air at 3 to 15 psig. The controls automatically maintain a system steam pressure of 275 psig. The controls for refuse burning and oil burning are inter-related but may be manually separated.

Refuse feeding, i.e., the feeding stoker speed, is automatically regulated from a controller which senses steam pressure. This controller feed station is equipped with a HAND-OFF-AUTOMATIC feature. The refuse-to-air ratio is automatically maintained by adjustment of the furnace forced draft fan inlet vane. The signal index of steam flow minus oil flow determines the action of the inlet vane controller. A manual refuse-to-air ratio set station allows trimming of air by the operator.

Oil firing is automatically controlled, according to steam pressure, by the direct actuation of an oil flow control valve. The controller for oil flow has a HAND-
OFF-AUTOMATIC feature. The desired oil-to-air ratio is automatically maintained by adjustment of the inlet vane of the oil burner forced draft fan. This adjustment is made by the signal index of oil flow minus air flow to the burner. A remote manual station provides for trimming of the air by the operator.

Under automatic operation, employing both refuse and oil firing, control signals to the oil burner are withheld until refuse burning cannot maintain steam pressure to the desired level. When this condition is reached, as indicated by the maximum stoker-feed signal and a predetermined drop in steam pressure, the oil burner controls will activate to satisfy the desired steam pressure.

A variable-speed magnetic drive and variable inlet vanes are provided for the induced-draft fan. Fan speed and inlet vane position are determined by a furnace draft controller. The controller sequences the change of fan speed and inlet vane positioning as follows: vane position is utilized over the low range of operation, vane position and speed change over the middle range, and speed change over the high range of operation.

The selection of automatic or manual potentiometers for speed regulation of the fan magnetic drive is provided on the instrument panels.

Summary and Conclusions

The utilization of waste heat from municipal incinerators has been an important consideration in the minds of economy-minded engineers for some years. Earlier, batch feed installations with waste-heat boilers have produced from 1 to 2 lb of steam maximum per pound of refuse. Recent improvements in furnace design, continuous feeding of refuse and removal of residue have resulted in more constant furnace temperatures which should result in more efficient steam production.

It must be realized that not all municipal installations economically justify maximum steam production, especially smaller plants and many larger plants not operating 24 hours a day. Many plants have no market for so much steam.

This design is an attempt to obtain the maximum steam production from waste heat from a modern design of incinerator plant. Calculations indicate that it is logical to expect an increase in steam production of at least 50 per cent over earlier installations in this country. Undoubtedly, experience with this design will indicate further advances that can be made in future installations having a similar purpose.

References

[5] Steam, Babcock & Wilcox Co., 1955, pp. 11-24, Fig. 24.
[7] Ibid, pp. 7-22, Fig. 20.

Appendix A

Weight Balance at Design Load and 50 Per Cent Excess Air

<table>
<thead>
<tr>
<th>Refuse</th>
<th>Per Cent</th>
<th>Lb/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible</td>
<td>62.5</td>
<td>9,375</td>
</tr>
<tr>
<td>Water</td>
<td>25.0</td>
<td>3,750</td>
</tr>
<tr>
<td>Noncombustible</td>
<td>12.5</td>
<td>1,875</td>
</tr>
<tr>
<td>Total refuse as fired</td>
<td>100.0</td>
<td>15,000</td>
</tr>
</tbody>
</table>

Combustion Air

Assume theoretical air equals 700 lb per million Btu generated and that atmospheric air contains 0.013 lb moisture per lb dry air. With 50 per cent excess air,

Dry air = 78,750 lb/hr
Moisture in air = 1,025 lb/hr
Total atmospheric air input to furnace = 79,775 lb/hr
Total input to furnace = 79,775 + 15,000 = 94,775 lb/hr

Residue

Assume residue contains 5 per cent unburned carbon,

Total residue = 1,875 ÷ 0.95 = 1,973 lb/hr
Noncombustibles = 1,875 lb/hr
Unburned carbon = 98 lb/hr

Products of Combustion

Deductions from Table 2 in [4] indicate analysis of an average municipal refuse on a moisture-and-ash-free basis, as

Carbon = 51.51 per cent
Oxygen = 41.14 per cent
Hydrogen = 6.44 per cent
Sulphur and nitrogen = 0.91 per cent

from which the net hydrogen in the refuse would be

\[ 6.44 - \frac{41.14}{8} = 1.30 \text{ per cent of combustibles} \]

Net hydrogen = 0.013 (9,375) = 122 lb/hr requiring 976 lb oxygen per hour from the combustion air.

Similarly, the total hydrogen in the refuse would be 0.0644 (9,375) = 604 lb/hr and the oxygen 0.4114 (9,375) = 3,856 lb/hr.

Dry products of combustion consist of original dry combustion air minus oxygen required to combine with net hydrogen to form water vapor, plus the original combustibles reduced by the oxygen and hydrogen which form
water vapor and the carbon in the residue.
Product from combustion air \(78,750 - 976 = 77,774\) lb/hr
Products from combustibles
9375-604-3856-98 \(4,817\)
Total dry gases \(82,591\) lb/hr
Moisture in products of combustion:
- Moisture in refuse \(3,750\) lb/hr
- Moisture in combustion air \(1,025\) lb/hr
- Moisture from hydrogen forming water vapor \(5,436\) lb/hr
Total moisture in products of combustion \(10,211\) lb/hr
Total output from furnace:
- Residue \(1,973\) lb/hr
- Dry gases \(82,591\) lb/hr
- Water vapor \(10,211\) lb/hr
Total Output \(94,775\) lb/hr

### Appendix B

**Theoretical Heat Balance at Design Load and 50 Per Cent Excess Air**

The following assumptions are included in these heat balance calculations:
- Entering air and refuse temperatures 80°F
- Gas temperature entering convection section of the boiler 1,700°F
- Temperature of residue leaving grate 800°F
- Specific heat of residue 0.25
- Specific heat of dry flue gas [5] 0.265
- Specific heat of actual flue gas [5] 0.290

#### Gross Heat Input from Refuse

\[15,000 \times 5,000 = 75,000,000\text{ Btuh}\]


- a. Inherent moisture \(3,750 \times 1,040 = 3,900,000\) Btuh
- b. Hydrogen in refuse \(9 (0.0644 \times 9,375) \times 1,040 = 5,150,000\) Btuh
Total \(9,050,000\) Btuh

#### Net Heat Input from Refuse

\[75,000,000 - 9,050,000 = 65,950,000\text{ Btuh}\]

### Losses from Furnace

a. Furnace walls [7]
\[0.009 \times 75,000,000 = 675,000\text{ Btuh}\]
b. Sensible heat in residue
\[1,973 \times 0.25 (800 - 80) = 356,000\text{ Btuh}\]
c. Unburned carbon in residue
\[98 \times 14,093 = 1,380,000\text{ Btuh}\]
Total Losses \(2,411,000\text{ Btuh}\)

### Available Heat for Steam Production

\[65,950,000 - 2,411,000 = 63,539,000\text{ Btuh}\]

### Heat Absorbed by Water Walls

From Meissner's curves [1] the net heat release required, per square foot of EPRS per hour for various furnace temperatures with 50 per cent excess air are shown as follows:
- Furnace temperature 1,700°F
  - Heat absorbed by water walls 19,939,000
  - Heat absorbed per sq ft EPRS/hr 108,000
  - Sq ft water wall surface based on net heat release of 63,539,000 Btuh 588

#### Heat in gases leaving furnace section (above 80°F)

\[43,600,000 - 40,900,000 = 38,200,000\text{ Btuh}\]

#### Heat absorbed by water walls

\[19,939,000 - 22,639,000 = 25,339,000\text{ Btuh}\]

#### Heat absorbed per sq ft EPRS/hr

\[108,000 - 88,000 = 20,000\text{ Btuh}\]

### Estimated Steam Production

#### Btu/lb steam at 275 psig
\[1,202.6\text{ Btuh} \times 1\text{ lb steam} = 1,202.6\text{ Btuh}\]

#### Btu/lb feedwater at 228°F
\[196.2\text{ Btuh} \times 1\text{ lb feedwater} = 196.2\text{ Btuh}\]

#### Btu required per lb steam
\[1,202.6 - 196.2 = 1,006.4\text{ Btuh}\]

#### Gas temp leaving furnace
\[1,700 - 1,600 = 1,500\text{ F}\]

#### Gas temp leaving boiler
\[580 - 565 = 552\text{ F}\]

#### Heat absorbed by convection boiler
30,200,000 + 27,850,000 = 55,050,000 Btuh

#### Steam production (lb/hr)

| Convection | 30,000 | 27,700 | 25,350 |
| Water walls | 19,800 | 22,500 | 25,200 |
| Total | 49,800 | 50,200 | 50,550 |