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RETROFIT COST RELATIONSHIPS

FOR HAZARDOUS WASTE INCINERATION

by

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DISCLAIMER

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory -- Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report provides information on the potential costs associated with upgrading existing hazardous waste incineration facilities to comply with RCRA performance standards. It is intended primarily for EPA utilization in assessing cost/benefit trade-offs, although it may also be useful to other individuals or organizations interested in hazardous waste incineration economics. The Incineration Research Branch, IERL-Ci, may be contacted for additional information on this subject.

David G. Stephan, Director
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ABSTRACT

The U.S. Environmental Protection Agency is currently performing a Regulatory Impact Analysis (RIA) of the RCRA performance standards for hazardous waste incineration facilities. One of the key elements of this RIA effort is the development of representative cost data for hazardous waste incineration, including (1) capital costs for new facilities designed in accordance with RCRA requirements, (2) operation and maintenance (O&M) costs for these facilities, and (3) retrofit costs for existing facilities to comply with RCRA standards. This report addresses the latter costs.

The objective of the study was to develop a methodology, and an accompanying set of empirical cost relationships, that could be used to estimate the costs of retrofitting/upgrading various components of existing hazardous waste incineration facilities to comply with RCRA performance requirements. Both the methodology and the retrofit cost relationships were intended to focus on major capital additions or subsystem modifications that could be required for RCRA compliance.

The results of the study are expressed in a series of empirical relationships between the costs for various capital modifications/additions and factors that significantly impact these costs, e.g., capacity, materials of construction, etc. Costs are developed for (1) various aspects of combustion system retrofit to improve destruction of toxic waste constituents, (2) scrubbing system component addition, replacement, or upgrading to improve particulate and/or HCl removal, and (3) addition or replacement of ancillary equipment mandated by combustion or scrubbing system retrofit. The costs are based on a combination of in-house engineering and vendor-supplied budgetary cost estimates.

Because the performance status of many existing incineration facilities is unknown, particularly with respect to waste destruction efficiency in the combustion process, it was not possible to predict within the framework of this study what the actual retrofit requirements may be for the existing incinerator population to comply with RCRA standards. Therefore, this study was not designed to predict what the total retrofit costs would be for industry as a whole. Rather, the results were intended only as a cost estimating tool to aid EPA decision-making purposes.

This report is submitted in partial fulfillment of Contract No. 68-03-3043 by Acurex Corporation, Energy & Environmental Division, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 1, 1982 to July 1, 1983, and work was completed as of July 11, 1983.

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SECTION 1

INTRODUCTION

Under the Resource Conservation and Recovery Act (RCRA), the U.S. Environmental Protection Agency is required to establish a federal hazardous waste management system, including standards for hazardous waste incineration facilities. As part of that effort, the EPA Office of Solid Waste is currently executing a Regulatory Impact Analysis (RIA) of performance standards for hazardous waste incinerators (HWI). The RIA is intended to help determine the costs and benefits of various regulatory standards. This study provides background information for the RIA by addressing the cost of retrofitting existing hazardous waste incinerators to improve performance and limit exhaust emissions.

The objective of this report is to provide retrofit cost relationships for modifications or additions to existing hazardous waste incineration systems. "Incineration system" refers to all the equipment necessary to burn hazardous waste in compliance with regulatory requirements. Thus, an incinerator system includes the waste handling and feed system, the incinerator itself with associated ash-handling equipment, downstream air pollution control devices (APCD's) such as scrubbers and absorbers, flue gas handling equipment, and exhaust stack.

This report provides a methodology for estimating the costs of retrofitting various components of an existing HWI system for the purposes of:

- Increasing removal efficiency of principle organic hazardous constituents (POHC)
- Reducing particulate loading to <0.08 gr/dscf
- Reducing HCl in flue gas by 99 percent for wastes containing >0.5 percent chlorine

Some existing HWI systems may require no modifications to meet proposed standards. Other systems may require extensive, multiple component modifications. For still others, retrofit may not be feasible because of economic, space, or equipment design limitations. Thus, caution should be exercised in applying the retrofit cost estimates provided in this report to a specific situation.

Retrofit costs include the installed cost of new equipment for the existing incinerator system, any incremental operation and maintenance costs over and above those of the original system, and downtime costs associated with system retrofit. This study focuses on the major cost factor: capital costs for new equipment.

The study excludes minor equipment modifications/additions. For example, burner and refractory replacement costs for an existing incinerator are quantified, but minor changes such as burner/air register adjustments fall under the category of "fine-tuning." Fine tuning costs are generally minor compared to the cost of major capital modifications/additions and they are very facility specific. This study also excludes the costs of trial burns and other permitting requirements (for both construction and operation) associated with facility retrofitting because these costs are highly case-specific. Estimates of trial burn and other permitting costs for new facilities are presented in Section 4 of Reference 1.

The approach taken here relies heavily on contacting major equipment vendors and reviewing their experience in HWI retrofits. Engineering estimates were used to augment the collected data, especially material requirements and installation costs. Because the study assumed a wide range of waste characteristics and various incinerator system designs and configurations, a detailed engineering study was not possible. Rather, budgetary engineering estimates, based on vendor data, were made. For budgetary purposes, the equipment costs should be accurate to within ±30 percent. Larger uncertainties are associated with installation costs, as discussed in subsequent sections.

This retrofit cost study was performed in conjuction with a larger-scale project to estimate capital and operation/maintenance (O&M) costs for new hazardous waste incineration facilities designed in accordance with RCRA performance standards. The results of this larger-scale study are presented in a report entitled, "Capital and O&M Cost Relationships for Hazardous Waste Incineration" (Reference 1). The results of the retrofit cost study overlap to some degree with the results presented in Reference 1. In cases where this overlap occurs, only the major assumptions and bottom-line cost estimating relationships are presented herein. The reader should refer to Reference 1 for detailed derivations and background information.

The next section of this report reviews the incinerator systems considered. Section 3 presents the engineering economic premises. Section 4 through 8 provide retrofit cost relationships for various incineration system components. Section 9 concludes with a brief discussion of downtime considerations. The format of this report is user oriented. Cost relationships are provided, but the actual application of these functional relationships is left to the user of this report.

SECTION 2

INCINERATOR SYSTEMS CONSIDERED

The hazardous waste incineration designs and capacity ranges addressed in this study are as follows:

- Liquid injection (1 to 100 million Btu/hr)
- Rotary kiln (1 to 100 million Btu/hr)
- Multiple chamber, hearth (1 to 50 million Btu/hr)

Design temperature ranges are assumed to be 1,500° to 1,800°F for kilns and hearth incinerator primary chambers, and 1,800° to 2,400°F for kiln/hearth incinerator afterburners and liquid injection furnaces.

The hazardous wastes burned in these incinerators are assumed to be hydrocarbon or aqueous based with heating values ranging from essentially 0 to 15,000 Btu/lb, and moisture levels of 0 to 90 percent. It is assumed that chlorine is the only halogen present. Ash and salts may also be present in variable amounts.

Uncontrolled particulate emissions from burning these wastes are assumed to range up to 2.0 gr/dscf, and flue gas chlorine (HCl) concentrations may range from 0 to a maximum of 2 percent by volume. For the purposes of this study (and in Reference 1), venturi scrubbers are assumed for particulate control and packed tower absorbers are assumed for HCl removal. The generalized air pollution control system is shown in Figure 1. As indicated in this schematic, a water quench is installed upstream from the scrubbers to reduce gas temperature to <200°F, and an ID fan and stack are installed downstream. Inclusion of a waste heat boiler upstream from the quench is optional. For more detailed information on air pollution control system design, or incinerator design, the user should refer to Sections 2 through 4 of Reference 1.

The hazardous waste incineration system upgrade goals addressed in this study are to:

- Increase removal efficiency of principle organic hazardous constituents (POHC)

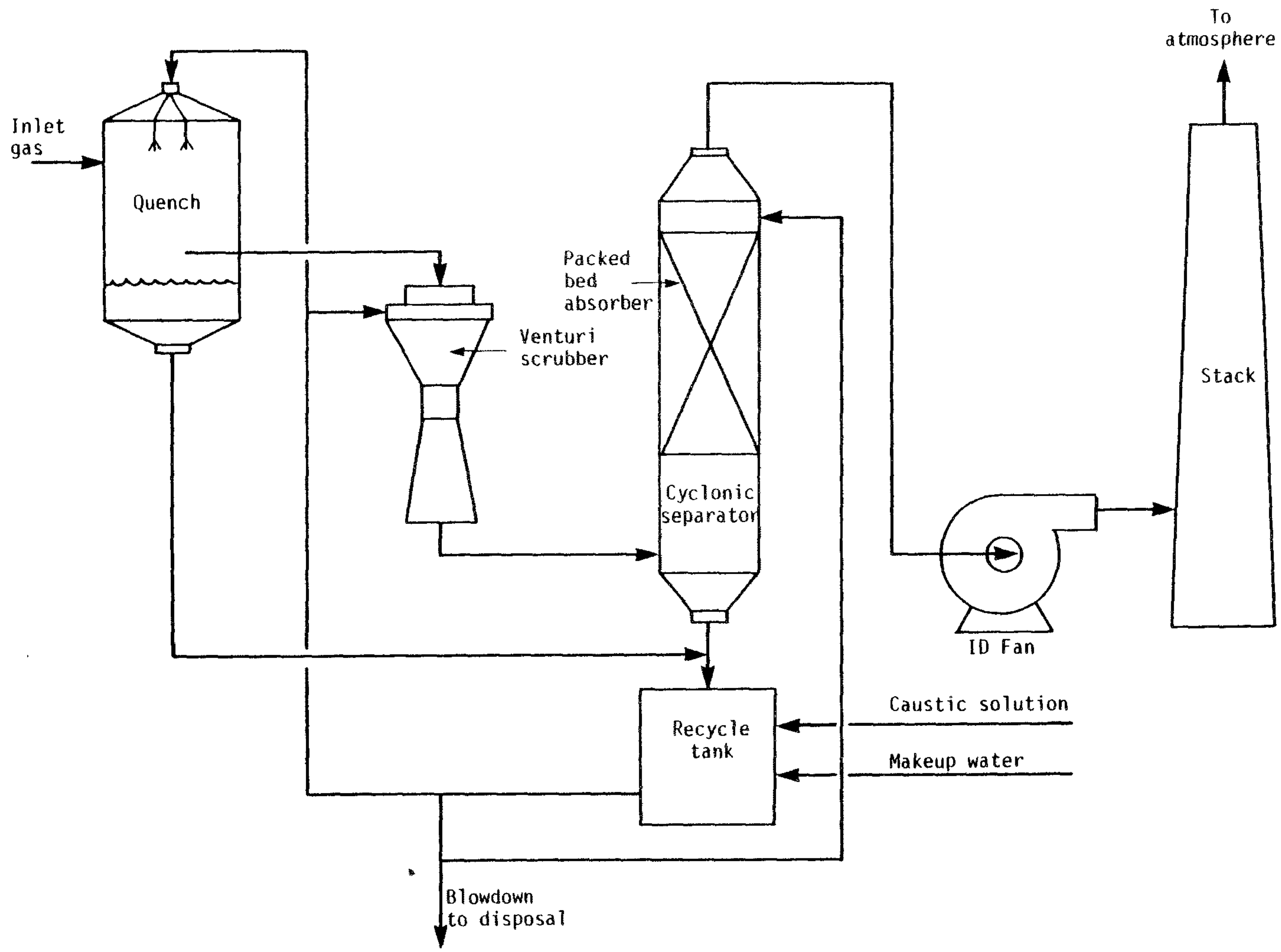

Figure 1. Generalized flow diagram for quench/scrubber system.

- Reduce particulate loading to ≤0.08 gr/dscf

- Reduce HCl in flue gas by 99 percent for wastes containing >0.5 percent chlorine

Because the correlation of POHC removal efficiency with combustion conditions is not well established, quantification of the specific combustion system upgrade requirements is not possible. Therefore, this study only estimates the typical costs associated with hardware modifications that may be implemented to improve combustion efficiency, raise combustion temperatures, and increase residence times at peak temperatures. Rigorous correlation of POHC removal efficiency with costs is not possible at this time.

The specific HWI retrofit modifications/additions considered for improving incinerator efficiency and minimizing exhaust emissions are:

- Combustion system retrofit
  - Burner replacement
  - Refractory replacement
  - Combustion chamber replacement
- Quench addition
- Waste heat boiler addition
- Scrubbing system addition/replacement/modification
  - Venturi scrubber replacement
  - Acid gas absorber addition/replacement/modification
  - Complete system retrofit
- Flue gas handling equipment addition/replacement
  - Fan and motor
  - Stack
- Total incineraton system replacement

SECTION 3

ENGINEERING ECONOMIC PREMISES

This study considers the retrofit or modification of components of an existing hazardous waste incineration system with ready access to equipment; i.e., there is no extreme congestion at the site. The equipment layout scheme is assumed to have no unusual configurations or complex ductwork due to space limitations. This is usually a good assumption because hazardous waste incinerators are generally located in open space, away from congested urban areas. Even a dedicated incineration facility which serves a process chemical plant is rarely located in the middle of the congested plant but rather at its periphery. If, however, site congestion is a problem, retrofit costs will increase accordingly, due primarily to increased installation costs and other site-related and field work.

3.1 CAPITAL COSTS

Total capital costs for retrofitting are given by the sum of the direct and indirect costs, plus contingency costs. Direct costs are the sum of the fabricated equipment costs, freight, and installation.

The equipment cost includes necessary instrumentation and controls where appropriate. Installation costs include foundations and supports, ductwork, piping, insulation, electrical, and all necessary labor. In this study, installation cost is usually specified as a percentage of the purchased equipment cost. A range is generally specified to account for variations in retrofit difficulty.

Indirect costs associated with the retrofit must be added to the installed equipment cost (direct cost). Indirect costs include:

- Engineering (10 percent of direct costs)
- Construction field expense (10 percent of direct costs)
- Construction fee (8 percent of direct costs)
- Startup (2 percent of direct costs)

The owner of the incinerator or an engineering contractor must perform an engineering feasibility study on the merits of retrofitting equipment to upgrade incinerator and/or air pollution control equipment performance. If a go ahead decision is made, then bid specifications and vendor bid reviews must be completed. An engineering study is also required to integrate the new or upgraded component(s) to ensure system compatibility.

Construction field expenses include the cost of scaffolding, service, and utility facilities and other remote support. A general contractor is required to coordinate all construction activities.

Startup costs are estimated to be 2 percent of direct costs. Unlike a completely new facility, the contractor only needs to be directly concerned with the particular component(s) being modified or retrofitted. All other components of the incineration system are assumed to be operational. There is less downtime associated with waiting for other components to be "de-bugged" and operator training is usually minimal.

Finally, a contingency of 15 percent of direct plus indirect costs should be added to obtain the total cost.

3.2 COMMENTS ON RETROFIT DIFFICULTY

Costs of extensive retrofitting can be higher than those for a new installation, due primarily to installation costs and site-related indirect costs. Examples of increased retrofit difficulty factors include:

- Service relocations (e.g., pipe racks, wiring, access roads)
- Convenience of staging area (proximity of staging area to installation site)
- Difficulty of rigging (site constraints which hinder use of high lift equipment)
- Operating interferences (construction which requires an incinerator shutdown)
- Structural relocation (building space layout considerations)
- Foundation site preparation (dependent on terrain and site geology)
- Long duct runs and bypasses
- Elevated structures
- Existing equipment limitations (e.g., obsolescence, internal space constraints)

The above difficulties are due mainly to space limitations, and can only be evaluated on a site-specific basis. If space limitations are not a problem, then potentially, retrofit costs could be as low as "grass roots" costs. On the other extreme, space limitations and/or equipment constraints could make retrofit impractical altogether.

3.3 OPERATION AND MAINTENANCE COSTS

In general, additional operation and maintenance (O&M) costs can be expected with retrofitted components in an existing hazardous waste incinerator system. The associated O&M costs of the modified facility should be calculated as specified in Reference 1. Then, the difference in system O&M costs before and after retrofit can be identified. This cost difference can then be attributed to the overall cost of upgrading an existing incineration system. In the following sections on component equipment costs, significant O&M cost differences are noted where appropriate.

SECTION 4

COMBUSTION SYSTEM RETROFIT

A number of potential combustion system modifications can be considered for upgrading the performance of an existing hazardous waste incinerator (HWI). Incinerator performance (e.g., POHC destruction efficiency) can potentially be upgraded by increasing combustion chamber temperature above the original design specification and/or increasing effective residence time at peak temperature. Combustion system modifications that have the potential to achieve these improvements include:

- Adjusting burner/air registers for higher combustion efficiency
- Replacing kiln seals to reduce air infiltration
- Modifying solids feed systems to minimize air infiltration
- Replacing existing burners with new higher efficiency, lower excess air design burners to achieve more rapid mixing, higher mean temperature, and longer times at peak temperature
- Replacing existing refractory to accommodate higher temperature operation
- Replacing the combustion chamber with a new unit designed for higher temperature and/or longer residence time operation

The first three modifications listed above are essentially fine tuning adjustments for achieving more efficient operation of a hazardous waste incinerator. The actual hardware changes and/or operational changes involved are variable from HWI facility to facility. Furthermore, because they are generally simple modifications of relatively low cost, they will not be treated further in this study.

This section focuses on the major modifications of burner, refractory, and combustion chamber retrofit.

4.1 BURNER REPLACEMENT

4.1.1 Description and Purpose of Retrofit

A complete burner system includes the burner itself plus valve train, blower and damper assemblies, flame safeguards, and controls. In addition to introducing high-Btu wastes, burners may be used to introduce secondary fuels (either supplementary fuel to augment combustion or low heating value wastes which must be injected peripherally). Alternatively, separate burners may be used for supplemental fuel firing.

In rotary kiln, hearth, and liquid injection incinerators, the burner design and placement affect the amount of excess air required as well as influence fuel/waste/air mixing and combustion efficiency. Burner designs have advanced sufficiently in recent years that a new burner may achieve higher efficiency with more rapid mixing and higher temperatures than many of the older burners currently operating in the field. Thus a new burner(s) may be retrofitted to improve combustion efficiency, accommodate a waste different from the one originally designed for, or to introduce supplemental fuel.

4.1.2 Applicability and Limitations

Increasing incinerator efficiency through burner replacement is potentially applicable to all incineration systems in which the waste is introduced via burners, rather than by lances. Of course, the combustion chamber must be able to accommodate the flame envelope and zonal heat release rate of the new burners, as well as being physically compatible with the new burner assembly. Such determinations must be done on a case-by-case basis.

4.1.3 Assumptions and User Guidelines

The retrofit burner costs developed here assume the following:

- The entire burner system, not just the nozzle, is replaced
- Burners are sized similar to dual-fuel burners firing residual oil and natural gas
- Off-the-shelf, rather than custom burners, are available and applicable. This assumption is qualified below as a "best case" scenario for baseline cost estimating purposes.

The actual improvement in combustion efficiency and resultant increased temperature and/or residence time must be determined on a site-specific basis.

4.1.4 Costs

Figure 2 presents purchased equipment cost as a function of burner capacity. These costs include blowers, dampers, flame safeguards, and

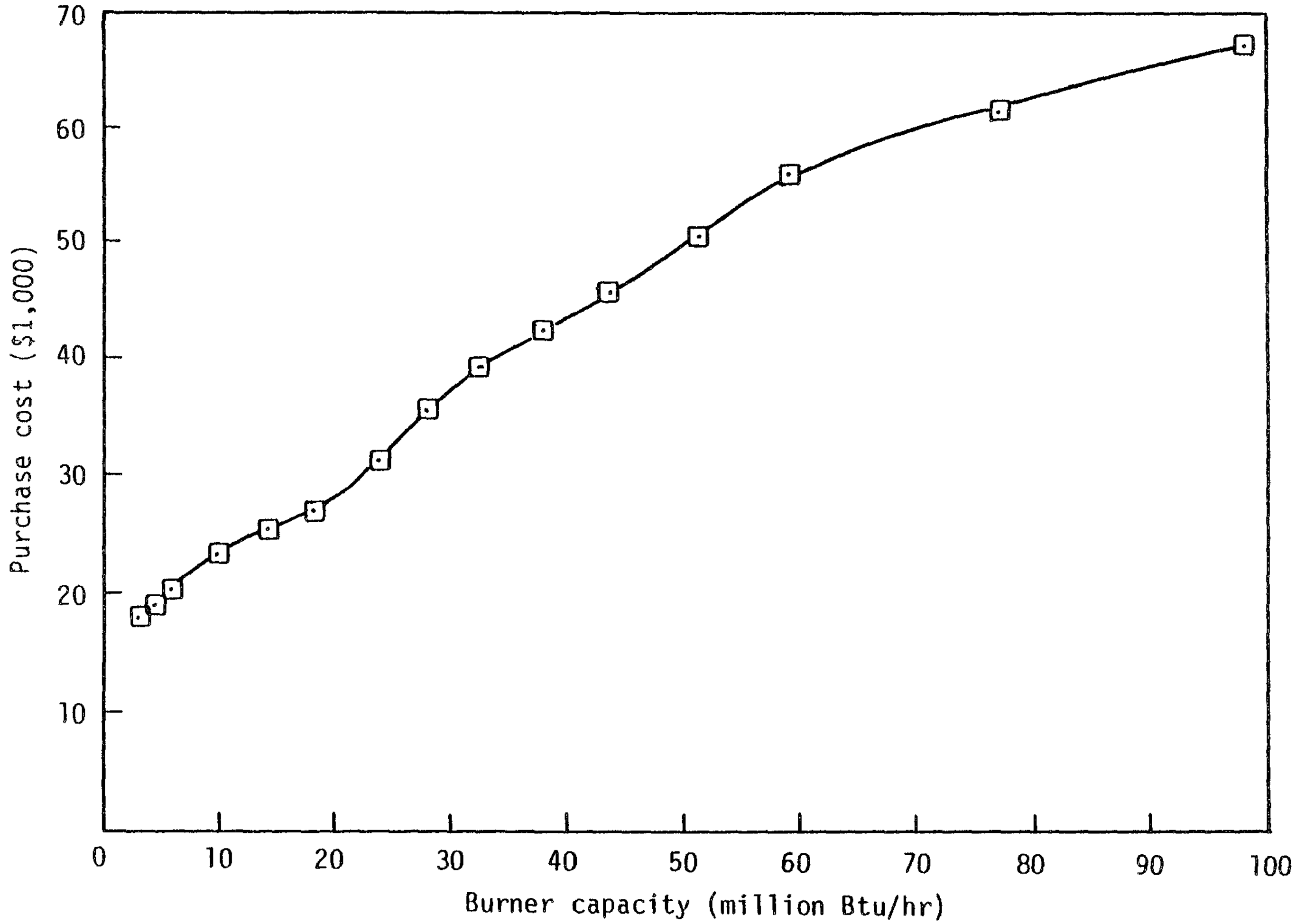

Figure 2. Purchase cost of new burners (July 1982).

combustion controls. Retrofit installation cost is roughly 50 percent of the purchased cost. The costs presented are from one vendor, based on a dual-fuel burner with half of the nominal heat input capacity coming from natural gas. It should be noted that many vendors prefer to custom fabricate burners for the specific fuel and facility. Due to the inherent site-specific nature of this design methodology, prices for these custom burners will be higher than stock designs. Thus, it is not possible at this time to produce a generalized cost for custom burners. The costs presented here for standard burners should be considered as baseline, minimum costs if new burners were to be retrofitted in an existing HWI.

To obtain the total retrofit cost, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed equipment cost, as specified in Section 3.

No additional operation and maintenance considerations are required beyond those specified in Reference 1. If supplementary fuel is required, the additional fuel costs are calculated as in Reference 1.

4.2 REFRACTORY REPLACEMENT

4.2.1 Description and Purpose of Retrofit

The combustion chambers of incinerators are lined with refractory, nonmetallic insulating materials resistant to high temperatures. Refractory for incinerators is ordered by the type and thickness required, depending on the environment (thermal cycling, temperatures, abrasion, erosion, presence of acid/alkali) expected. Refractories may be in brick or castable form, and are often priced in terms of brick equivalents (one brick is 9 in. by 4-1/2 in. by 3 in.).

Replacing the existing refractory with a higher grade material is a means of accommodating higher incinerator temperature operation to promote POHC destruction. Methods to estimate costs for refractory replacement are presented below.

4.2.2 Applicability and Limitations

Refractory is routinely replaced (e.g., every 1 to 5 yr, depending on service conditions) due to the wear associated with normal operation. Thus, refractory upgrade/replacement is an option for incinerators for which the existing refractory is inadequate to handle the desired higher operating temperature. However, the changes required to handle new operating conditions must not be so extensive as to make combustion chamber replacement necessary. For example, increasing the temperature increases the gas volume which reduces residence time. High temperatures may also necessitate thicker refractory, which reduces the chamber volume, thereby also reducing the residence time. Both of these factors may reduce residence time below what is necessary for waste destruction.

4.2.3 Assumptions and User Guidelines

Refractory replacement costs are based on the following incinerator design assumptions:

- Nominal heat release rates are 30,000 Btu/hr-ft^3 for liquid waste incinerators and rotary kilns and 15,000 Btu/hr-ft^3 for hearth primary chambers
- Liquid waste incinerators and afterburners are cylindrical with length-to-internal diameters of 3:1
- Rotary kiln incinerators have length-to-internal diameter ratios of 2:1
- Hearth incinerator primary chambers are rectangular with length:width:height ratios of 2:1:1
- Afterburner residence times are nominally 2 sec at design exit gas temperature

4.2.4 Costs

Refractory replacement costs include removal, installation, and material costs. Refractory material requirements and costs are first estimated. The volume of refractory required can be estimated as follows:

Rotary kiln (walls and feed plate):

$$V_r = 2\pi\ h\ D_i\ (h + 1.125\ D_i)$$

$$\text{with } D_i = \left(\frac{Q_T}{15{,}000\pi}\right)^{1/3}$$

Liquid injection incinerator:

$$V_r = 3\pi\ h\ D_i\ (h + 1.167\ D_i)$$

$$\text{with } D_i = \left(\frac{Q_T}{22{,}500\pi}\right)^{1/3}$$

Afterburner:

$$V_r = 3\pi\ h\ D_i\ (h + 1.167\ D_i)$$

$$\text{with } D_i = \left[\frac{q_{TG}\ (T_{I2} + 460)}{11{,}700\pi}\right]^{1/3}$$

Hearth primary chamber:

$$V_{r_i} = 10\ W^2\ h$$

$$\text{with } W_i = \left(\frac{Q_T}{30{,}000}\right)^{1/3}$$

where

V_r = refractory volume (ft^3)

h = thickness of refractory (ft)

D_i = inside diameter of incinerator (ft)

Q_T = maximum firing rate of incinerator (Btu/hr)

q_{TG} = total gas flow out of incinerator (scfm)

T_{I2} = temperature in afterburner (°F)

W_i = internal width of hearth primary chamber (ft)

The total gas flow, q_{TG}, is calculated as in Section 3.4 of Reference 1. Typical afterburner temperatures range from 1,800° to 2,400°F. The thickness of refractory required is typically 9 in. for all incinerators and temperatures expected here, although a range of 6 in. (two bricks) to 13-1/2 in. (one brick plus 9 in. of insulating firebrick) exists depending on the application and vendor. For some applications involving relatively light service, castable refractory may be used because of ease of repair and economy. Although the actual thickness used will vary as much as with brick, a thickness of 6 in. should be adequate since castable is a better insulator than brick.

Based on a 9 in. by 4-1/2 in. by 3 in. brick, one cubic foot contains 14.2 brick equivalents. The cost of the brick depends on the application, although the general range is from $.80/brick to $3.00/brick. Exotic bricks used for high temperature and severe environments may cost well over $10.00/brick.

Although many properties of a given refractory must be taken into account before choosing the best refractory for a specific application, the initial criterion is the alumina content. Generally, the high alumina refractories cost more and will withstand high temperatures better than low alumina refractories. For low temperatures of 1,400° to 1,800°F, a brick composed of approximately 45 percent alumina is appropriate. A 60 percent alumina refractory is appropriate for temperatures up to approximately 2,400°F, and a 90 percent alumina refractory would be used for temperatures above 2,600°F, although such high alumina is approaching the exotic classification. Resistance to acid, alkali, erosion, and thermal shock are incorporated in refractories to various degrees of design compromise, depending on the application. However, refractory prices reflect the severity of the various chemical and physical demands imposed by the environment in which it will be used.

Table 1 presents some representative prices for refractory bricks in potential applications. These are based on vendor estimates. Mortar should also be included in the price of materials, assuming 315 lb/1,000 brick equivalents and an approximate cost of $600/ton. This amounts to an additional $0.10/brick. Although some incinerator manufacturers prefer to use castable refractory, castables have been costed only for application without chlorine, alkali, or other waste components which attack the castable bonding material. The castable is costed for the hydrocarbon cases for the liquid injection incinerator where it doesn't have to withstand chemical attack. The prices in Table 1 were selected as representative of a durable refractory in common use. Depending upon the specific application (waste characteristics, incinerator design, cycling duty, severity of service, etc.), refractory material costs could vary by a factor of 2.

Replacement costs for all the refractory in an incinerator (not just patching) is composed of removal, installation, and material costs. Removal costs are roughly equal to installation costs, while installation costs range from 1 to 4 times the materials cost, depending on the cost of the materials and the difficulties associated with installation in a particular facility, such as access to the combustion chamber. Therefore, total installed replacement costs (material, installation, and removal of previous material) will range from 3 to 9 times the cost of the material. A representative total installed cost is 5 times the material cost.

TABLE 1. ESTIMATED COST OF REFRACTORY (DOLLARS PER BRICK)[a] (JULY 1982)

		Temperature		
Incinerator	Waste	1,400° to 1,800°F	1,800° to 2,200°F	2,200° to 2,600°F
Liquid injection or afterburner	Hydrocarbons	1.60	1.60	1.60
	Hydrocarbons plus chlorine and/or alkali	1.80	2.60	2.60
Rotary kiln or hearth	All	2.60	2.60	2.60

[a]A brick equivalent is 9 in. by 4-1/2 in. by 3 in.

4.3 COMBUSTION CHAMBER REPLACEMENT

4.3.1 Description and Purpose of Retrofit

The combustion chamber is the heart of rotary kiln, liquid injection, and hearth incineration systems. It consists of a shell, burners, refractory, combustion controls, and blowers. The combustion chamber excludes the feed system, pollution control devices, and quenches. Within the scope of this study, combustion chambers are assumed to be retrofitted to a facility only if the increased performance demands cannot be met by modification of the existing unit, due to physical or space constraints. For example, increasing the operating temperature substantially would necessitate replacing the refractory with a thicker lining of more expensive brick. This, in turn, reduces the internal volume of the incinerator, and combined with the increased temperature, reduces the effective residence time such that a complete, new combustion chamber may be required.

4.3.2 Applicability and Limitations

Combustion chamber replacement is, in principle, potentially applicable to all incinerator designs. Specific limitations can only be ascertained on a specific incinerator design and site location basis.

4.3.3 Assumptions and User Guidelines

In estimating combustion chamber retrofit costs, the following design criteria are assumed:

- Liquid injection incinerators are designed to accommodate operating temperatures up to 2,200° to 2,400°F. Nominal residence time is 2 sec. The refractory lining is 6 to 8 in. of >3,000°F castable or 60 to 80 percent alumina firebrick (backed by insulating castable), which is suitable to withstand corrosive environments. Separate air-atomized guns and valve trains are provided for fuel, high- and low-Btu wastes. Combustion air blowers and accessories, complete flame safeguard and combustion control instrumentation are also included.

- Rotary kiln incinerators are designed for 1,500° to 1,800°F operation in the kiln and up to 2,400°F operation in the afterburner. Nominal gas residence time is 2 sec. The kiln itself consists of a stainless steel shell with dual girth gears, trunnion roll, and drive assemblies. The primary refractory lining is 70 percent alumina, 9 in. thick in the kiln and afterburner. The afterburner is horizontally aligned and integrally connected to the kiln breeching. Accessory equipment includes an ash quench tank and conveyor, ram feeder for bulk solid wastes, feed chute and double air-lock assembly for drum feeding in large units, high-Btu waste/fuel burners in the kiln and afterburner, low-Btu waste guns and slurry lances in the kiln feed plate, combustion air blowers, and a complete instrumentation package.

- Hearth incinerators are two-chamber units designed for 1,400° to 1,800°F operation in the primary chamber, 1,800° to 2,000°F operation in the secondary chamber, and 1 to 2 sec retention time in the secondary chamber, depending on capacity. Refractory is 3,000°F rated castable. Accessories include a ram feeder for solids, waste/fuel burners in the primary and/or secondary chambers (startup burners in both), an air blower, and control instrumentation. An ash ram, ash quench tank, and ash conveyor are also included in >10 million Btu/hr units.

4.3.4 Costs

Figures 3 through 5 present purchased equipment cost as function of incinerator capacity for hearth, rotary kiln, and liquid injection incinerators, respectively. Of course, the type of waste burned will have some effect on the cost, since it influences burner design, residence time, and temperature requirements. However, these estimates are based on reasonably conservative design criteria, and should be acceptable within the limits of budget pricing.

The cost of installing a new combustion chamber ranges from 25 to 100 percent of the purchased equipment cost. Typically a new installation will cost between 35 and 50 percent of the purchased equipment cost depending on size, degree of prepackaging, and other such considerations. A retrofit installation cost will approach the upper end of this range because the old unit must be removed. Freight charges of 5 to 10 percent of the purchased equipment cost should also be included in the total installed equipment cost.

To obtain the total capital cost, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed equipment cost, as specified in Section 3.

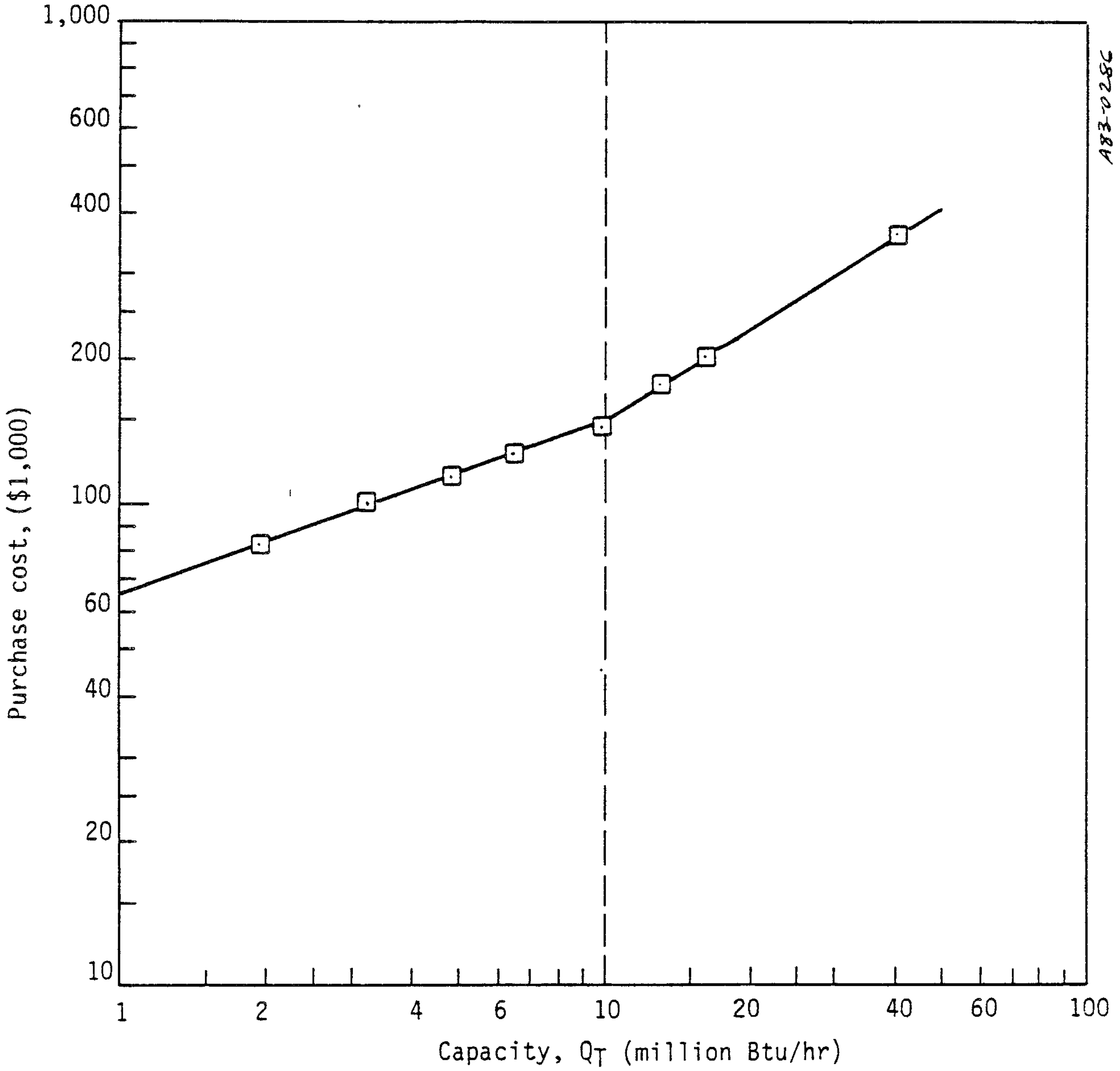

Figure 3. Purchase cost of multiple-chamber, hearth incinerators (July 1982).

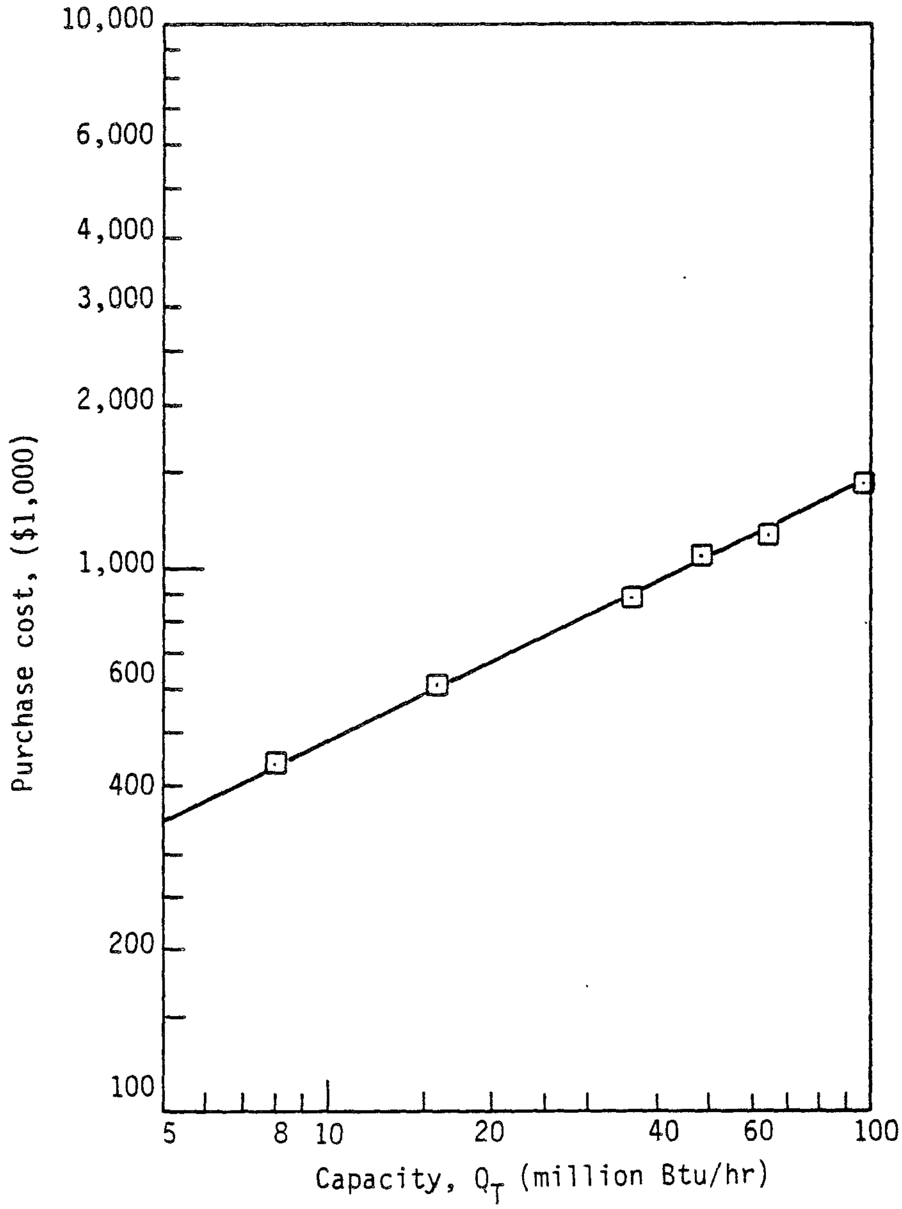

Figure 4. Purchase cost of rotary kiln incinerators (May 1982).

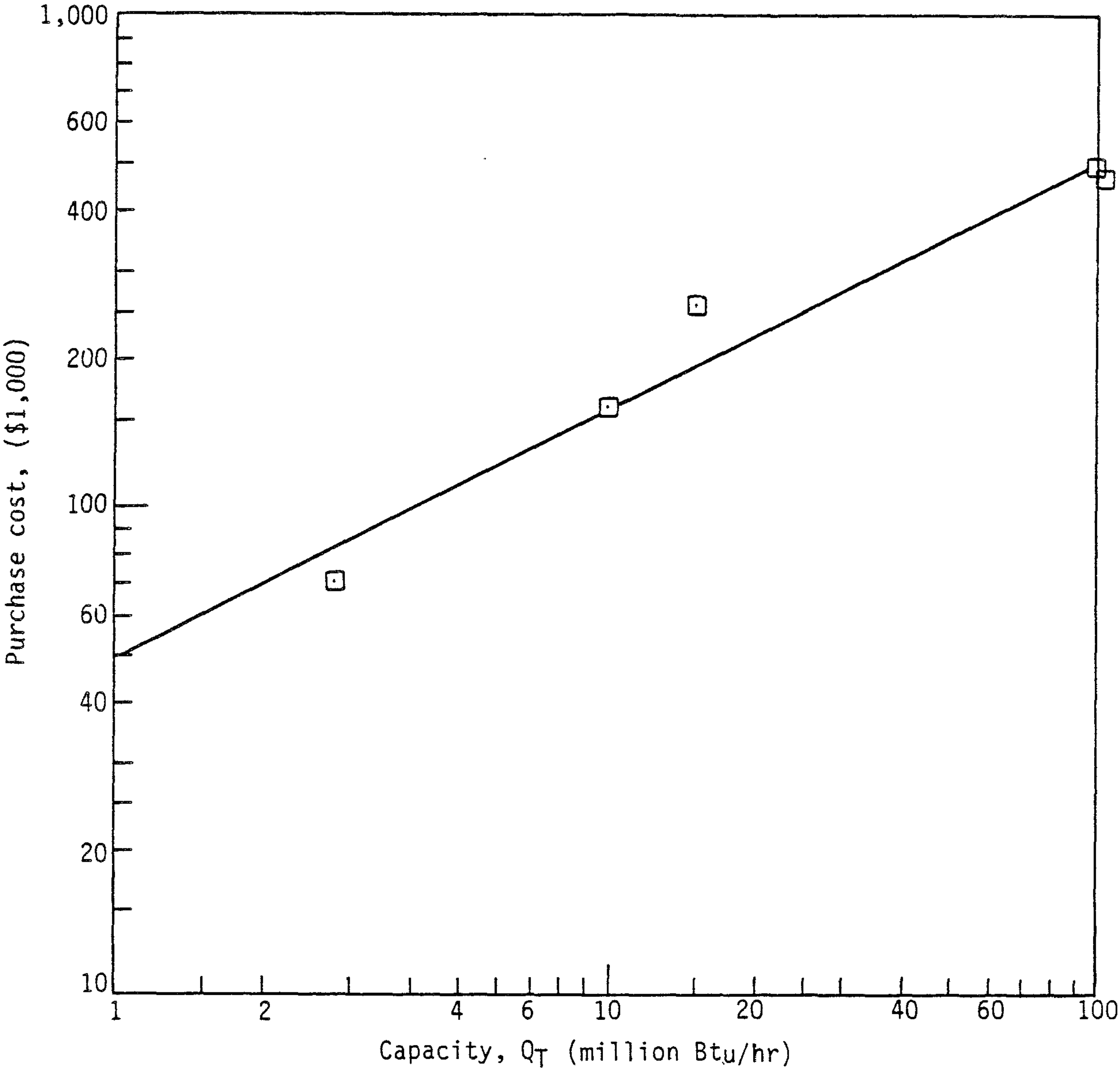

Figure 5. Purchase cost of liquid injection incinerators (July 1982).

SECTION 5

QUENCH/WASTE HEAT BOILER ADDITION

If air pollution control devices such as venturi scrubbers or acid gas absorbers are added to an existing incineration system, some means of cooling the hot flue gas prior to entry into the air pollution control devices (APCD) must be provided. Alternative cooling methods include a water quench or a waste heat boiler followed by a low-temperature quench. Energy recovery through a waste heat boiler may be preferred if the specific application is cost effective.

Quench replacement could also be required under circumstances where the incinerator is upgraded to operate at a substantially higher temperature. In many such cases, however, the existing quench may only require modification rather than replacement. Additional spray nozzles providing more cooling capacity can be added at a relatively low cost compared to complete quench system replacement. The costs for spray nozzle addition are not treated here because they are relatively minor compared to the costs associated with the major modifications and additions considered in this study.

5.1 QUENCH ADDITION

5.1.1 Description and Purpose of Retrofit

Quenches are used to reduce the temperature of the incinerator exit gas from 1,800° to 2,400°F down to adiabatic saturation temperature to protect the air pollution control system. Several quench designs are suitable for this purpose, including spray towers; submerged exhaust, pot-type quenches; and in-line, high-pressure spray quenches utilized with wetted throat venturi scrubbers. Quenches are frequently supplied by scrubbing equipment vendors as part of the overall gas cleaning/flue gas handling system. This retrofit scenario, in which an entire quench/scrubbing/flue gas handling system is added to the facility, is addressed in Section 6.

In some situations, however, it may be necessary to replace only the quench. In other cases, the scrubbing system may be purchased component by component from different vendors rather than from a single turnkey contractor. These are the scenarios addressed in this section.

5.1.2 Applicability and Limitations

- The costs presented in this section are applicable for quench addition, along with other scrubbing system components, or quench replacement in an existing gas cleanup system

- These costs also apply to high-temperature quench operation, so they are not applicable for facilities utilizing waste heat boilers

5.1.3 Assumptions and User Guidelines

- Spray tower quenches are assumed for cost estimating purposes. This type of quench design is frequently supplied as a separate equipment item.

- For standard service (low acid), quench towers are constructed of steel, lined with monolithic gunned refractory. For severe acid environments (up to 2 percent HCl in the gas), quenches are lined with dense, acid-resistant brick backed with an acid-resistant shell coating. Costs for these quenches can be considered virtual worst-case costs.

- Inlet gas temperatures range from 2,000° to 2,300°F. Vendors contacted during the course of this study indicated little difference in cost over this inlet temperature range. Outlet temperature is <200°F.

- Quenches come equipped with feedwater, drain, and gas inlet/outlet connections, spray nozzles and fittings, and booster pump

5.1.4 Costs

Figure 6 presents purchased equipment costs for quench systems as a function of mass flowrate of gas at the inlet, $(F_{TG})_I$. $(F_{TG})_I$ is a function of incinerator design, excess air rate, and fuel composition, and can be calculated by the methods shown in Section 3.4.7 of Reference 1. All costs are based on budgetary estimates from vendors.

Installation costs include the foundation, feedwater connections, ducting, and refractory installation (if the unit is field erected). Installation costs will vary from 30 to 50 percent of purchased equipment cost depending on whether the unit is field erected or packaged. These installation costs also assume that space is available to install the unit. Installation cost can double for quench replacement in facilities with tight space constraints.

To obtain the total retrofit cost, indirect costs such as engineering, construction field expenses, and contingency must be added to the installed equipment cost. The calculation procedures are presented in Section 3 of this report.

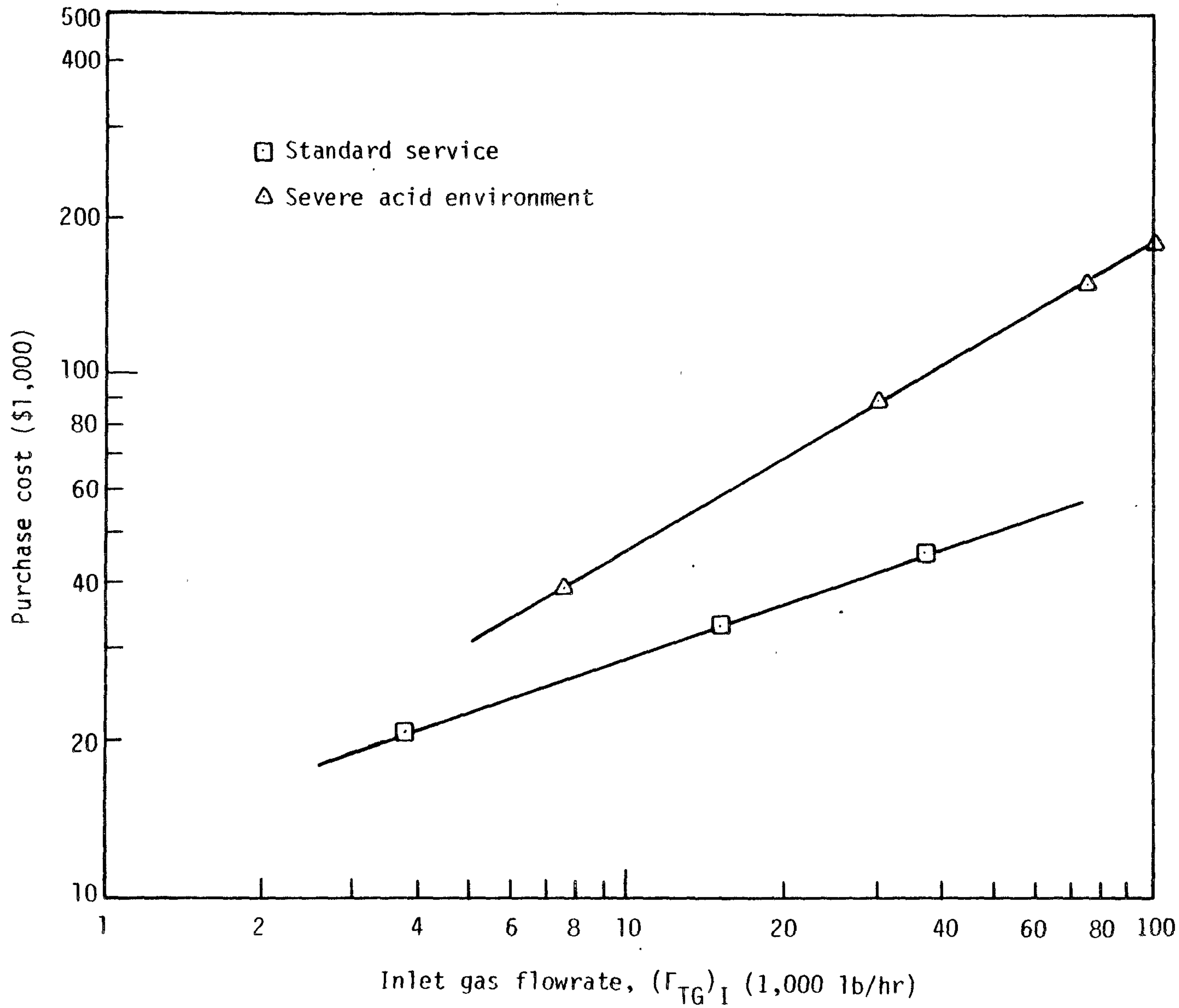

Figure 6. Purchase cost of quench towers (July 1982).

No significant additional operation and maintenance costs due to retrofit are anticipated beyond those associated with the quench itself. Operation and maintenance costs can be calculated as per Reference 1.

5.2 WASTE HEAT BOILERS

5.2.1 Description and Purpose of Retrofit

Waste heat boilers are potential cost saving alternatives to full-scale quench systems. They recover energy by making steam with the heat recovered from cooling the incinerator exhaust gas stream to 450° to 550°F. After the gas leaves the waste heat recovery system, a low-temperature quench is needed to cool the gas to <200°F to protect the downstream scrubber (see Section 5.3).

5.2.2 Applicability and Limitations

A waste heat recovery boiler may be applicable if:

- A need exists for the steam
- Alkalai metals or other low-fusion temperature inorganics which cause substantial fouling problems are not present in the waste feed
- The cost of the waste heat boiler and associated equipment (downstream quench) relative to the cost of a full-duty quench is justified by the steam provided

5.2.3 Assumptions and User Guidelines

- Firetube or watertube boilers may be used for energy recovery, although firetube designs are preferred, particularly in smaller facilities
- Inlet gas temperatures may range from 1,600° to 2,200°F with little impact on cost, based on vendor-supplied information. Exit gas temperatures are 450° to 550°F.
- Costs include the packaged boiler system plus standard trim (feedwater connection and regulator, blowoff valves, etc.), but no platforms, ducting, or control interface with upstream or downstream subsystems
- Watertube boilers are all baretube construction. One cost curve is provided for units of standard construction, and a second curve is provided for high HCl and high particulate service applications.

5.2.4 Costs

Figure 7 presents purchased equipment costs of waste heat boilers as a function of mass flowrate of flue gas $(F_{TG})_I$. These costs are based on vendor estimates.

Installation costs include foundations, feedwater connections, ducting, and startup. Installation costs for retrofit may range from 100 to 200 percent of the purchased equipment cost when the complete system is installed (depending on the size of the equipment and difficulty of finding a clear space for the boiler to be installed). Installing the boiler on an existing foundation to lines already in place, without extra ducting and piping, may run 30 percent of the purchased equipment cost. However, a minimum installation cost factor of 50 percent is recommended to account for platforms and control interfacing with other system components.

To obtain the total retrofit cost, indirect costs such as engineering and construction field expenses and contingency costs should be added to the installed equipment cost. These additonal costs should be calculated as in Section 3 of this report.

Operation and maintenance costs for retrofit applications are not expected to differ from those presented in Reference 1 and should be calculated in the same manner.

5.3 LOW-TEMPERATURE QUENCHES

5.3.1 Description and Purpose of Retrofit

Low-temperature quenches are used to saturate the waste heat boiler exhaust gas with water and cool it enough to protect downstream equipment. This practice is not critical if a venturi scrubber is installed downstream, however, it is important if only an acid gas absorber is utilized. Since the inlet gas for this application (400° to 600°F) is much cooler than for the high-temperature quenches (1,600° to 2,400°F), low-temperature quenches will be somewhat less expensive. The largest portion of the cost difference arises from the lower temperatures which do not require a refractory-lined chamber.

5.3.2 Applicability and Limitations

A small quench system will be needed in situations where a waste heat boiler exhausts to an APCD which requires a low (170° to 190°F) entrance temperature.

5.3.3 Assumptions and User Guidelines

Low-temperature quenches are similar to high-temperature quenches except that the lower inlet temperatures require a smaller volume, no refractory lining, and fewer spray nozzles. As in the high-temperature quench systems, the exhaust gas is quenched to saturation.

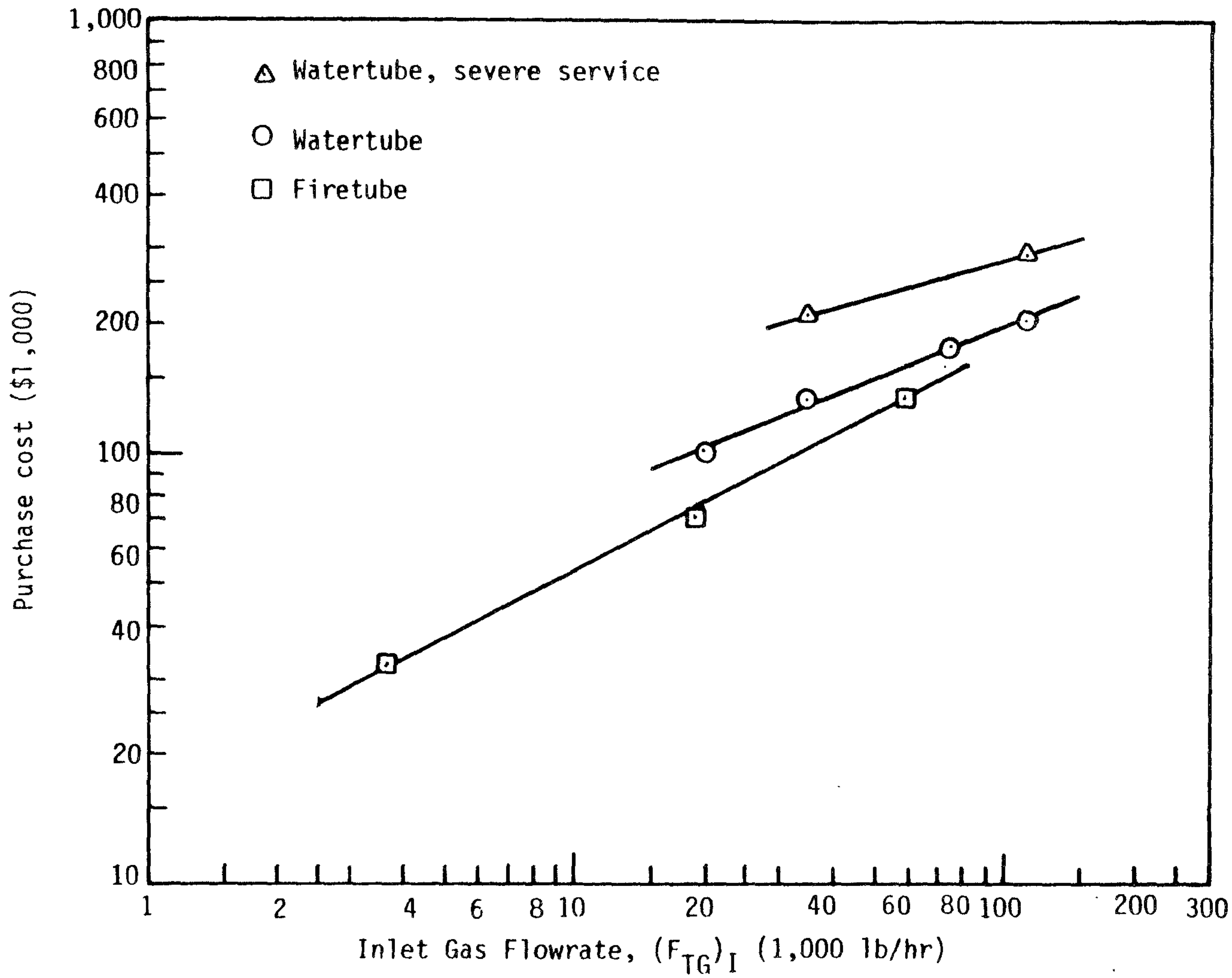

Figure 7. Purchase cost of waste heat boilers (July 1982).

5.3.4 Costs

Figure 8 presents purchased equipment costs for low-temperature quench systems as a function of the waste heat boiler exhaust gas flowrate (F_{TG}). F_{TG} is defined for high-temperature quenches (Section 5.1).

Installation costs are approximately 30 percent of delivered equipment cost. This cost should not be significantly different for a retrofit installation because these are relatively small systems, unless space constraints are critical. A reasonable allowance for freight is 5 percent of the purchased cost. To obtain the total retrofit cost, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed equipment cost. These additional expenses are calculated as per Section 3 of this report. The installation of a small quench will affect operation and maintenance costs only as indicated in Reference 1.

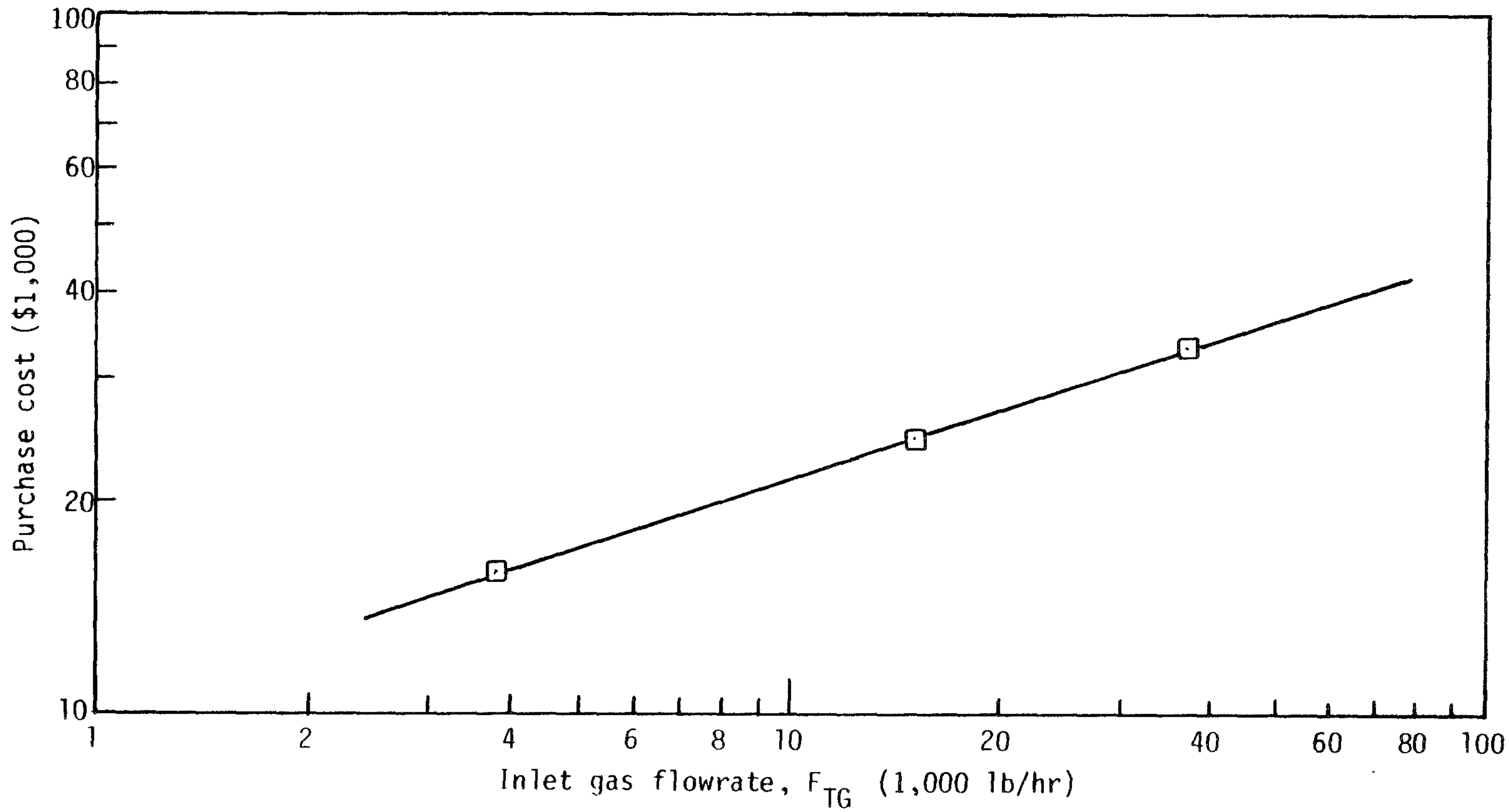

Figure 8. Purchase cost of low-temperature quenches (July 1982).

SECTION 6

SCRUBBING SYSTEM ADDITION/REPLACEMENT/MODIFICATION

Based on RCRA performance standards for hazardous waste incineration facilities, scrubbing system retrofit may be required to achieve either or both of the following requirements:

- Reduce particulate loading in the flue gas to $\leq$0.08 gr/dscf, and/or
- Improve HCl removal efficiency to $\geq$99 percent, if the waste feed contains >0.5 percent organically bound chlorine

Depending on the design and performance of the existing scrubbing system (if any), retrofit requirements may range from relatively minor adjustments in operation to the addition of a complete quenching/scrubbing/flue gas handling system. In certain cases, it may be possible for a facility to comply with the particulate control requirement simply by increasing pressure drop across an existing venturi scrubber. This assumes, of course, that the existing scrubber and fan are somewhat overdesigned for the original operating conditions. At the other extreme are older incineration facilities designed without particulate or HCl emission controls. In these cases, complete scrubbing and flue gas handling systems may need to be installed to comply with RCRA standards.

A myriad of potential retrofit scenarios exist between these extremes. Within the limits of this study, it was not possible to address every possible retrofit scenario. Therefore, the analysis is limited to retrofit cases where major capital additions or modifications are required. These scenarios are:

- Complete system addition, including quench, venturi scrubber, caustic recycle acid gas absorber, ID fan, and stack
- Particulate scrubbing system addition or replacement, including venturi scrubber and ancillary equipment
- Acid gas absorption system addition or replacement
- Acid gas absorption system modification for caustic recycle operation

Costs for these four retrofit scenarios are presented in the following sections. Section 7 addresses the costs for situations where only the flue gas handling system (fan, stack), and not the scrubbing system, requires modification.

6.1 COMPLETE SYSTEM ADDITION

6.1.1 Description and Purpose of Retrofit

In older hazardous waste incineration facilities designed without emission control equipment, addition of a complete gas-conditioning, particulate and HCl scrubbing, and flue gas handling system may be required to meet RCRA standards. For the purposes of this study, a "complete system" is assumed to include an in-line high-pressure spray quench, venturi scrubber, cyclonic separator with an integral packed tower absorber, caustic recycle system, ID fan, and exhaust stack, plus ductwork, piping, platforms, foundations, and controls.

6.1.2 Applicability and Limitations

The addition of a complete scrubbing system is primarily applicable to older incineration facilities constructed before the advent of strict regulations for particulate and HCl emissions. The costs presented below are for complete scrubbing systems designed to remove both particulate and HCl in accordance with current regulatory requirements. These costs are based on estimates from several vendors, and reflect modern design practices for HWI applications. However, they may not be applicable for all facilities because:

- It is assumed that all equipment is provided by a single turnkey vendor. Costs for scrubbing systems constructed component-by-component may be lower or higher, depending on the specific facility design and other economic factors.
- Quenching, particulate scrubbing, and acid gas absorption equipment design and materials of construction may differ from those assumed in this study. The design features and materials of construction assumed herein are common for HWI applications, but variations do exist. For example, ionizing wet scrubbers (IWS's) may be used in place of venturi scrubbers for particulate control in larger facilities. These types of trade-offs are discussed later in this section.

6.1.3 Assumptions and User Guidelines

A complete scrubbing/gas handling system is assumed to include the components listed in Table 2. The approximate contribution of each component to the total system cost is also listed. These guidelines are based on vendor-supplied information.

TABLE 2. SCRUBBING/FLUE GAS HANDLING SYSTEM COMPONENT COST BREAKDOWN

Component	Percentage of total system cost
In-line quench, venturi, wetted elbow	9
Cyclonic separator, integral packed tower absorber	30
Caustic system	17
ID fan	18
Stack	10
Ductwork	3
Piping	3
Platform, foundations	4
Instrumentation and controls	6
TOTAL	100

Critical compnent materials of construction are:

- High nickel alloy quench, venturi throat, and wetted elbow
- High-grade, chemically resistant, high-temperature fiberglass resin with a thick fiberglas shell for the cyclonic separator and packed tower
- Polypropylene tower packing
- Inconel or Hastelloy fan wheel with a rubber-lined steel housing

Baseline costs are for a 30-in. W.C. venturi pressure drop, which is typical for HWI applications.

6.1.4 Costs

Typical purchased costs for scrubbing/flue gas handling systems receiving combustion gas directly from the incinerator are presented in Figure 9. The inlet gas flowrate (q_{QI}) in acfm is given by:

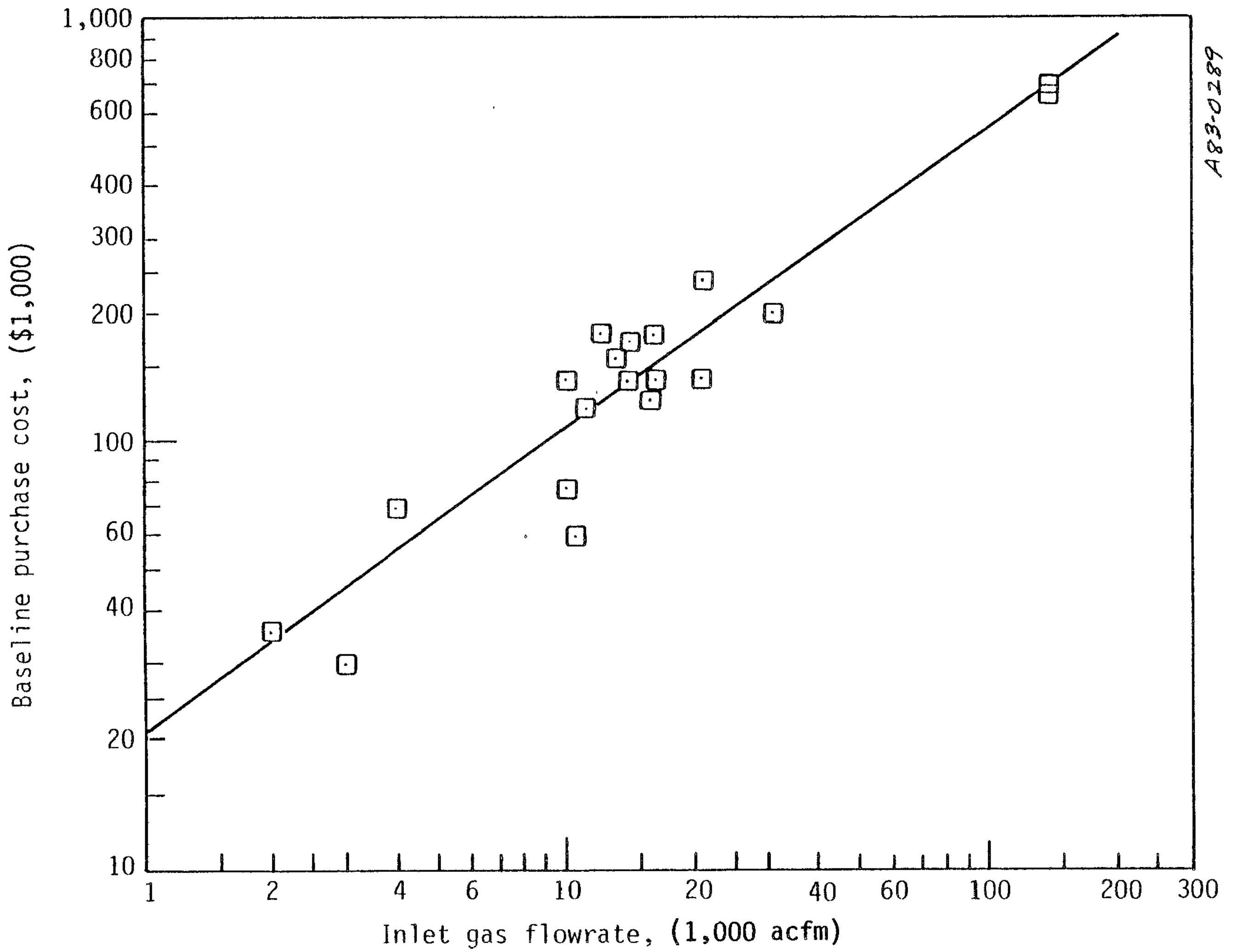

Figure 9. Purchase cost of scrubbing systems receiving 1,800° to 2,200°F gas (July 1982).

$$q_{QI}, \text{ acfm} = (q_{TG})_i \left(\frac{T + 460}{520}\right)$$

where $(q_{TG})_i$ = volumetric gas flowrate at the incinerator exit (scfm)

T = incinerator exit gas temperature (°F)

The costs shown previously in Figure 9 are based on a design inlet temperature of 2,200°F, and a venturi pressure drop of 30-in. W.C., which are typical conditions. For "worst case" pressure drops of 100-in. W.C., the total system cost is approximately twice that shown in Figure 9 due to more rigorous structural requirements and the inclusion of multiple high-head fans.

Figure 10 presents purchased costs for the same basic scrubbing systems designed to handle approximately 500° to 550°F gas from waste heat boilers. Differences in cost for these scrubbing systems versus the scrubbing systems designed for 2,200°F inlet gas reflect the differences in quench duty and saturated gas flowrates through the venturi, absorber, and fan.

Installation costs for scrubbing systems are typically about 50 percent of the purchased equipment cost, although they may run 100 percent of the purchased cost in difficult retrofit cases. Depending on location, freight costs may run 5 to 10 percent of the purchased cost. To obtain the total retrofit cost, it is also necessary to factor in indirect costs and contingency as specified in Section 3.

O&M costs will almost certainly be increased by scrubber system performance upgrading regardless of whether the complete system, or only components thereof, are retrofitted. Incremental O&M costs due to upgrading can be projected from "before" and "after" O&M cost estimates using the methods given in Reference 1.

6.2 PARTICULATE SCRUBBING SYSTEM ADDITION/REPLACEMENT

In many cases, it may not be necessary to include HCl absorption capability in the retrofitted scrubbing system. The purpose of this section is to estimate the total installed costs of retrofitting venturi scrubbing systems into hazardous waste incineration facilities for control of particulate emissions only, not HCl or other acid gases. The degree of particulate control is determined by the requirements set forth in the RCRA Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities, Subpart O. The January 23, 1981 Interim Final Rule (promulgated June 24, 1982) requires control of particulate matter to a level not exceeding 180 mg/dscm corrected to 12 percent CO_2 (0.08 gr/dscf). For purposes of this retrofit cost study, a range of values from 0.08 to 0.03 gr/dscf have been evaluated. As particulate emission requirements become more stringent, the subsequent venturi scrubber performance demands and costs will increase accordingly. This section estimates these relationships.

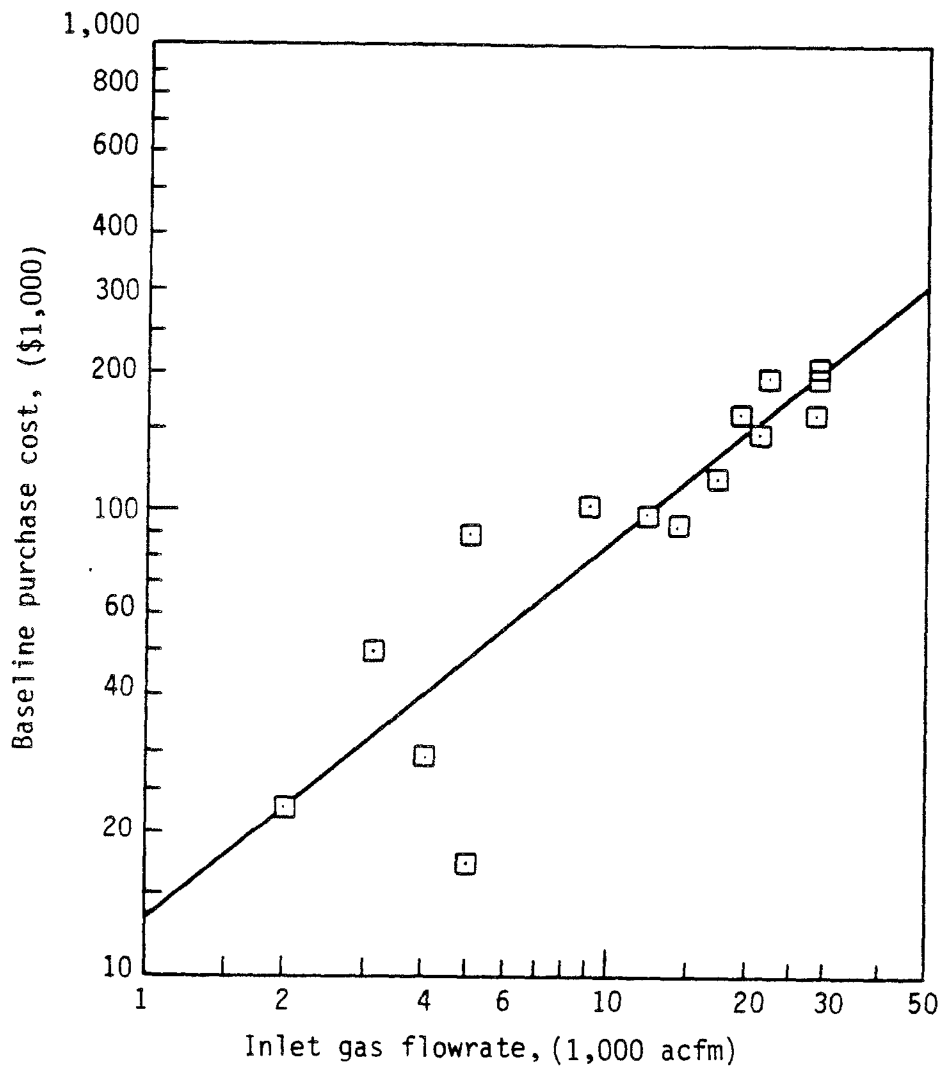

Figure 10. Purchase cost of scrubbing systems receiving 500° to 550°F gas (July 1982).

6.2.1 Description and Purpose of Retrofit

Particulate matter in hazardous waste incinerators is formed from metal salts in the waste, metal oxides formed in combustion, and products of incomplete combustion. Most existing incinerators control particulate emissions with a venturi scrubber. Venturi scrubbers operate on the principle that high relative velocities between the gas to be cleaned and the scrubbing liquid promote particle collection. High relative velocities in the venturi scrubber are achieved in the converging section. Liquid is introduced at a point where the gas stream has reached high velocities, causing atomization of the liquid and entrainment in the gas stream. Dust particles are trapped by droplets in this turbulent region and subsequently removed from the gas stream, typically in a cyclonic separator, which is an integral component of the scrubbing system.

Other pollution control devices have been considered for use in hazardous waste incinerators, such as baghouses, cyclones, and electrostatic precipitators (ESP), but the vast majority of existing facilities employ venturi scrubbers. Baghouses are unable to withstand the temperature and corrosivity, and water buildup can blind bags. Cyclones cannot obtain the required efficiency with the relatively small particulate typical of these facilities, and ESP's have a high capital and operating cost.

IWS's are gaining in popularity. IWS's are capable of simultaneously removing corrosive gases and particulate material. Particles are electrostatically charged in an ionizer section prior to passing through a packed bed scrubbing section where a caustic scrubbant enters crossflow with the gas stream. While capital costs for the IWS are substantially higher than conventional venturi systems, operating costs appear to be lower. This is a result of the low pressure drop of the IWS relative to a venturi scrubber, thus saving on induced draft (ID) fan costs and electrical operating costs. This electrical energy saving is somewhat offset by the power required in the ionizer section. Detailed IWS vendor quotes for retrofit cases will be supplied in a subsequent report serving as an addendum to Reference 1.

For purposes of this analysis, it is assumed that existing particulate controls, if any are employed, have been designed to meet regulations which, in general, are less stringent than 0.08 gr/dscf. Particulate emission standards from 0.08 to 0.03 gr/dscf are being evaluated in this study for their impact on scrubber retrofit costs. Therefore, these new emission standards require an upgrading of scrubber performance. In theory, this can be done by either modifying an existing scrubber (specifically, increasing pressure drop to improve collection efficiency) or by replacing an existing unit with one capable of better performance. Given the assumption of the need for substantial performance improvement, modification can be eliminated as an option. Structural requirements greatly limit increases in pressure drop essential to improved performance. Thus, only the complete replacement option has been considered.

6.2.2 Applicability and Limitations

Guidelines are presented in the following paragraphs to determine the total retrofit cost of a replacement venturi scrubber system for a range of inlet gas flowrates. Guidelines are also given for determining required pressure drops across the venturi scrubber in order to achieve the specified particulate emission rates. Since these guidelines are only approximations developed for this study, and subject to specific assumptions detailed below, they should not be used in a quantitative design sense. This can only be done if a facility's actual incinerator outlet particle size distribution is known. Venturi scrubber performance is highly dependent on such data. If such data are available, the more detailed methods presented in Reference 1 can be used to estimate pressure drop requirements.

6.2.3 Assumptions and User Guidelines

In this study and in Reference 1, it is conservatively assumed that particulate removal devices such as venturi scrubbers are required if the particulate loading in the incinerator effluent is greater than the desired outlet loading. Incidental removal in pot-type quench systems, fallout to waste heat boiler dust hoppers, and incidental removal in acid gas absorbers can provide some particulate control for large particle sizes, but very little control of submicron particulate.

Venturi pressure drop requirements are sensitive to the required particulate removal efficiency, and quite sensitive to the aerodynamic particle size distribution. Typical pressure drop requirements are a 20- to 40-in. W.C., with a 30-in. W.C. being a good midrange value for first cut estimating purposes. However, pressure drop requirements may range up to 100-in. W.C. for >98 percent collection of extremely fine submicron particulate. Virtual worst-case pressure drop requirements are shown in Table 3* as a function of the required outlet grain loading and collection efficiency. These values are based on a conservative inlet grain loading of 2 gr/dscf and a mean aerodynamic particle diameter of 0.7 μm.

6.2.4 Costs

As indicated in Section 6.1.3, the quench/venturi scrubber typically account for 9 percent of the purchased cost of a complete scrubbing/flue gas handling system. Even for the optimum retrofit scenario, however, where the existing cyclonic separator, fan, stack, and scrubber controls can still be utilized, additional (new) ductwork and piping will be needed when the quench/venturi scrubber are replaced. Thus, the equipment costs for this "best case" retrofit scenario are approximately 15 percent of the total system costs presented in Figures 9 and 10.

*More detailed methods to estimate pressure drop requirements are given in Reference 1.

TABLE 3. PRESSURE DROP VERSUS OUTLET PARTICULATE LOADING AND COLLECTION EFFICIENCY[a]

Outlet particulate loading (gr/dscf)	Collection efficiency (percent)	Pressure drop (in. W.C.)
0.08	96.0	40
0.07	96.5	45
0.06	97.0	55
0.05	97.5	65
0.04	98.0	80
0.03	98.5	100

[a]Conservative values based on an inlet grain loading of 2 gr/dscf and a mean aerodynamic particle diameter of 0.7 μm.

In many cases, it may be necessary to add or replace a complete particulate scrubbing system, including the quench/venturi, cyclonic separator, ID fan, and stack, plus ductwork, piping, platforms, foundations, and controls. Equipment costs for this retrofit scenario are approximately 55 to 65 percent of the total system purchased costs presented in Figures 9 and 10.

The previously mentioned costs are based on a "typical" venturi pressure drop requirement of a 30-in. W.C. The values presented in Table 3 are based on a very conservative inlet grain loading and particle size distribution. For the virtual worst case pressure drop requirement of a 100-in. W.C., purchased costs for complete particulate scrubbing systems (but no acid gas absorption) are approximately 110 to 130 percent of the costs presented in Figures 9 and 10.

Installation, freight, and indirect cost factors are approximately the same as those presented in Section 6.1.4 for complete HWI scrubbing systems.

6.3 ACID GAS ABSORPTION SYSTEM ADDITION/REPLACEMENT/MODIFICATION

The purpose of this section is to estimate the total installed costs of either increasing the performance of an existing absorber or of retrofitting an acid gas absorber into a hazardous waste incinerator for control of HCl emissions. The degree of HCl removal is set forth in the RCRA Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities, Subpart O. The January 23, 1981 Interim Final Rule requires 99 percent HCl removal efficiency for incinerators burning wastes containing more than 0.5 percent chlorine. There is no requirement for incinerators burning wastes containing less than 0.5 percent chlorine.

6.3.1 Description and Purpose of Retrofit

There are three options that may be available to owners and operators of hazardous waste incinerators to meet the 99 percent removal efficiency requirement.

1. Increase efficiency of an existing acid gas absorber by adding transfer units (i.e., increasing packed bed depth in a packed bed absorber or adding trays in a tray tower absorber).

2. Increase efficiency on an existing once-through water scrubbing unit by changing to a caustic recycle system.

3. Retrofit an absorber to an existing incinerator.

Option 1 is not considered in this analysis because the gains in HCl removal efficiency obtained by adding packed bed depth or trays is usually marginal, unless the original design is completely inadequate. For a given increase in efficiency, packed bed depth increases exponentially to a realistic maximum of approximately 10 ft. Beyond that depth, liquid channeling becomes a problem and may actually be detrimental to efficiency.

This section presents the cost relationships for the remaining two options.

6.3.2 Applicability and Limitations

Guidelines are presented in the following paragraphs to determine: (1) the total retrofit cost of increasing HCl removal efficiency of an existing absorber by changing scrubber liquid systems, and (2) the retrofit cost of replacing an existing absorber. Because these guidelines are only approximations and subject to the specific assumptions detailed below, they should not be used in a quantitative design sense. This can only be done if operating parameters of the facility in question are known. In general, however, the retrofit of an acid gas absorber should not be a difficult project in terms of space requirements. Absorber units are vertical structures of relatively small diameters, and should not present undue difficulties. Cost guidelines presented here are generally applicable to all facilities burning chlorinated wastes containing in excess of 0.5 percent chlorine.

6.3.3 Assumptions and User Guidelines

Partial removal of HCl is achieved in quench systems and in venturi scrubbers, although an HCl removal efficiency in excess of 90 percent usually requires the addition of an absorber. Once-through water absorbers can achieve the required 99 percent HCl removal in many cases. In certain retrofit situations, however, conversion to caustic scrubbing will be required.

Packed bed or tray tower absorbers can be used for HCl removal with reasonably similar capital and operating costs. Lime or caustic soda can be used for HCl neutralization. For the purposes of this study, caustic soda solution scrubbing in packed towers absorbers is assumed as explained in Section 6.1.3.

There is some finite amount of water in the fired waste so that the adiabatic saturation temperature remains relatively low (less than 180°F) at the inlet of the packed bed absorber. There is a negligible amount of free chlorine in the flue gas, thus obviating the formation of sodium hypochlorite, a strong oxidant that attacks most packing materials. It is assumed that no hydrogen fluoride is present in the flue gas. If any one of these conditions is not met, then a more expensive packing material such as Kynar, may have to be used, raising the cost of the APCD system up to 50 percent.

6.3.4 Costs

Equipment costs for complete acid gas absorption systems, without venturi scrubbers for particulate control, are approximately 85 percent of the costs for complete scrubbing systems shown in Figures 9 and 10. Correspondingly, the costs for conversion to a caustic recycle system run about 25 percent of the costs presented in Figures 9 and 10. This includes allowances for the recycle tank and pumps, additional piping, and pH controls.

Installation, freight, and indirect cost factors are roughly the same as those presented in Section 6.1.4.

SECTION 7

FLUE GAS HANDLING EQUIPMENT

Flue gas handling equipment in an incinerator system includes the following components:

- Ductwork
- Fan and motor
- Exhaust stack

Major cost impacts on gas handling equipment due to air pollution control equipment addition/modification or stringent environmental regulation would fall on the fan and stack systems. Ductwork modification costs are relatively minor, and have already been included with the various APCD modifications. The addition or modification of APCD's may require a higher pressure drop capacity fan. Local environmental regulations may require taller exhaust stacks for better pollutant dispersion. The scrubbing system retrofit costs presented in Section 6 generally include allowances for new fans and stack. However, separate fan and stack costs are presented in this section for situations in which only these equipment items, and not the scrubbing system components themselves, need to be replaced.

7.1 INDUCED DRAFT FAN ADDITION/REPLACEMENT

7.1.1 Description and Purpose of Retrofit

In hazardous waste incineration systems, induced draft (ID) fans are commonly used to move the incinerator off-gas through the system. In the following discussion, the term "fan" refers to the complete fan and motor assembly. These fans are usually located downstream of any pollution control equipment. The fans are designed for a specific pressure drop (ΔP) and range of gas flowrates. Small ΔP changes can be accommodated by an existing fan. However, should the ΔP increase significantly (>5-in. W.C.) due to added upstream equipment and ducting or modified operation, more pressure head must be supplied by the fan system. This is done either by adding a booster fan in series with the existing fan or replacing the fan with one of higher capacity.

7.1.2 Applicability and Limitations

There are no strict rules to determine when to add a booster fan as opposed to replacing the existing fan. The advantages and disadvantages of each should be determined on a case-by-case basis. One general rule is not to connect more than two fans in series. This creates complicated control schemes making the fan system difficult to operate. In general, more than two fans in series may be required if pressure head requirements are over a 100-in. W.C.

Several factors affect the choice of adding a booster fan versus replacing the existing fan due to upstream air pollution control equipment changes. These include:

- Space limitations
- Pressure drop increase
- Change in stream conditions (moisture content, acid content, etc.)

If space is not available for ducting and an extra fan, one way to decrease space requirements would be to replace the existing fan with one that will meet the added requirements. If the pressure load required is increased significantly by adding upstream pollution control equipment and/or simply increasing venturi scrubber ΔP, two fans in series might need to be added to the existing fan to add the necessary pressure load. This creates the control problem mentioned earlier. In that case it might be preferable to replace the existing fan with two new fans in series which provide all the required pressure load. A change in stream conditions may make the existing fan incapable of easy operation even with a booster fan. In this case, the existing fan might have to be replaced.

7.1.3 Assumptions and User Guidelines

Retrofit fan (including motor) costs were estimated based on assumed pressure drops for the various pieces of equipment and applying these pressure drops over a range of gas flowrates. The assumed pressure losses for the various pieces of equipment are as follows:

- Incinerator 4- to 5-in. W.C.
- Waste heat boiler 4-in. W.C.
- Quench 1-in. W.C.
- Venturi scrubber 20- to 100-in. W.C.
- Acid gas scrubber 2- to 7-in. W.C.
- Demister 1- to 10-in. W.C.

An overdesign factor of 25 percent was used on pressure load. With the above pressure losses and the overdesign factor, the pressure load range of interest is a 40- to 160-in. W.C.

The fan costs are based on several material considerations. The fan shafts and blades are exposed to 140° to 180°F saturated gas with approximately 0.02 percent by volume acid. Therefore, these parts are assumed to be Inconel or Hastelloy for corrosion resistance. The fan housing and inlet box are assumed to be rubber-lined carbon steel. If acid or alkaline waste is not going to be fired in the incinerator, carbon steel, which is much cheaper than Inconel or Hastelloy, could be used for the fan blades and shafts.

7.1.4 Costs

Cost curves for fans in various gas flowrate and pressure drop ranges are presented in Figures 11 and 12. These costs include:

- Fan wheels and shafts
- Electric motor(s) and controls
- Inlet box and damper
- Cooled bearing with vibration and temperature sensors
- Coupling and interconnecting ducting, where applicable

As shown in Figures 11 and 12, the cost of carbon steel fan is less than for corrosion-resistant fans.

Careful consideration should be given before using these costs because fan costs are very dependent on fan type. For example, several vendors do not offer fans which can supply 160-in. W.C. pressure; however, others have machines which can supply that pressure but have flow limitations. Also, fan design affects the cost. One manufacturer could not supply costs for a rubber-lined housing because his fan design does not permit lining the housing. Therefore, his costs were higher because the housing is costed as corrosion-resistant stainless steel.

Below a gas flowrate of 10,000 acfm, fan costs become dependent on fan type. Several vendors needed special fan designs requiring fairly complex manufacturing procedures to give a high-pressure head fan (>40-in. W.C.), whereas vendors of fans of a different design could supply the required low-flow and high-pressure fan from one of "standard design."

Installation of fans usually takes approximately 6 to 8 man-weeks with a crane needed for approximately 1/2 to 2 days. Installation costs are usually less than $20,000 to $30,000. These costs include:

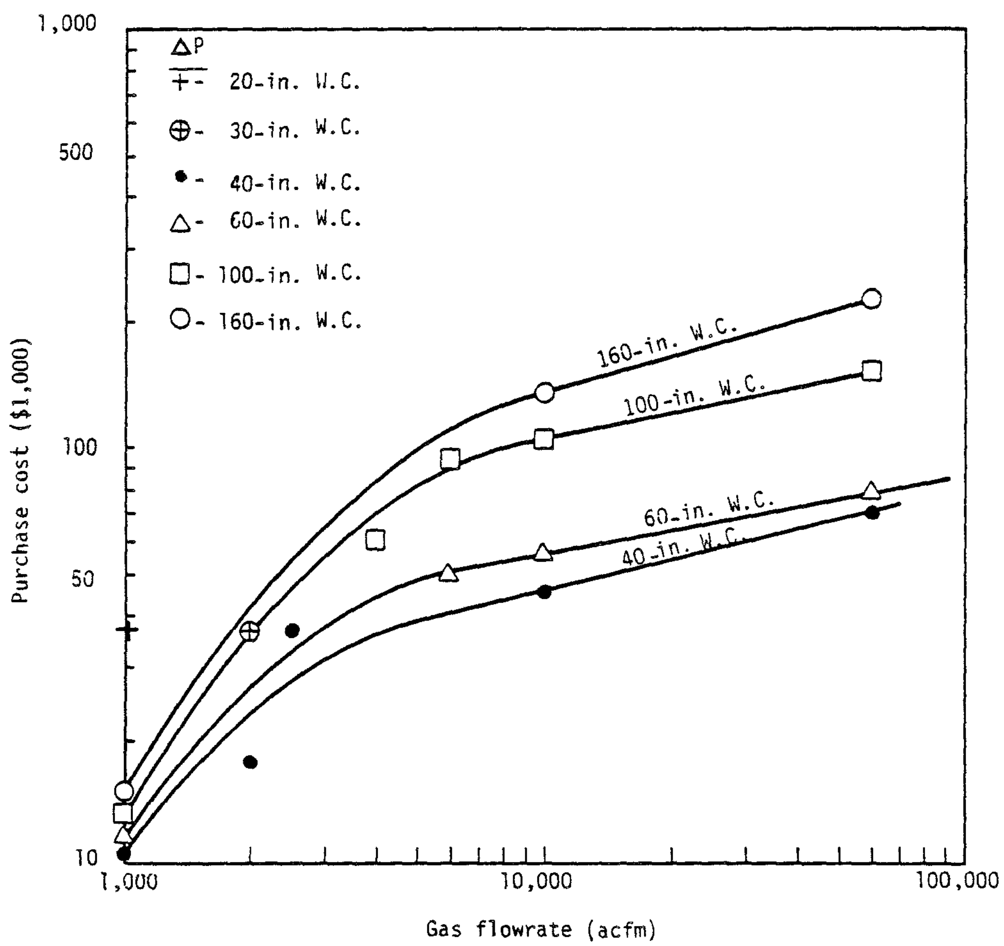

Figure 11. Purchase cost of carbon steel fans (July 1982).

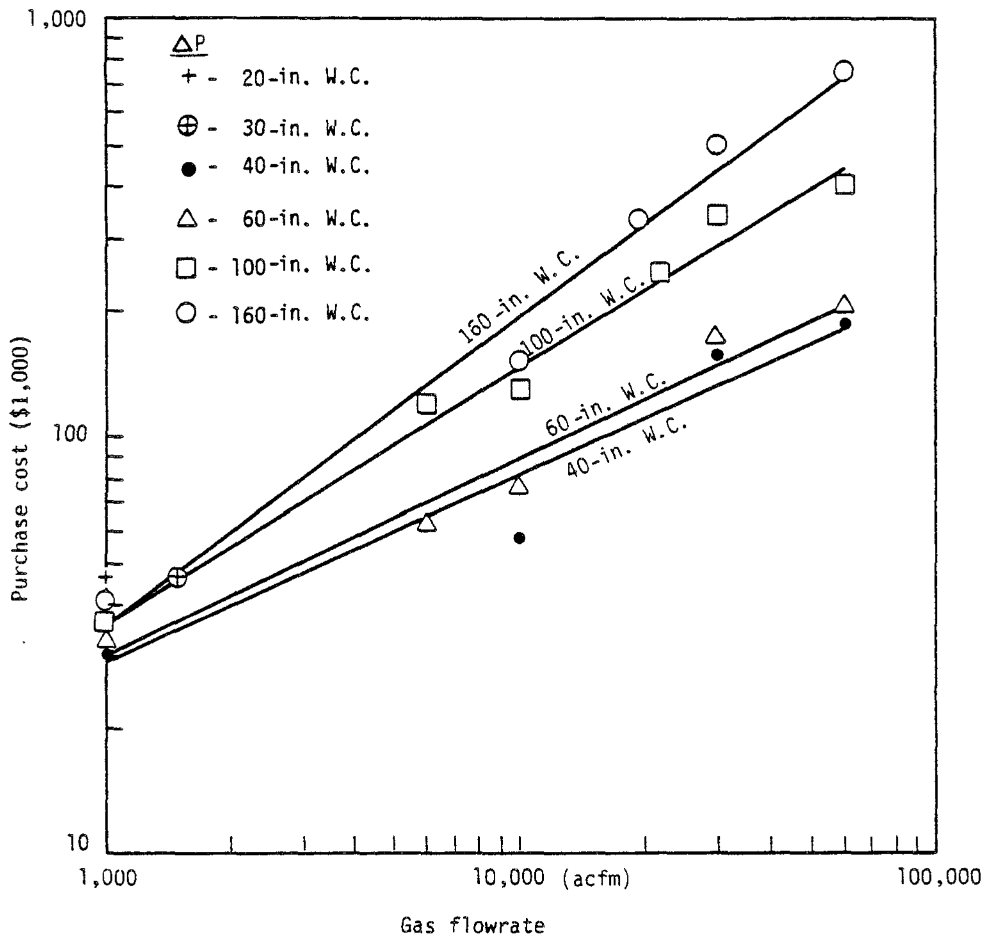

Figure 12. Purchase cost of corrosion-resistant fans (July 1982).

- Structural
- Electrical
- Crane rental
- Labor

There is very little dependence of installation costs on fan size. However, if two fans are being installed, costs are higher because of interconnecting ductwork erection, added crane rental, and labor.

Maintenance procedures on these fans should be no different than those for the existing fans. Thus maintenance costs should be calculated in the same manner as given in Section 5 of Reference 1. However, should a booster fan be added to an existing fan, or two fans be used to replace a single existing fan, the maintenance costs will be greater than for the single fan case. This is reflected in Reference 1 as a function of the difference in capital cost. Operation costs will be no different than for the existing fan except for the additional power costs. This cost can be calculated using the formula contained in Section 3.6 of Reference 1.

Finally, to obtain total retrofit costs, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed equipment costs, as specified in Section 3.

7.2 STACK REPLACEMENT

7.2.1 <u>Description and Purpose of Retrofit</u>

Small diameter stacks are used to vent the flue gas from incinerator systems, the purpose being to discharge the combustion products away from the immediate work area. However, an existing stack may have to be replaced with one of taller design to meet a local ordinance and/or to achieve better dispersion of the waste products.

In general, stacks can be constructed from a variety of materials, including:

- Fiber-reinforced plastic (FRP)
- Carbon steel
- Stainless steel
- Refractory-lined carbon steel
- Monel or Hastelloy

Because hazardous waste incinerators often fire acid- or alkali-producing wastes, carbon steel and possibly stainless steel cannot be utilized because of corrosion problems. Carbon steel stacks lined with acid resistant plastic have been utilized, but thermal expansion incompatibility problems have been reported in limited applications. The exotic materials such as Hastelloy are too expensive except for special applications. FRP stacks are the preferred design because of their lower cost and high corrosion resistance, but can only be used if the incinerator has a downstream quench and scrubber system which cools the flue gas to at least 250°F before it reaches the stack. If high-temperature exhaust gases must be vented, then a corrosion-resistant refractory brick-lined carbon steel stack is generally specified.

Small diameter stacks up to 6 ft in diameter have been installed up to 200 ft high by proper use of guy wires.

7.2.2 Applicability and Limitations

Incinerator systems with quench and APCD equipment generally use FRP stacks. If an emergency vent stack is required or if the incinerator routinely exhausts its hot gases directly to the stack, then the refractory-lined stack is called for. The actual selection and design of the stack must be done on site-specific basis.

As to design diameter and height limitations, those must be based on local ordinances, meteorology, topography, geology, etc. Some guidelines are given in the following paragraphs.

7.2.3 Assumptions and User Guidelines

It is assumed that the stack is free standing, e.g., not an integral part of an acid gas scrubber column. A retrofit or replacement stack usually costs no more than a "grass roots" stack. The new stack is merely erected next to the old one, and the appropriate ductwork and breeching connected.

A rough design guideline for stack diameter D is given by

$$D = \left[\frac{4 q_{TG} \left(\frac{T = 460}{520} \right)}{60\ \Pi \nu} \right]^{0.5}$$

where q_{TG} is the total flue gas flowrate (scfm) calculated in Section 3 of Reference 1, T(°F) is the exhaust gas temperature (exact temperature dependent on APCD configuration), and ν is the stack exit gas design velocity, usually 40 to 60 ft/s.

7.2.4 Costs

Figures 13 and 14 present fabricated costs of FRP and refractory-lined steel stacks, respectively, as a function of stack height and diameter. Note that costs are fairly linear with stack height. Indeed, stacks are usually erected from prefabricated 20- to 40-ft flanged sections. The costs of refractory-lined stacks are nearly double that of FRP stacks.

A good estimate of installation costs for either design is that installation costs are comparable to the fabricated material costs. Finally, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed cost to obtain total the retrofit cost, as specified in Section 3.

No additional operational or maintenance impacts are expected with the new stack.

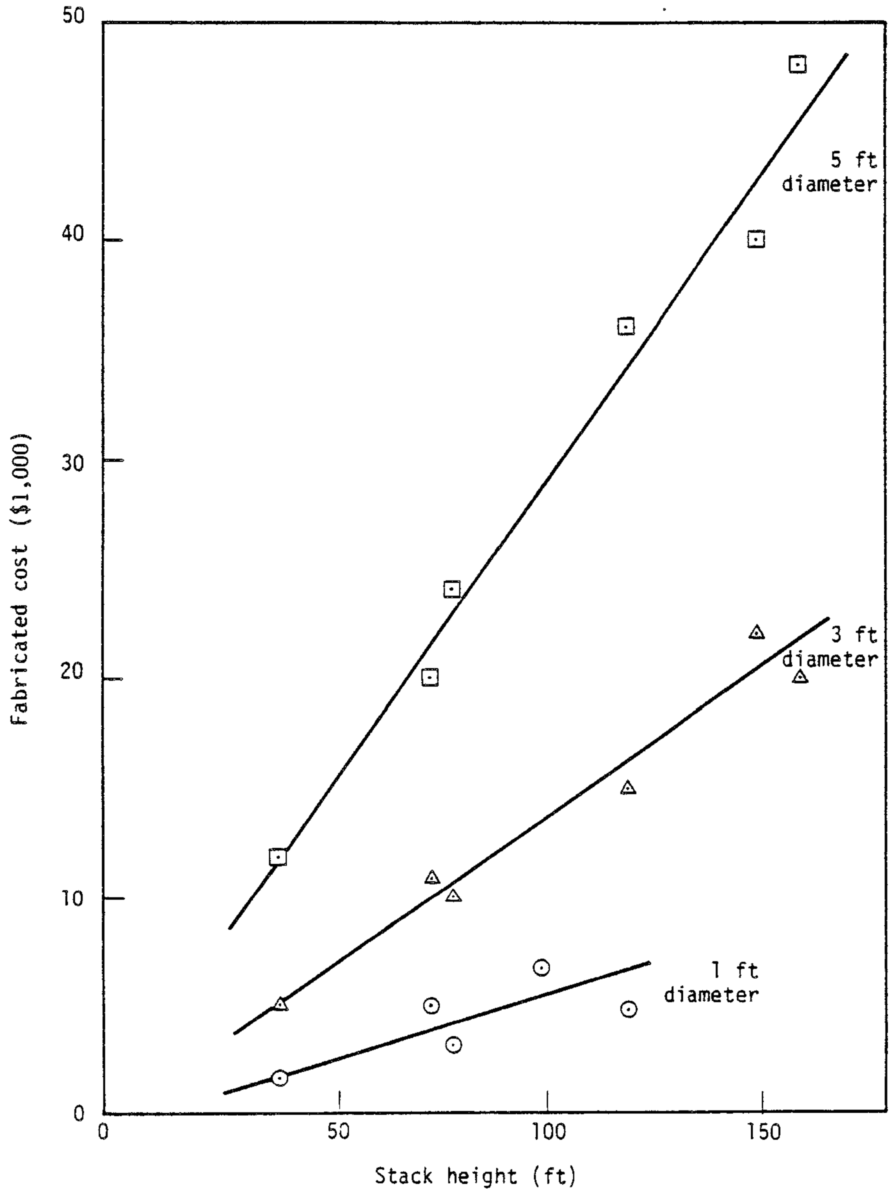

Figure 13. Fabricated cost of FRP stacks (July 1982).

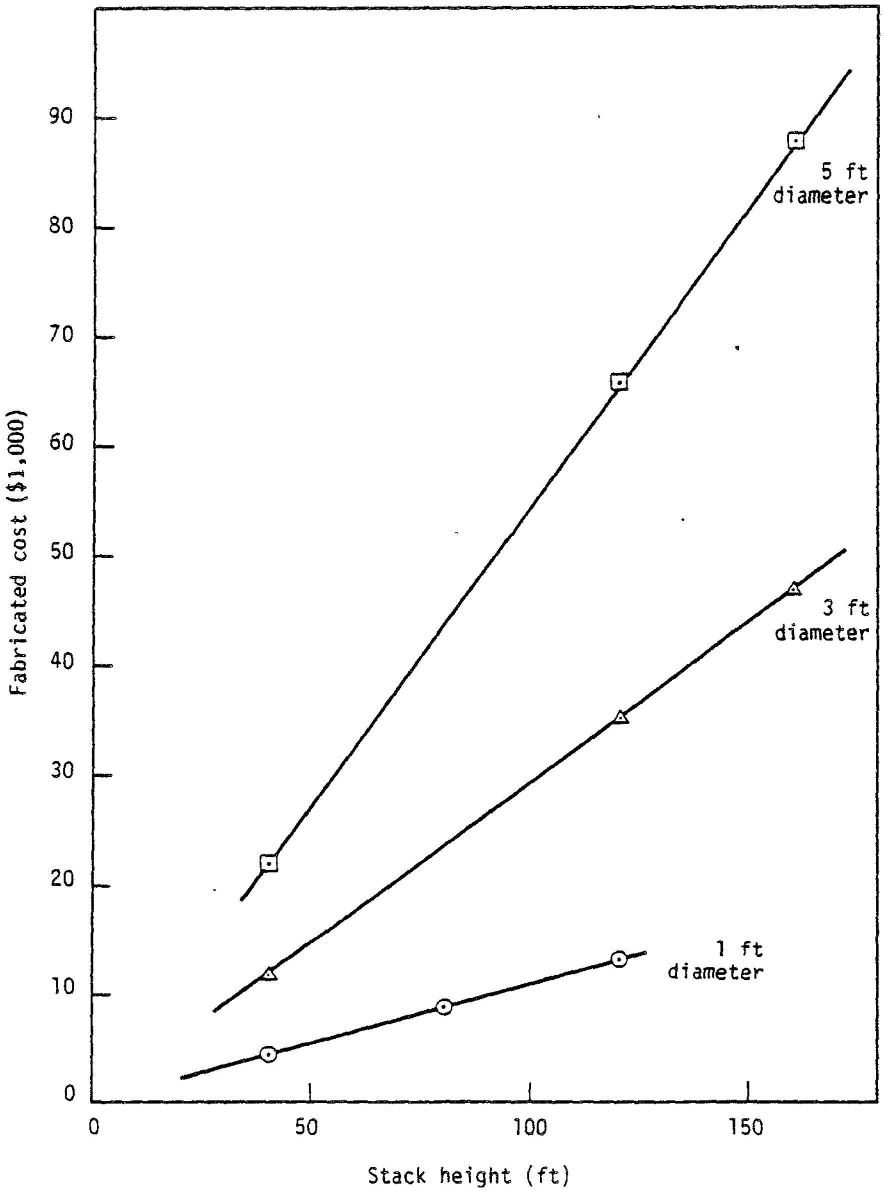

Figure 14. Fabricated cost of refractory-lined steel stacks (July 1982).

SECTION 8

TOTAL INCINERATION SYSTEM REPLACEMENT

Upgrading an aging hazardous waste incineration system by component modification or retrofit to meet regulatory compliance may not necessarily be the optimum choice. Total system replacement may be preferred. The actual decision may be based on a number of business factors, although the physical condition of the existing equipment and the comparative costs of retrofit versus total system replacement are key criteria.

8.1 DESCRIPTION AND PURPOSE OF REPLACEMENT

If the existing incinerator and air pollution control system is beyond its economic life for tax depreciation purposes and major capital additions or modifications are required for regulatory compliance, then total system replacement may be applicable. Total system replacement may also be appropriate if the annualized capital and operating costs of the proposed new system are less than those projected for the existing system after modification. Finally, total system replacement may be the only reasonable alternative if the existing system cannot be effectively retrofitted, e.g., because of equipment obsolescence. However, other political and business-related factors will also impact the decision.

As defined here, an incineration system includes all equipment necessary to burn hazardous waste in compliance with existing and likely near-term regulations. Equipment includes:

- Incinerator proper, with associated ash-handling equipment
- Quench and/or waste heat boiler
- Venturi scrubber
- Acid gas absorber
- Flue-gas-handling equipment
    - Ductwork
    - Fan and motor
    - Stack
- Instrumentation and controls

The costs presented in this section do not include allowances for waste heat boilers. However, Figure 7 in Section 5.2 can be used to estimate incremental costs for waste heat boiler addition, if desired. Costs for waste storage and handling equipment are also deleted herein due to their site-specific nature. If necessary, however, these costs can be estimated as shown in Sections 3 and 4 of Reference 1.

8.2 APPLICABILITY AND LIMITATIONS

Total system replacement is a potential option available to all hazardous waste incineration systems facing major capital additions or modifications. Economics and the ability to meet regulatory performance standards will be the major deciding factors. Repermitting requirements and limitations, including state and local, must also be considered.

8.3 ASSUMPTIONS AND USER GUIDELINES

Total system replacement makes sense only if major capital expenditures are necessary to bring the existing incinerator system up to compliance. To determine whether a new system is more viable, first the cost of upgrading the existing system by component must be estimated, using the guidelines presented in Sections 4 through 7. Note that the existing system may need a combination of retrofits, e.g., a new combustion chamber, venturi scrubber, and fan and blower assembly. These projected retrofit expenditures can then be annualized along with associated operation and maintenance costs and combined with the annualized capital carrying charges and operation and maintenance costs of the existing facility. This combination gives the total annualized capital and operating costs of the proposed modified facility.

These projected costs can then be compared with the estimated annualized capital and operating costs of the proposed new facility. The remaining lifetime of the modified facility can be estimated from the physical condition of the equipment, the kind of wastes fired, and the operating environment (e.g., operating hours in a year, cyclic versus continuous operation, erosion and corrosion potential of the exhaust gas, etc.). The lifetime of a new incinerator system is estimated to be approximately 15 to 20 years for depreciation purposes.

This is only one method of evaluating the merits of total system replacement versus existing system upgrade. The user can apply alternative criteria.

8.4 COSTS

Purchased equipment costs of complete liquid injection, hearth, and rotary kiln hazardous waste incineration systems were obtained from vendors who offer complete systems. These estimated costs are shown graphically in Figures 15 through 17 as a function of heat input capacity. The systems include all the equipment discussed earlier, including the air pollution control devices for particulate and acid gas removal. The costs are necessarily generalized estimates because incinerator system costs are

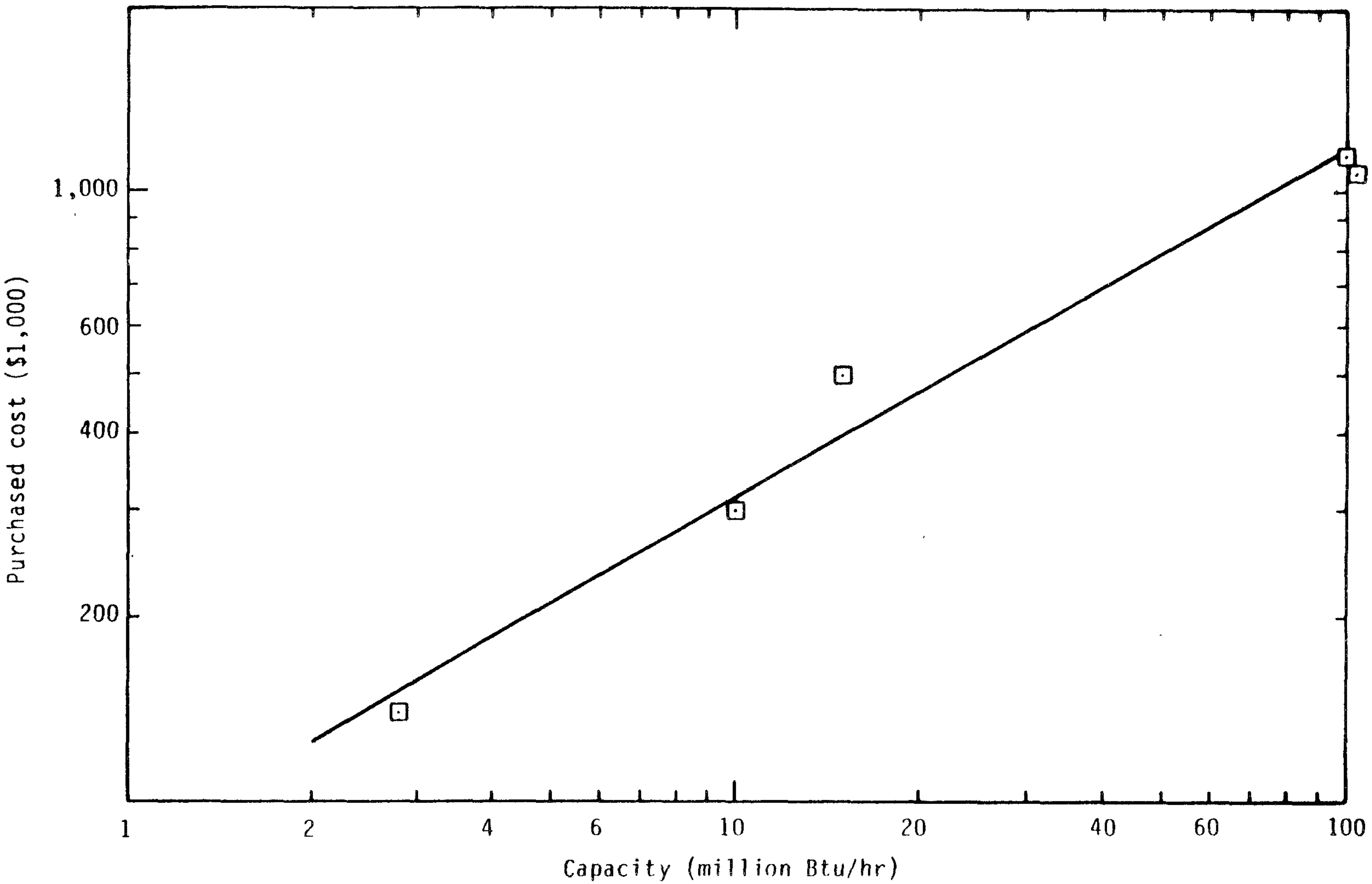

Figure 15. Purchased costs of complete liquid injection incineration systems (July 1982).

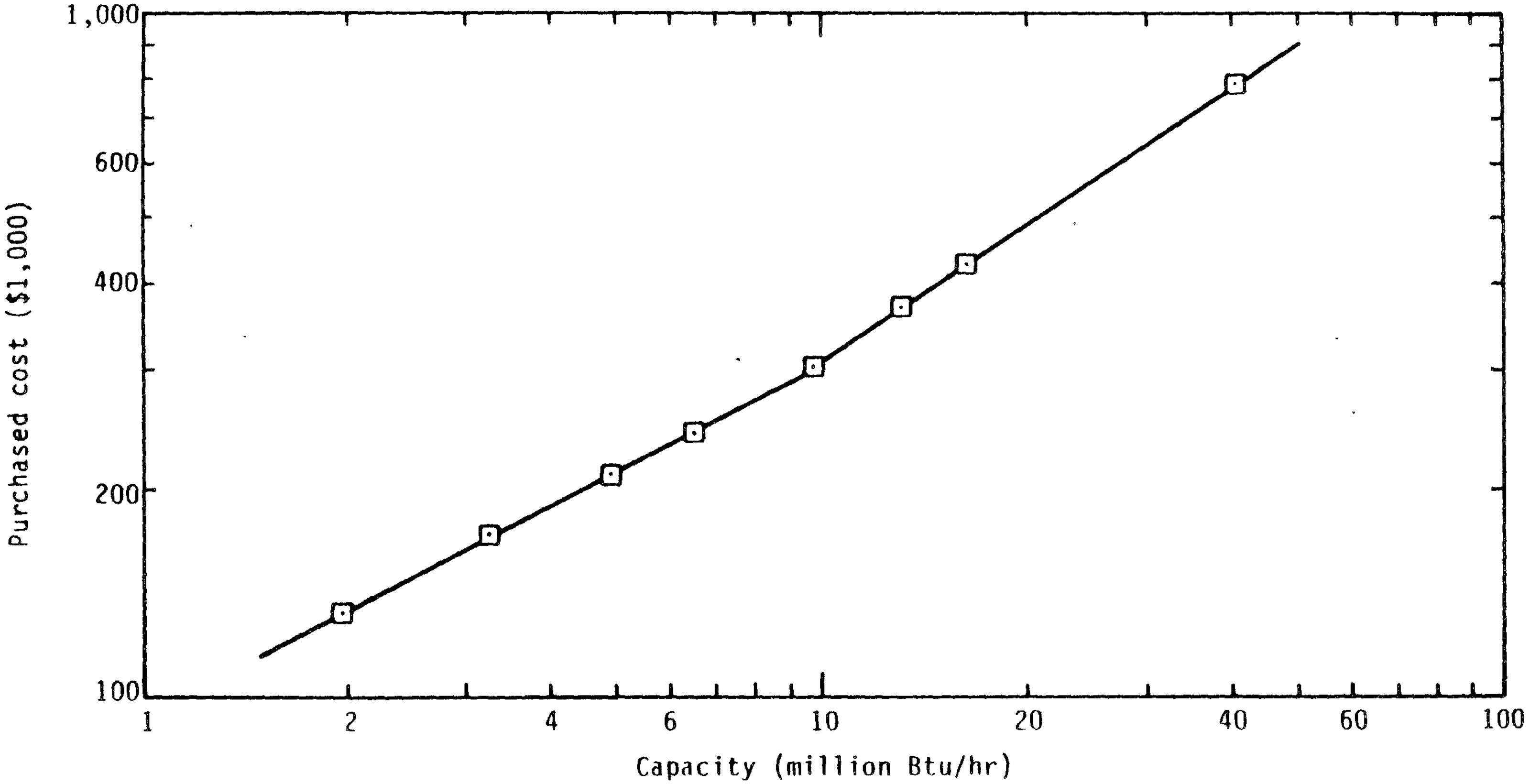

Figure 16. Purchase cost of complete multiple-chamber, hearth incineration systems (July 1982).

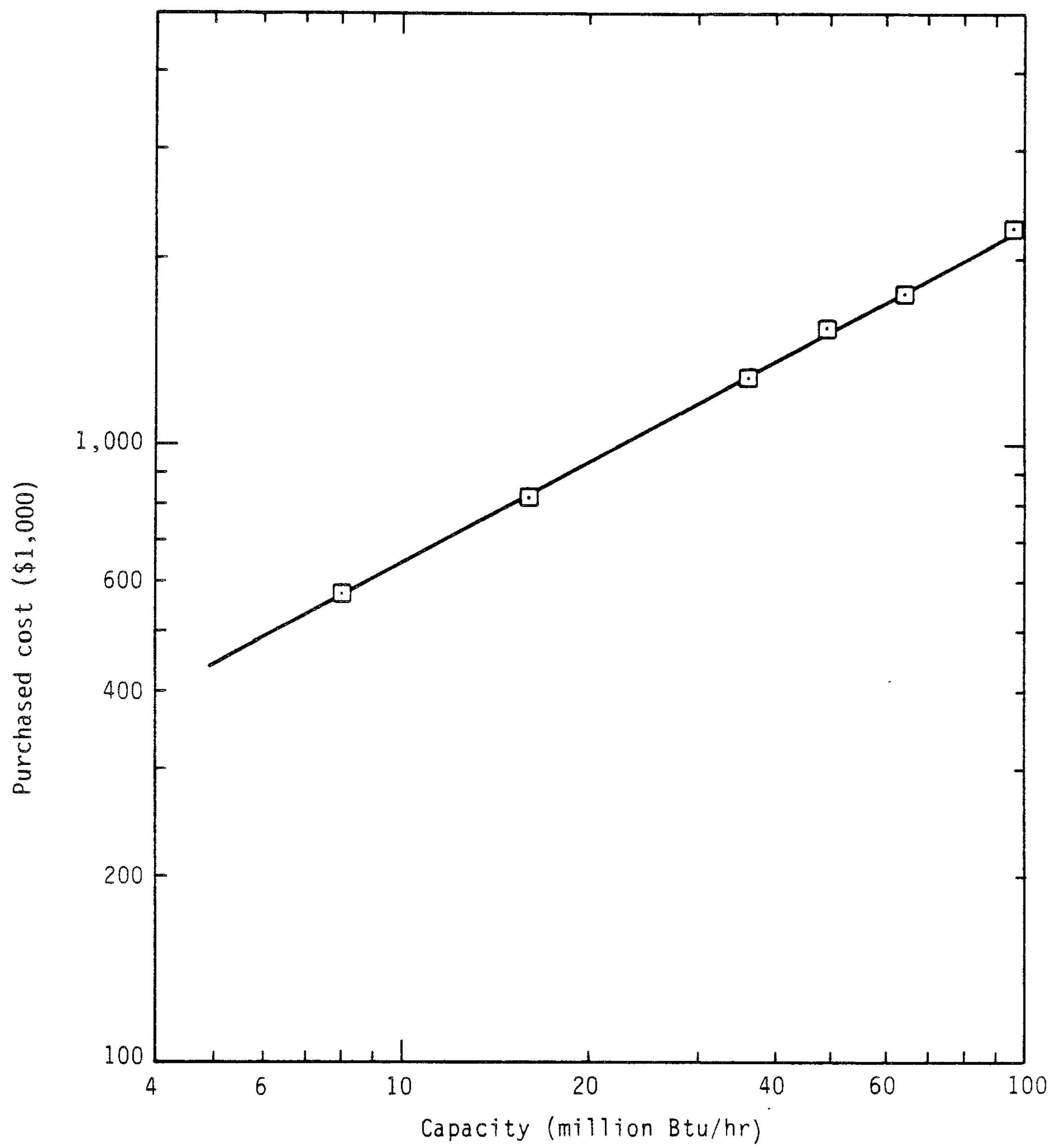

Figure 17. Purchase cost of complete rotary kiln incineration systems (May 1982).

dependent on the properties of the waste fired, but the costs should be good budgetary estimates (±30 percent), well within the accuracy requirements of this study, and suitable for making preliminary retrofit decisions. As expected, a new, complete incineration system usually costs less than the sum of the retrofit costs for individual components.

Installation costs were estimated by the vendors to be 30 to 50 percent of the purchased equipment cost, depending on degree of prefabrication, and freight costs should run about 5 percent. To obtain the total facility cost, indirect costs such as engineering and construction field expenses and contingency costs must be added to the installed cost, as specified in Section 3.

Operation and maintenance costs can be estimated per Reference 1.

SECTION 9

DOWNTIME CONSIDERATIONS

A less obvious cost of retrofitting or modifying components of an incinerator system is downtime cost. If an operating incineration system must shutdown for installation of new equipment or modifications, then the real costs associated with that downtime should be included in the total cost to achieve regulatory compliance. However downtime costs are nebulous and difficult to estimate because (1) the allocation of costs during this downtime is difficult to assess and (2) such costs are highly site specific. Nevertheless, some general guidelines are presented here.

Costs incurred during incinerator downtime include:

- Capitalized cost of original equipment, taxes, and insurance
- Operating labor
- Cost of alternate interim waste disposal for dedicated incineration facilities
- Lost revenue for commercial incineration facilities
- Credit for fuel, utilities, etc. not used

The capitalized cost of the existing facility for the period of downtime can only be estimated on a site-specific basis. Estimated installation times for retrofitting various components of an incinerator system are given in Table 4. Note that the times are only typical values; retrofit and startup difficulties could easily double the times for component retrofits.

However, the downtime could actually be less than total installation time. For example, erection of a scrubber could occur while the incinerator continues to operate. The incinerator may only need to be shut down for the 1 to 2 days required to cut in the necessary ductwork, after erection of the scrubber module. Thus, if true downtime is only on the order of days or a week, modifications and or retrofits could be scheduled during a routine maintenance outage to minimize costs. Such determinations must be made on a site-specific basis.

Operating costs and "credits" are determined by the specific facility or can be estimated using Reference 1 guidelines. The cost of alternate interim

TABLE 4. ESTIMATED INSTALLATION TIMES FOR INCINERATOR SYSTEM COMPONENTS

Retrofit component	Typical installation time[a]
Refractory	4 weeks
Burners	2 weeks
Combustion chamber	4 weeks
Quench	2 weeks
Waste heat boiler	4 weeks
Venturi scrubber	2 weeks
Acid gas absorber	2 weeks
Fan and motor	1 weeks
Stack	1 weeks
Total system	
Small (10 to 20 million Btu/hr heat input)	3 months
Large (>20 million Btu/hr heat input)	3 to 6 months

[a]Includes startup, but not lead time for engineering design and equipment fabrication.

disposal is again highly site specific. Transportation of the waste to an alternate facility can be very costly, depending on the nature of the hazardous waste and the distance to the facility. Table 5 gives baseline, bare minimum cost estimates for burning hazardous wastes. The costs are those charged by a municipally owned incinerator, which offers its service basically at cost.

In conclusion, downtime costs are highly variable and case specific. Only general guidelines can be presented here.

TABLE 5. BASELINE HAZARDOUS WASTE INCINERATION COSTS

Quantity of waste (million lb/yr)	Base price[a,b,c] ($/lb)
0 to 6	0.045
6 to 12	0.042
>12	0.038

[a]Surcharge or Credit for Heating Value

Heating value (10^3 Btu/lb)	Surcharge ($/lb)	Credit ($/lb)
0-1	0.027	
1-2	0.023	
2-3	0.019	
3-4	0.015	
4-5	0.012	
5-6	0.009	
6-7	0.006	
7-8	0.003	
8-9	0	0
9-10		0.003
10-11		0.006
11-12		0.009
>12		0.012

[b]Residue Surcharge

$0.013/lb ash

[c]Acidity Neutralization Surcharge

Surcharge = (W) x (Y)

where

W = lb of neutralizing agent (NaOH)/lb of waste

Y = Cost of 50 percent caustic solution = $0.08/lb

REFERENCES

1. McCormick, R. J., and R. J. DeRosier, "Capital and O&M Cost Relationships for Hazardous Waste Incineration," Contract No. 68-03-3043, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1983.

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16. ABSTRACT

This study reports a methodology, and an accompanying set of empirical cost relationships, that can be used to estimate the costs of retrofitting/upgrading various components of existing hazardous waste incineration facilities to comply with RCRA performance requirements. (Operation and maintenance costs and costs for new facilities are addressed in a companion report entitled, "Capital and O&M Cost Relationships for Hazardous Waste Incineration.") Both the methodology and the retrofit cost relationships were intended to focus on major capital additions or subsystem modifications that could be required for RCRA compliance.

The results of the study are expressed in a series of empirical relationships between the costs for various capital modifications/additions and factors that significantly impact these costs, e.g., capacity, materials of construction, etc. Costs are developed for (1) various aspects of combustion system retrofit to improve destruction of toxic waste constituents, (2) scrubbing system component addition, replacement, or upgrading to improve particulate and/or HCl removal, and (3) addition or replacement of ancillary equipment mandated by combustion or scrubbing system retrofit. The costs are based on a combination of in-house engineering and vendor-supplied budgetary cost estimates.

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