AIR POLLUTION CONTROL FOR SMALL RESOURCE RECOVERY FACILITIES

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ABSTRACT

Many small resource recovery facilities are likely to be constructed. Due to recent concern over health effects due to emissions of acid gas and determination that the control technology is available, even small resource recovery facilities are likely to have acid gas control systems. The systems will be typically comprised of dry scrubbers and baghouses. The design parameters which are significant with respect to acid gas control are discussed. Both capital and operating costs are indicated for a typical 200 TPD facility with a breakdown of the operating costs. Operating experience with European installations is discussed.

ENVIRONMENTAL ISSUES

Federal New Source Performance Standards (NSPS) for municipal incinerators became effective in 1971 and require that emissions of particulate matter (TSP) be limited to 0.08 gr/dscf (180 mg/Nm^3) (corrected to 12% CO_2). For most incinerators which have an inlet loading to the air pollution control (APC) equipment of approximately 2 gr/dscf (4500 mg/Nm^3), the necessary removal efficiency is 96%. Incinerators with dual combustion chambers, typically modular units, have inlet loadings of about 0.2 gr/dscf (450 mg/Nm^3) and require only 60% removal efficiency. These APC requirements are typically met with electrostatic precipitators. For resource recovery facilities (RRF) greater than 250 TPD (230 tpd) capacity whose construction commenced after June, 1984, the NSPS for industrial boilers reduced the allowable TSP emission to 0.04 gr/dscf (90 mg/Nm^3).

EPA regulations pursuant to the 1977 Clean Air Act Amendments specify that 250 TPD (230 tpd) incinerators are subject to Prevention of Significant Deterioration (PSD) requirements which also apply to sources of more than 250 TPY (230 tpy) of any regulated pollutant. Individual states are free to adopt regulations which are even more restricted. PSD regulations require that Best Available Control Technology (BACT) be applied and that impacts be within incremental standards. BACT determination is based on environmental, energy and economic considerations, and is decided on a case-by-case basis. A summary of the BACT determinations made by APC agencies in 16 states, between 1980 and 1986 indicates that, of 28 approvals, only one applied 1971 NSPS limits, 15 have applied stricter TSP limits, without acid gas control and 12 have applied both acid gas control and stricter TSP limits. In fact, several states (including California, Connecticut, Massachusetts, New Jersey, New York, Oregon, and Washington) now require acid gas control, for all new RRF.

EPA published a preliminary assessment of emissions from municipal waste combustion in July 1987, which identified the acid gas hydrogen chloride (HCl) and chlorinated dibenzo dioxins (CDD) and chlorinated dibenzo furans (CDF) as health concerns. Dry scrubbers in combination with either baghouses or electrostatic precipitators were identified as available control technology which is effective in controlling potentially toxic organic and metal pollutants, as well as acid gases. EPA also announced plans to propose revised NSPS for new municipal waste combustors and to provide guidelines for existing municipal waste combustors in November 1989. The NSPS are to be promulgated and guidelines finalized in December 1990, with states required to amend their implementation plans by September 1991 [1].

Table 1 has been prepared to indicate the future course of RRF development in the United States. The impetus for RRF development is usually threefold: imminent landfill closure or high cost, significant potential revenue from steam or electricity sales, and, substantial quantity of MSW with controllable disposal options. Given the possibilities of continued landfilling, recycling and composting, RRF is expected to constitute the ultimate disposal for approximately one-half of U.S. MSW in the foreseeable future. Considering the current status of RRF that are in operation or under construction, most of the metropolitan areas with population in excess of 1,000,000 have already implemented large projects. In terms of future RRF's it appears that many small RRF's with capacities less than 400 TPD (360 tpd) are needed.

On the basis of average emissions determined by stack test, one of the prominent uncontrolled emissions from RRF is HCl. As Table 1 indicates, RRF with capacity of 200 TPD (180 tpd) can be required to apply BACT to HCl removal due to PSD requirements. Some states also have an HCl ambient impact guideline based on the OSHA limits for industrial exposure. Ambient impacts are related to stack concentrations, other stack parameters, meteorology and receptor locations. When a formula such as Connecticut's conversion factor is used to translate the HCl impact guideline into a stack concentration and that value is compared to uncontrolled emissions, it is probable that a removal efficiency of 90% is required.

Based on the concepts that many future RRF will have a capacity of approximately 200 TPD (180 tpd) and that acid gas control capable of 90% removal of HCl and 99% removal of TSP is necessary, the focus of this paper is on the APC costs for RRF of that size and with that capability. Capital and operating costs associated with APC for 200 TPD (180 tpd) RRF are presented in Tables 2 and 3. RRF of this size suffer diseconomies of scale with regard to capital cost, but operation and maintenance (O&M) costs on a per-unit capacity basis are typical of all RRF [2].

TABLE 1 RESOURCE RECOVERY FACILITIES, EMISSIONS, IMPACTS

United States Population (million)	225
MSW (tons/day)	450,000 (1) (410,000 tpd)
Cities with Population greater than 1,000,000	40
RRF with Capacity greater than 1000 tpd (900 tpd)	30 (2)
Cities with population greater than 100,000	200
RRF with Capacity less than 400 tpd (360 tpd)	50 (2)
PSD Emission Threshold (tpy)	250 (230 tpy)
200 tpd (180 tpd) RRF Uncontrolled HCl Emission (tpy)	250 (3) (230 tpy)
HCl Impact Guideline (ug/m^3 - peak)	70 (4)
Connecticut Correction Factor for Stack Concentration from Ambient Concentration	500 (5)
Allowable HCl Emission (ppm)	40 (6)
Uncontrolled Emission (ppm)	400 (7)
Necessary HCl Reduction (%)	90

Footnotes:

(1) 4 pound/capita-day (1.8 kg/capita-day)
(2) in operation or under construction [18]
(3) .75 lb/MMBtu, 9 MMBtu/T (320 9/GJ, 10 GJ/t) [19]
(4) 1 percent of OSHA standard
(5) stack height 40m, flow rate 20m^3/sec equation [20]
(6) guideline impact, Connecticut correction, stack temperature 300°F (150°C)
(7) 100 percent excess air [19]

SCRUBBER TECHNOLOGY

Dry scrubber technology has been in use since the late 1970s. Primary use in the United States has been on coal-fired plants, while in Europe and Japan, the primary use has been on refuse-fired plants.

In the United States, wet scrubbing technology developed in response to the 1971 NSPS for coal-fired boilers. A number of operating problems developed and were gradually resolved during the 1970's. In 1979, the NSPS were changed to require scrubbing of flue gas from all utility coal-fired boilers. However, only 70% efficient scrubbing is necessary when low-sulfur coal is utilized. Since then, approximately 20 units have been designed with dry scrubbers which can achieve this removal efficiency. The advantages of dry scrubbing include reliability, dry solid waste and no reheat requirement [3–5].

In the late 1970s West Germany adopted regulations limiting the emission of HCl from refuse incinerators to approximately 60 ppm, thereby requiring approxi-

TABLE 2 TYPICAL 200 TPD RESOURCE RECOVERY FACILITY CAPITAL COST OF ACID GAS CONTROL SYSTEMS

Flue Gas Flow Rate (acfm)	60,000	(1700 am^3/min)
Inlet Temperature (°F)	400	(200°C)
Outlet Temperature (°F)	300	(150°C)
Slurry Flow Rate (gpm)	8	(30L/min)
Spray Dryer Dimensions (ft) (1)	14'D x 70'H	(4mDx20mH)
Baghouse Air Cloth Ratio ($acfm/ft^2$)	2	($0.6am^3m^2min$)
Baghouse Dimensions (ft) (2)	20'W x 40'L x 40'H	(6mWx12mLx12mH)
Stack Dimensions (ft) (3)	5'D x 130'H	(1.5mDx40mH)
Lime Silo Dimensions (ft) (4)	6'D x 24'H	(1.8mDx7mH)
Capital Cost ($)	2,250,000	

Footnotes:

(1) Assumed 10 sec residence time.
(2) Assumed 12"D x 20' bags (0.3mD x 6m).
(3) Height assumed to be 2.5 times building height.
(4) Assumed 1 week lime storage at stoichiometric ratio of 2.

TABLE 3 TYPICAL 200 TPD RESOURCE RECOVERY FACILITY ADDITIONAL O & M COSTS FOR ACID GAS CONTROL SYSTEM

MSW Processed (tpy)	62,000	(56,000 tpy)
Lime Consumed (tpy)	1,800 (1)	(1600 tpy)
Flue Gas Flow Rate (acfm)	60,000 (2)	(1700 am^3/min)
Capital Cost ($)	2,250,000	
Additional Waste Disposal(tpy)	6,200 (3)	(5600 tpy)
Lime Cost ($/yr)	180,000 (4)	
Energy Revenue Lost ($/yr)	37,000 (5)	
Repair Cost ($/yr)	45,000 (6)	
Waste Disposal Cost ($/yr)	124,000 (7)	
Total Cost ($/year)	386,000	

Footnotes:

(1) Assumed stoichiometric ratio of 2, 0.3% Sulfur, 0.6% Chlorine.
(2) Inlet to acid gas control system.
(3) Assumed lime conversion to hydrated form, capture of all SO_2 and HCl, 50% solids content.
(4) Assumed lime cost of $100/ton ($90/t).
(5) Assumed pressure drop of 10" wc (.25 Pa), power cost of $.05/kWh.
(6) Assumed 2%/year of capital cost.
(7) Assumed disposal cost of $20/ton ($18/t).

mately 90% removal. According to vendors with substantial European experience, HCl was recognized as a more prominent pollutant than SO_2 in refuse-fueled flue gas. Japan soon adopted similar regulations.

In Europe, there are two basic types of dry scrubbers that are in use. First, Europeans employ a totally dry system where dry hydrated lime is injected into the reactor vessel to react with the acid gases in the flue gas. Hence, both the inlet to the reactor and the outlet from the reactor is a dry powder. Second, the Europeans employ what they call a wet/dry or quasi-dry system where lime slurry is injected by atomization into the spray dryer to react with the acid gases in the flue gas. The European wet/dry or quasi-dry scrubber is what is called a dry scrubber in the United States.

There are approximately 10–15 dry and wet/dry systems in operation at the present time in Europe, with a somewhat greater number in Japan. Approximately half are totally dry and the other half are wet/dry. There are several dry scrubbers in operation or under construction at RRF in the United States.

ACID GAS CONTROL SYSTEM DESIGN

Typical acid gas control systems (as illustrated in Fig. 1) on RRF achieve approximately 90%, 75% and 99% removal efficiency for HCl, SO_2 and TSP (including lime products and unreacted lime), respectively [6, 7]. Flue gas is contacted in the spray dryer by finely atomized slurry, consisting of insoluble hydrated lime particles in water. Simultaneous physical changes and chemical reactions occur. Water evaporates from the slurry and adiabatically humidifies the flue gas, but not enough water is added in the slurry to cool the flue gas to its saturation temperature. The flue gas residence time must be long enough to allow chemical reaction and drying of the lime particles and reaction products to occur. The droplets of water vapor provide a large surface area for lime particles and acid gas molecules to come into contact [8]. The main chemical reactions which occur are as follows:

$$Ca(OH)_2 \text{ (solid)} + 2HCl \text{ (gas)}$$

$$= CaCl_2 \text{ (solid)} + 2H_2O \text{ (liquid)}$$

$$Ca(OH)_2 \text{ (solid)} + SO_2 \text{ (gas)} + \tfrac{1}{2} O_2 \text{ (gas}$$

$$= CaSO_4 \text{ (solid)} + H_2O \text{ (liquid)}$$

On the basis of stack tests, HCl inlet concentrations in flue gas from RRF average 400 ppm [19]. According to vendors with substantial European experience, for inlet HCl concentrations above approximately 500 ppm, the removal efficiency is very good. For concentrations of less than 500 ppm the removal efficiency decreases rapidly.

On the basis of stack tests, SO_2 inlet concentrations in the flue gas from RRF on coal-fired plants average 150 ppm [19]. Tests have shown that with SO_2 inlet loadings of 350 to 900 ppm the removal efficiency of SO_2 appears to be optimum. The removal efficiency decreases for inlet loadings less than 350 ppm apparently due to the lower probability of the gas coming into contact with the slurry particles. This phenomenon can be mitigated by increasing the amount of reagent.

Tests on coal-fired plants indicate that the removal

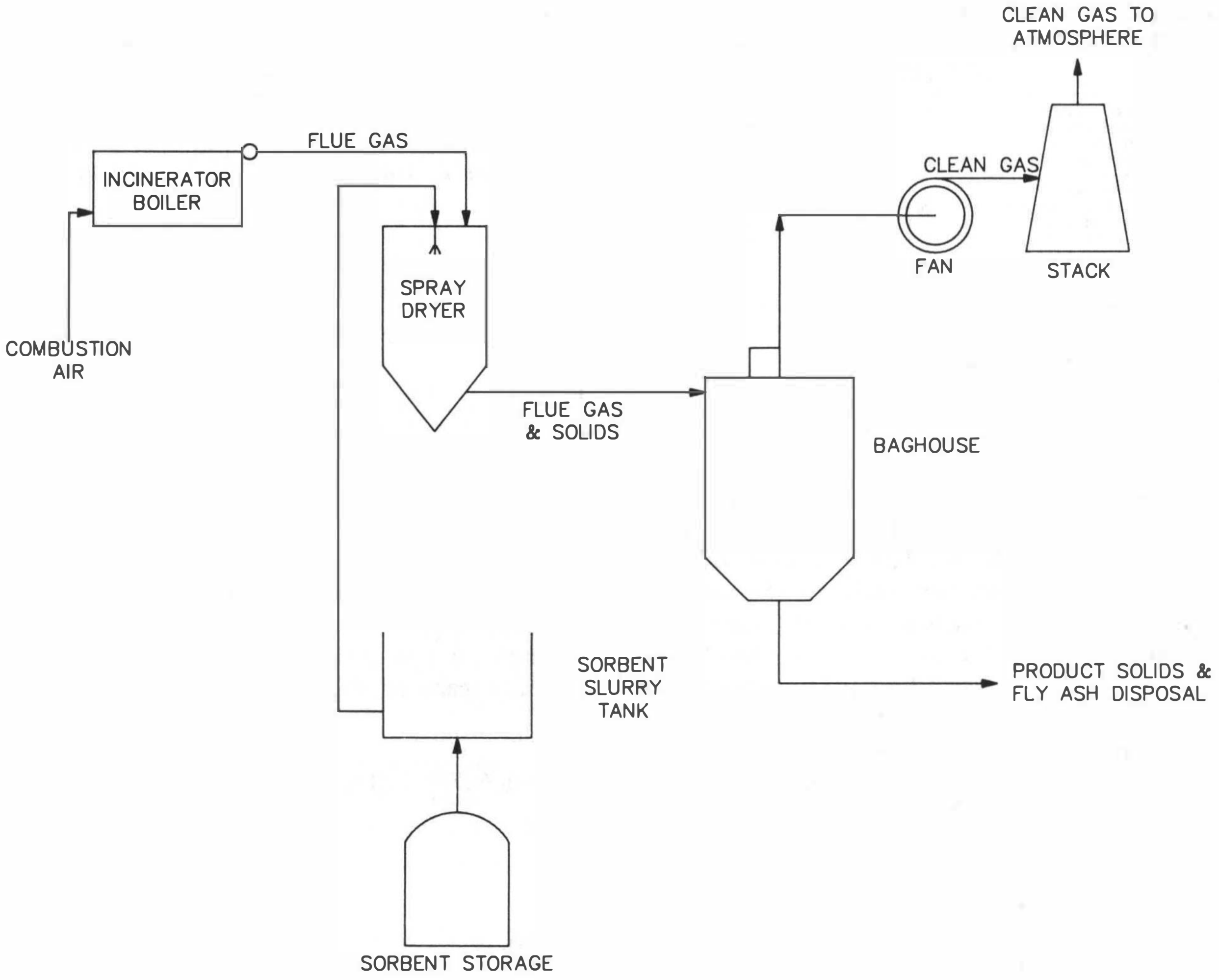

FIG. 1 TYPICAL ACID GAS CONTROL SYSTEM SCHEMATIC FOR SMALL RRF

efficiency of sulfur dioxide at temperatures above 200°F (93°C) at the reactor exit falls off significantly. Temperatures of less than 200°F (93°C) are needed for good sulfur dioxide removal whereas the removal of hydrogen chloride is not as restrictive with respect to temperature according to vendors with substantial European experience.

Certain variables are significant with respect to effective scrubber performance. Sufficient residence time must be provided within the reactor vessel for neutralization and drying to occur. Either a close approach to saturation temperature or high stoichiometric ratios of reagent to acid gas have been shown to increase removal efficiencies of SO_2 in coal-fired applications [18]. A close approach and low stoichiometric ratio is typical of coal-fired plants where SO_2 removal is the main consideration. A high approach and high stoichiometric ratio is typical of RRF where HCl removal is the primary concern. The primary variables affecting HCl and SO_2 reaction in the spray dryer are residence time, stoichiometric ratio and approach to saturation temperature. Typical values for residence time, stoichiometric ratio and approach to saturation temperature in a spray dryer for RRF are 10 sec, 2 moles of lime per mole of SO_2 and 0.5 mole of HCl, and 150°F (83°C) [9, 10]. Nozzles in the reactor vessel must be oriented at such an angle of dispersion so as to avoid buildup of salts on the inside walls of the reactor.

The spray dryer produces a waste product composed of reacted and unreacted sorbent and fly ash. This material is collected in the downstream baghouse. Baghouses are bulk collection devices which generally have low outlet loadings regardless of inlet concentrations. The primary design parameter for baghouses is the air:cloth ratio, which has a typical value of 2 acfm/ft^2 (0.6 am^3/m^{2}min) for reverse air applications [11].

Electrostatic precipitators on the other hand, function as fractional removal devices, with additional collection equipment removing smaller sized particulate. The primary design parameter for electrostatic precipitators is the specific collection area, which has a typical value of 0.3 ft^2/acfm (1m^{2}min/am^3).

ACID GAS CONTROL SYSTEM COSTS

A number of dry scrubber installations in Europe and the U.S. were visited with special emphasis on obtaining both performance and cost data [12]. In addition, published summaries have been reviewed as well as vendor quotations for several incinerators currently under construction (including Marion County, Oregon and Skagit County, Washington and the proposed retrofit of Windham, Connecticut) [13, 14].

Expected capital and operating costs for a typical 200 TPD (180 tpd) RRF are presented in Tables 2 and 3, respectively.

Table 2 indicates the important engineering parameters related to design of the acid gas control system including flue gas flow rate and temperature drop, from which the dimensions of the spray dryer, baghouse, lime silo and stack are determined. The capital cost estimate includes these items of equipment as well as lime slaking equipment, piping, ductwork, fans, pumps and motors. The plan area for this equipment, as indicated on Fig. 2, is approximately 30 ft × 100 ft (10 m × 30 m). The tallest piece of equipment is the dry scrubber vessel, which has a height of approximately 70 ft (20 m). Of the total capital cost of $2,250,000 approximately 55% is for equipment, 10% for foundations and structural steel and 35% is for erection and startup services. On an annualized basis per unit of MSW, with amortization at 10 percent per year, capital costs are approximately $3.50/T ($3.50/t).

The four primary constituents of O&M cost are reagent, energy, repairs and waste disposal. No additional labor is expected to be necessary after the initial operating period. Typical unit costs for lime, electric energy and waste disposal are indicated in Table 3. Of the total annual cost of $386,000, approximately 45% is for reagent, 10% for energy, 10% for repairs and 35% for waste disposal. On a per unit of MSW basis, O&M costs are approximately $6/T ($5.50/t).

Variations to the capital and O&M costs are expected for a variety of different emission requirements. For TSP removal efficiency requirements of approximately 95% either an electrostatic precipitator or a pulse-jet baghouse may be appropriate. The capital cost is less than that presented in Table 2 for either alternative. The O&M cost for the ESP is similar to that presented in Table 3, while that of the pulse jet baghouse is higher. For lower SO$_2$ removal efficiency, an all-dry scrubber is applicable which will have a lower capital cost and higher O&M cost.

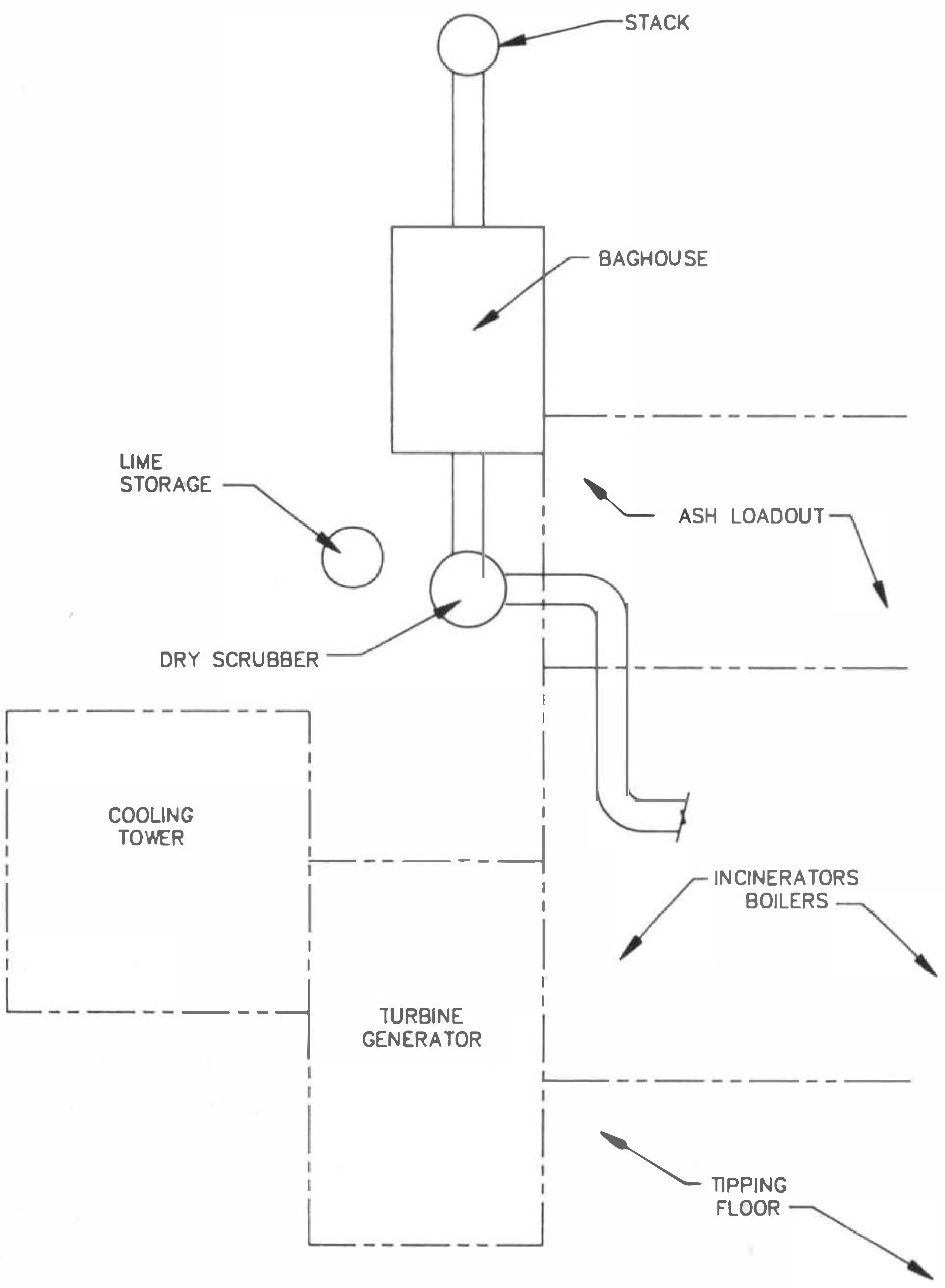

FIG. 2 TYPICAL ARRANGEMENT FOR SMALL RRF ACID GAS CONTROL SYSTEM

OPERATION

In Europe the dry and wet/dry scrubber systems appear to have functioned satisfactorily enough to meet the objectives of their intended use. Problems associated with the operation of the scrubbers do not influence significantly the availability of the plant. In fact, most of the problems are external to the reactor vessel itself. Most of the problems are of a mechanical nature rather than a chemical nature. Mechanically, the problems are mainly associated with the transport of lime feed to the reactor and the transport of reacted material and ash from the baghouse to the storage silo. Also, problems are experienced with the unloading of the waste product onto trucks for transport to a waste landfill. Of particular note, wet/dry scrubbers experience some problems with slaking of the lime and the transport of the slaked lime to the reactor itself. The other problem experienced with wet/dry scrubbers is caking inside the reactor vessel walls. Apparently the design of the nozzles that atomize the lime slurry injected into the reactor is extremely important in avoiding caking inside the reactor walls. During the startup period, approximately the first year, one person is required for operation and maintenance of the scrubber system. After the initial shakedown period, very little operating and maintenance effort beyond that needed for basic operation of the RRF is needed to operate and maintain dry and wet/dry scrubbers.

In the United States, there have been more operating problems than in Europe. The typical U.S. installation is on a coal-fired plant rather than a RRF, however. In addition to those problems external to the scrubber vessel, caking on the walls of the vessel is a major concern with coal-fired plants. Resolution of this problem includes provision of redundant equipment and frequent maintenance. It is suspected that the major cause of caking is the much closer approach to saturation temperature practiced in the United States compared to Europe.

It should be pointed out that the long-term reliability of scrubbers, especially in terms of the corrosion potential of the reactor vessel is not yet established. However, there is no significant evidence to date to show that the long-term reliability of dry scrubbers will not be satisfactory. The selection of scrubber vendors experienced with installing systems on RRF is important [15–17]. As any transfer of technology entails, one can expect some problems with those vendors that do not have experience.

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