

DESIGN CONSIDERATIONS FOR DRY SCRUBBERS

NORMAN P. GETZ AND ROBERT W. PEASE, JR.

Roy F. Weston, Inc.
Burlington, Massachusetts

This paper presents comments and recommendations regarding conceptual design specifications for dry scrubbers (also known as wet/dry scrubbers) for use on waste-to-energy facilities. These recommendations would be used to develop minimum acceptable design parameters for requests for proposals for full-service or turnkey waste-to-energy contractors. The reason for presenting these comments and recommendations is that the authors perceive a general overestimation within the waste-to-energy industry as to the extent of applicable experience with the dry scrubber technology on waste-to-energy facilities. These recommendations, however, are more conservative than what certain full-service and turnkey contractors are willing to guarantee. Upon examination, the dry scrubber technology experience-base is actually quite limited (as of the time of writing of this paper in September 1987 and the time of responding to reviewers' comments in February 1988). Based on this limited experience, the authors are reluctant to consider or recommend dry scrubber designs that deviate significantly from this experience because of a concern that unsuccessful operation will result.

Unsuccessful operation of a dry scrubber can be defined in several ways. Foremost is the situation in which the required removal efficiencies are not achieved, thereby potentially resulting in facility shut-down, reduction in throughput, or equipment replacement. Although this scenario is uppermost in our

minds as we review dry scrubber designs, the authors' concerns are also focused on a second, more likely scenario, one in which good operations are adversely impacted to achieve the required removal efficiencies. Based on certain design reviews, two areas have been identified in which operation could potentially be adversely affected: the reagent feed system; and the downstream particulate removal system; in particular, fabric filters.

Since fabric filters are more susceptible to dry scrubber operational upsets than electrostatic precipitators, fabric filters are of greater concern. The susceptibility of fabric filters to dry scrubber operational upsets is because the lime reagent used in the scrubber is hygroscopic and tends to become cement-like if moist or wet. Should this occur, either because of incomplete drying of the slurry water in the scrubber (caused by insufficient allowable temperature differential through the scrubber or by improper scrubber design), or because of a flue gas temperature at the fabric filter (operating near the dew point) which is lower than design, full or partial blinding of the fabric within the fabric filter would likely result [1].

Electrostatic precipitators are not as affected by moist or wet lime reagent because the gas flow through this device does not pass through small diameter pores (which could become clogged). However, electrostatic precipitators could face reduced efficiency if the moist or wet reagent "sets-up" on collector plates and could

not be removed by rapping. The remedy, if this were to occur, for an electrostatic precipitator is less costly and less time consuming than for a fabric filter because it involves surface scraping of plates, rather than whole-bag replacement.

WASTE-TO-ENERGY EXPERIENCE

The authors recommend that certain criteria be adhered to regarding experience-bases which are utilized for future designs. Ideally, experience or data should be taken from a facility 2 years old or greater, to observe a variety of operating conditions; the facility should be full-scale and not pilot scale; the facility's operating conditions should generally match those of the facility being designed; the data from the facility should be obtained by independent parties rather than by the facility operator; and the facility should have experienced successful operations. In the event that these criteria are not fully satisfied, caution and conservatism should be used by persons attempting to utilize this experience.

For dry scrubbers on waste-to-energy facilities, there is to the author's knowledge (at the time of this writing) only one facility world-wide that meets all of the above criteria; that being the Munich, Germany facility. Other European facilities with acid gas control have wet scrubbers, dry/dry scrubbers, retrofit devices that do not qualify as wholly designed systems, or dry scrubbers that do not meet the time or the independent party criteria stated above.

There are several facilities, on the order of four to six, in Japan that have operated with dry scrubbers for more than 2 years; however, their experience is not relevant or transferable to U.S. systems because the inlet temperatures to the scrubbers (a critical design parameter which is described in more detail later in this paper) are typically in excess of 600°F whereas the trend in the United States is to lower this value to below 400°F. In the authors' opinion, this difference in temperatures is sufficient to exclude data from those facilities for U.S. design purposes. Furthermore, data taken by an independent party is available for only one of those facilities.

The U.S. experience is with facilities in: Framingham, Massachusetts; Marion County, Oregon; and Commerce, California. Framingham has been in operation for several years; however, it does not have a designed dry scrubber and has, instead, lime slurry injection in an existing refractory-lined chamber downstream of a temperature quench water spray in the same chamber. Moreover, the temperature at the point of injection is likely to be similar to the Japanese fa-

cilities (no temperature measurements or other data, except for outlet HCl concentrations, have been taken for this system). For these reasons, the Framingham facility is not appropriate for developing or transposing design parameters to future U.S. systems.

The Marion County facility has been in operation for approximately one year. Although there have been no data obtained from this facility by independent parties, the authors have been in communication with the owner/operator and the dry scrubber equipment supplier regarding its performance and have incorporated this experience (conservatively, since the facility does not meet two of the previously-listed criteria) in the development of conceptual design specifications.

The Commerce facility does have independent party data available for its operations; however, since this facility has started up recently (approximately 3 months prior to this writing), we cannot lean too heavily on those data for future systems.

Facility data that, in the authors' opinion, are suitable for interpretation and for use in the design of future systems is presented in Table 1. These data best meet the criteria established (2 years in operations, independent party taking data, full scale facility, successful operations, and technology equivalent to U.S. systems), although, as described earlier, only the Munich facility fully satisfies these criteria. The following observations can be made about the individual facilities presented:

(a) The City of Commerce, California facility was tested by an independent test company. The facility's test results show greater than 90% and 70% removal of HCl and SO₂, respectively. The outlet emission results are below 50 PPMDV at 12% CO₂ for HCl and SO₂. City of Commerce was tested in June 1987 for compliance with the permit. The inlet temperature to the scrubber is 460°F [2].

(b) The Marion County, Oregon two-train facility was tested by a now independent test company. No inlet scrubber data were reported for HCl or SO₂; therefore, the removal efficiencies are not known. The outlet emission results are below 50 ppmdv at 12% CO₂ for HCl and SO₂. The stack analysis obtained for HCl demonstrated emissions at 3.9 and 20 ppmdv at 12% CO₂ for boiler nos. 1 and 2, respectively. However, one stack analysis for SO₂ on boiler no. 2 demonstrated emission at 75 ppmdv at 12% CO₂. (Three stack analyses were obtained and averaged for SO₂ on boiler no. 2 and demonstrated emission at approximately 45 ppmdv at 12% CO₂.) The inlet temperature for boiler no. 2 scrubber is 383°F. Marion County was tested in October 1986 for compliance with the permit [3].

TABLE 1 IDENTIFICATION OF APPROPRIATE SCRUBBER DATA FOR USE IN SCRUBBER CONCEPTUAL DESIGNS

Facility	Inlet Temperature to Scrubber (°F)	Outlet Temperature from Particulate Control Device (°F)	HCl/SO ₂ Outlet Concentration (PPMDV @ 12% CO ₂)	HCl/SO ₂ Removal Efficiency (%)	Control Equipment
Commerce, California (a)	460	270 (b)	11.35/1.56 (c)	98.8/99.5	MB-DN-DS-DI-FF
Marion County, Oregon: Test 1	407	260	3.9/3.8	(d)	2 Units: MB-DS-DI-FF
Test 2	383	273	20.0/45	(d)	
Munich, Germany (a)	510	315 (b)	16.5/12.9	94.8/76.4	MB-DS-ESP
Claremont, New Hampshire	400-525	Data has not yet been released by regulatory agency.			MB-DI-FF

Abbreviations:

MB: Mass Burn
 DN: NO_x Control ("De-Nox")
 DI: Dry Injection
 DS: Dry Scrubber
 FF: Fabric Filter
 ESP: Electrostatic Precipitator

Footnotes:

(a) Average data
 (b) Inlet to particulate control device
 (c) Corrected to 3% O₂
 (d) Not known; no inlet data

(c) The Munich, West Germany facility was tested by an independent test company. The facility's test results show greater than 90% and 70% removal of HCl and SO₂, respectively. The outlet emission results are below 50 ppm_{dv} at 12% CO₂ for HCl and SO₂. Munich was tested in July 1984, 5 months after initial operation [4].

There are several facilities not shown in the table for which independent data were taken from the scrubbing systems. (The authors are awaiting receipt of the results from the Biddeford, Maine facility emission testing; however, the results are not available in time for inclusion in this report.) These include: several Japanese facilities; Zurich, Switzerland; Hogdalen, Sweden; and Wurzburg, Germany. As stated earlier, the Japanese data are not included because of its atypically (to the U.S.) high scrubber inlet temperatures. Zurich, Hogdalen, and Wurzburg data are not included because certain key measurements (such as gas flows, O₂, H₂O, or CO₂ concentrations) necessary for the conversion of the data to comparable units and values were not reported or were not measured.

The reader may be surprised at how few facilities are identified in Table 1. However, those are the facilities which, in the authors' opinion, represent the

state of experience for dry scrubbers on waste-to-energy facilities. It is because there are so few facilities shown that we take such a conservative position in concept design specifications for new facilities.

It should be noted that several facilities are presently in the startup or testing mode. These facilities are: Bristol, Connecticut; Hartford, Connecticut; St. Croix, Virgin Islands; Millbury, Massachusetts; London, Ontario; Jackson City, Missouri; Dutchess County, New York; and Orrington, Maine. We anticipate that the state of experience on an industry-wide basis will expand significantly as these facilities come on-line and go into long-term operations.

SELECTED CONCEPTUAL DESIGN PARAMETERS

There are several areas of conceptual design that are typically specified or reviewed. Certain of the critical ones include residence time, slurry/gas interface, and temperature differential through the scrubber.

Residence time affects the capability of the equipment to achieve a dry product, to maintain dry walls, to maintain adequate gas velocities through the unit,

and to allow enough time for reaction to occur. Based on available experience to achieve the typically-required removal efficiencies and outlet emissions (90% HCl and 70% SO₂ removal and 50 ppm_{dv}, corrected to 12% for HCl and SO₂ outlet emission), the authors specify 8 sec for an upflow reactor, and 18 sec for a downflow reactor. When issuing specifications such as these, contractors and equipment suppliers are invited and encouraged to provide appropriate data to justify an exception to the requirements. To date, the authors have not reviewed data that would alter (i.e., reduce) these specified retention times.

Slurry/gas interface relates to the ability of the equipment to mix the reagent with the flue gas such that chemical reaction will occur sufficiently to meet required removal efficiencies. The mixing must take place under all reasonable load conditions and slurry concentrations. This is essentially a state of the art rather than a state of science; therefore, one should look primarily to the equipment supplier's past successful operations in waste-to-energy facilities for comfort.

Differential temperature through the dry scrubber is a catch-all parameter that covers several design and operational issues. In particular, it is associated with the concentration of lime in the slurry and the dryness of the material as it exits the scrubber and enters the particulate control device. Specifications in regard to this parameter create the most controversy in scrubber design reviews. The reason for this controversy is that certain full-service and turnkey contractors, to obtain the highest thermal efficiencies possible, attempt to lower the design temperature differential through the scrubber to have more heat extracted by the economizer and, thereby applied to steam generation. On the other hand, the authors believe, based on the data presented in Table 1, that there exist no data that would justify a lower temperature differential than that recommended below. Furthermore, the authors believe that to reasonably achieve required removal efficiencies with lower temperature differentials, the operation of the slurry feed system and the downstream particulate control device would be jeopardized.

Specifically, with an assumed stack temperature of 250°F, a minimum dry scrubber temperature differential of approximately 130°F should be required with a scrubber-fabric filter system. A scrubber-electrostatic precipitator system would require an even greater temperature differential because the electrostatic precipitator does not provide secondary acid gas removal as does a fabric filter—by means of the dry excess reagent covering the filter bags. In other words, a scrubber requires an inlet temperature of approxi-

mately 400°F (assuming 20°F temperature loss in the downstream ducting and particulate removal devices). With this temperature differential (and with other good design parameters), one can be reasonably confident, based on the dry scrubber experience on waste-to-energy facilities shown in Table 1, that removal efficiencies will be achieved; that the lime slurry concentration will be low enough to reliably achieve proper gas/slurry interface without high maintenance costs; that a downstream fabric filter would not be partially or totally blinded by wet or hygroscopic reaction product thereby causing high pressure drop, high cost operation, or facility shutdown and filter replacement; and that a downstream fabric filter or electrostatic precipitator internal metal hardware would not be deteriorated by corrosion from wet or hygroscopic reaction product.

The authors' position has been criticized in several ways: full-service and turnkey contractors have stated that we should rely on their guarantees to perform; that we should rely on equipment supplier guarantees to perform; that we are standing in the way of innovation; and that the required removal efficiencies can be achieved in any event with increased lime slurry concentrations.

Our response is that there are insufficient industry data to justify any deviation from current successful designs; that if the contractor wishes to innovate it should allow for such innovation by installing hardware that could provide variable differential temperatures (including up to at least the recommended 130°F); and that the contractor's or the equipment supplier's guarantees are typically measured by testing over a limited time period during which time it could absorb operational problems to pass the test.

In general, this issue is resolved by including equipment flexibility to operate at a temperature differential of at least 130°F. This can be achieved by a flue gas bypass around the economizer; by a water side bypass (with appropriate tube drainage) around an economizer section; or by a steam coil heater prior to the dry scrubber. In all events, however, engineering analysis, energy projections, and feasibility opinions should be performed for the 130°F temperature differential case and not for lower cases.

OTHER DESIGN ISSUES

Other dry scrubber design issues that are either recommended or specified to increase reliability and operability are as follows:

- (a) If a fabric filter is in place, space and hardware

should be installed following the dry scrubber for dry injection of hydrated lime; this may allow reducing the temperature differential across the scrubber for thermal efficiency, it may allow continued operations when the scrubber is out of service, and it may provide additional lime injection capacity in the event that regulations become more stringent (this use, however, would not apply to an electrostatic precipitator since this device exhibits little acid gas removal because it exposes only a small portion of the gas stream to the collected lime).

(b) Dual 100% slakers for redundancy.

(c) Space for pretreatment of water in the event that the water is high in carbonate (which causes scale) or other impurities that would affect operations.

(d) One or two 4-hr (nominal acid gas loadings) slurry tanks.

(e) One slurry pump per combustion train and one standby pump (or common standby pump).

(f) Redundant slurry lines per combustion train.

(g) Dry scrubber vessel and slurry handling system sized for 120% of maximum acid gas loadings (to cover peak conditions and to provide a buffer in the event that the acid gas concentration increases in the future).

REFERENCES

[1] Theodore, Louis, and Buonicore, Anthony J. *Air Pollution Control Equipment*. New Jersey: Prentice Hall, Inc.

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[3] Ogden Projects, Inc. "Environmental Test Report." Prepared for Ogden Martin Systems of Marion, Inc. (Test dates, September 22, 1986 to October 8, 1986.)

[4] "Air Emission Tests at the Munich North, Refuse-Fired Power Plant." Cooper Engineers and Belco Pollution Control Corp. APCA paper, June 16-21, 1985.