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PARTICULATE SCRUBBING PERFORMANCE OF THE HIGH LEVEL CAVES OFF-GAS SYSTEM

The High Level Caves (HLC) Off-Gas System will be used for characterizing off-gas produced from a melter processing actual SRP waste. Prior to the final installation of this system in the HLC, performance tests were conducted at the ETF using off-gas from the Small Cylindrical Melter (SCM)-2. The purpose of these tests was to develop data for comparing small and full scale equipment performance. Overall and fractional DF data was obtained for the normal expected operating range of the wet scrubber portion of the system. The measured overall DF averaged 6.1 compared to a DF of 25 to 50 measured across the LSFM quencher. Comparison to theory was good. The predicted DF performance of this system was 11.0. Both the predicted and measured DF values were in a range that would be expected for this type of gas contacting equipment. Future tests with a small scale gas atomized scrubber are recommended for developing comparison data with full scale equipment at the ETF.

Discussion

The HLC off-gas system, depicted in Figure 1, was designed to provide a means for characterizing off-gas from the HLC slurry-fed melter. This system consists of a packed bed scrubber followed by a spray trap, cartridge filter, two gas bubblers and an iodine trap. The tests conducted at the ETF focused only on the particulate scrubbing performance of the packed column and off-gas spray trap.

Experimental testing consisted of passing unquenched off-gas from the SCM-2 through the HLC system at various off-gas throughput and recycled scrubber liquid rates that are expected during operation in the HLC. The overall system DF performance was ascertained by the ratio of the inlet to outlet aerosol concentration (as measured with absolute filters). The fractional DF (or DF as a function of particle size) was determined with a Univeristy of Washington Source Test Cascade Impactor. Off-gas was drawn through the system at a controlled rate as depicted in Figure 2. Off-gas temperature, scrub liquid flowrate, and aerosol concentration were determined during each test.

Experimental Results

Test conditions for each run are summarized in Table 1. In addition, overall DF values and liquid/gas ratios are presented.

Table 1. Summary of Test Conditions for The High Level Caves Off-Gas System

Run	Sampling Rate scfm	Sampling Rate slpm	Aerosol Concen. mg/Dscf	Sampling Location	Liquid Rate ml/min	Liquid /Gas Ratio (lbm/lbm)	DF (basis)
1	0.349	9.88	6.77	inlet	--		6.04 (1&2)
2	0.343	9.71	1.12	outlet	1360	115.2	
3	0.344	9.74	7.11	inlet	--		6.35 (3&2)
4	0.345	9.76	0.92	outlet	2550	218.4	7.33 (1&4)
5	0.286	8.09	1.39	outlet	2550	263.4	4.87 (1&5)
6	0.272	7.70	0.98	outlet	2550	276.9	impactor data not used for overall DF measurement
7	0.252	7.14	7.25	inlet	--	--	
8	0.277	7.84	11.23	inlet	--	--	

mg/Dscf = milligrams of aerosol/dry standard cubic foot of off-gas

The fractional DF performance (or DF as a function of particle size) was obtained by classification of the scrubber inlet and outlet aerosol distribution with a University of Washington Mark V Source Test Cascade Impactor. This device is a so-called "inertial" device that classifies particles based on aerodynamic behavior (particle density and shape). The impactor was used to sample off-gas at both the scrubber inlet and outlet. By expressing the resultant aerosol distribution as concentration for specific particle size range, then the DF as a function of particle size can be determined. Table 2 is a summary of the impactor data collected.

Table 2. Summary of Cascade Impactor Data

Scrubber Inlet

Gas Volume Sampled 5.602 ft^3
Sampling Time 20.0 min
Flowrate 0.280 ft^3/min

Stage No.	Weight Fraction Wt %	Cut Size μm_A
1	65.71	20.31
2	23.88	2.92
3	4.89	1.59
4	1.65	1.11
5	0.74	0.86
6	0.29	0.67
7	0.08	0.52
8	0.15	0.43
9	0.33	0.34
10	0.21	0.26
11	0.28	0.23
Filter	1.79	--

Scrubber Outlet

Gas Volume Sampled 16.720 ft^3
Sampling Time 60 min.
Flowrate 0.279 ft^3/min

Stage No.	Weight Fraction Wt %	Cut Size μm_A
1	0	20.85
2	23.55	2.99
3	23.67	1.63
4	14.05	1.14
5	3.81	0.89
6	3.37	0.69
7	1.79	0.53
8	0.62	0.44
9	1.00	0.35
10	1.50	0.27
11	3.82	0.24
Filter	22.9	--

1 - Cut size was determined from the expression

$$d_{50} = \left[\frac{2.05 \quad \mu D^3 N}{C\rho_p Q}\right]^{1/2}$$

where d_{50} = stage cut size, μm aerodynamic

μ = gas viscosity

D = jet diameter

N = Number of holes

C = Cunningham Slip Correction Factor

ρ_p = particle density ($\rho_p = 1$ by definition of aerodynamic diameter)

Q = Gas flowrate.

Table 2 (contd).

2 - Gas viscosity was calculated from

$$\mu = \sum_{i=1}^{n} \frac{\mu_i}{1 + \frac{1}{f_i} \sum_{\substack{j=1 \\ j \neq 1}}^{n} \left(f_j \Phi_{ij} \right)} \times 10^{-6}$$

where

$$\Phi_{ij} = \frac{\left[1 + \left(\mu_i/\mu_j\right)^{1/2} \left(W_j/W_i\right)^{1/4} \right]^2}{(4/\sqrt{2}) \left[1 + \left(W_i/W_j\right) \right]^{1/2}}$$

and

μ_i = viscosity of gas component, i, micropoise

W_i = molecular weight of gas component i

W_j = molecular weight of gas component j

f_i = wet gas fraction of gas component i .

Comparison of the various weight factions collected at the scrubber inlet and the scrubber outlet sample shows that the HLC system is quite effective for particles greater than 25 μmA. However, the first 5-8 stages for a similar sample obtained on the LSFM quencher would not show the presence of any aerosols (i.e. higher overall DF).

The differences in DF values measured on the HLC, SCM-2 and LSFM off-gas systems are not necessarily unique. To better understand the differences and explain the performance of the HLC a comparison to predictive performance correlations was made.

Predicting Off-Gas Scrubbing Performance

The HLC wet scrubber is a 3 in. OD column packed with 1/4 in. Raschig rings to a height of 11.0 in. This device can be modeled using packed tower performance data from the literature. Utilizing packed tower correlations, the fractional DF can be estimated from

$$DF = 1/Pt$$

and

$$Pt = \exp -\left[\frac{\pi}{2(j+j^2)(\varepsilon - Hd)} \left(\frac{Z}{dc}\right) K_p \right]^* \qquad [1]$$

* The expression presented in Reference 1 is incomplete. Refer to notebook DPSTN 3383 for additional information.

where P_t = fraction penetrating the tower

Z = tower height

d_c = tower packing diameter

ε = void fraction

Hd = liquid hold up

K_p = contacting parameter = $\frac{U_G d_{pa}^2}{9\mu_G d_c}$

with U_G = gas velocity

U_{GS} = superficial gas velocity

d_{pa} = aerodynamic diameter

μ_G = gas viscosity.

This model is based on the following simplifying assumptions:

1- gas flow may be described as flow through a series of "n" semicircular channels of width "b",

2- the number of semicircular bends, n, is related to the overall packing height, Z, packing diameter, d_c, channel width, b, where consistent units apply

$$n = \frac{z}{d_c+b} ,$$

3- the gas velocity through channels, U_{Gb}, is inversely proportional to the bed free volume

$$U_{Gb} = U_{GS} \frac{1}{(\varepsilon-Hd)} ,$$

4- particles are separated by inertial effects only,

5- the particle concentration, c, is constant such that

$$\left.\frac{\partial c}{\partial r}\right|_{\theta = const} \text{ and } \left.\frac{\partial c}{\partial \theta}\right|_{r = const} = 0,$$

6- the width of the semicircular channel, b, can be described as a fraction, j, of the diameter of a single packing element

$$b = jd_c ,$$

and

7- inertial effects only are considered (the scrubbing performance for submicron sized particles will be under estimated).

Substituting the values for the variables described above (data summarized in Table 3) and taking the liquid holdup Hd=0 for low liquid rates and shallow tower height, the overall bed DF can be expressed as

$$DF = \exp(-K\,\Psi)$$

where K = constant = 496.7
Ψ = contacting parameter

and $\Psi = 5536.1\,(dpa)^2$ for $U_G = 5.79$ cm/sec
$\Psi = 3977.6\,(dpa)^2$ for $U_G = 4.16$ cm/sec
d_{pa} = aerodynamic diameter, μm (10^{-4} cm) .

The measured and estimated DF values are shown in Figure 3. Considering the assumptions made, agreement with the packed tower correlation is reasonable.

Table 3. Summary of Data Used for Estimating HLC System Performance

Z = bed height, 27.94 cm
j = fraction of effective diameter, 0.2
$\varepsilon^1 = 0.62$
Hd= 0 (assumed for shallow bed operating below flooding point)
d_c = packing diameter, 0.635 cm
U_G = contacting velocity (ranged from 4.16 to 5.79 cm/sec)
μ_G = gas viscosity = 183 micropoise
d_{50} = aerodynamic diameter, μm (dependent)
d_B = bed diameter, 7.62 cm

Packed tower pressure drop = 0.25 in. of H_2O @ 0.35 scfm
Total heat rejection at nominal operating conditions was 526 Btu/hr.

Table 4 is a comparison of the HLC scrubber cut size as a function of gas velocity with tower height and packing diameter as parameters.

If the correlation is solved for a specific particle diameter (i.e. d_{pa} corresponding to 50% efficiency) then the effect of various design parameters can be ascertained. It can be shown then that

$$d_{50} = \left(3.971\ (j+j^2)(\varepsilon - Hd)\ \frac{d_c^{\ 2}}{Z}\ \frac{\mu_G}{U_G}\right)^{1/2} \times E\text{-}04$$

where d_{50} is the aerodynamic cut size corresponding to an overall efficiency of 50%.

Table 4. Effect of Tower Design on Scrubbing Performance

	Cut Size, d_{pa} Aerodynamic Diameter, µm		
Superficial Gas Velocity cm/sec	HLC System	5XHLC Tower Height	1/4 of Present Packing Diameter
1.0	12.5	5.6	3.1
2.0	8.8	3.9	2.2
4.16 *	6.1	2.7	1.5
5.79 *	5.2	2.3	1.3
8.0	4.4	1.9	1.1

* Gas velocities utilized during tests at the ETF

The first column is a summary of scrubbing performance for the system tested at the ETF. The second column in Table 4 shows the effect of gas velocity on cut diameter. As expected the cut size decreases (efficiency increases) as gas velocity increases. This would be expected since the momentum of the particle increases with U_G^2 and DF is roughly proportional to $\exp(U_G^2)$.

A 5X increase in tower height has the effect of halfing the cut diameter. However, this is not a practical design change. Reducing the column packing diameter also can effectively increase the overall DF. However, the trade off is against increased pressured drop which is limited in this system by the difference in height between the spray trap and the condensate tank drainline.

Overall DF Performance

Fractional efficiency data is useful for assessing the performance of a given scrubber and identifying limitations in design. The eventual goal though of any wet scrubber system is to reduce the concentration of particulates in a gas stream. Since the particle size distribution is known, the overall DF can be determined from

$$DF = \left[1 - \int_{-\infty}^{+\infty} H_1(X)\ d[H_2\ (X)] \right]^{-1}$$

where H_1 (X) represents the log normal function for the fractional efficiency, and H_2(X) the log normal function for the particle size distribution and X the particle diameter. The solution to this equation then becomes a simple relationship between the overall collection efficiency and the error function (erf) or

$$DF = \left[1 - \text{erf}\left[\frac{\ln D_m/Dpa}{(\ln^2 \sigma g + \ln^2 \sigma gc)^{1/2}} \right] \right]^{-1}$$

where D_m = mass mean aerodynamic particle diameter, μma

D_{pa} = cut point of the collection device, μma

σ_g = geometric standard deviation of the particle * size distribution (i.e. 84.1% size/50% size)

σ_{gc} = geometric standard deviation of the wet scrubber.

For the HLC system then

$$DF = \left[1 - \text{erf}\left[\frac{\ln D_m / \left((3.971)(j+j^2)(\varepsilon - Hd) \frac{dc}{z} \frac{\mu_G}{YG} \right)^{1/2} (E-04)}{\sqrt{\ln \sigma g^2 + \ln^2 (0.2493)}} \right] \right]^{-1}.$$

Substituting the values for the HLC test the following results were obtained:

	Predicted DF	Measured DF †	Measured DF ††
	11.0	6.04	11.9
		6.35	
		7.33	
		4.87	
Average		6.14	

* For a bi-modal distribution this is represented by (84.1% size/15.9% size)$^{1/2}$

† Based on Absolute Filters

†† Based on Cascade Impactor Data

The agreement between theory and experiment was good. As evidenced by the data above, the overall DF can be estimated from the packed tower correlation (utilized in this report) and scrubber inlet aerosol data (e.g. Dm and σg). The measured overall DF of the HLC system is typical for gas contacting equipment of this type. The mass fraction of aerosol greater than 1 mA for these tests was roughly 0.95. Since particles in this size range are separated by inertial means, considerably more energy (bed pressure drop or scrubber water pressure) would be required to improve the overall DF. Conceivably, this system could be modified to improve the DF for coarse (greater than 1.0 µm) particles. However, the DF for submicron particles (semivolatiles) cannot be effectively improved with this type of gas scrubber.

Summary

o The overall DF of the HLC system is roughly 6.14. However, this will not interfere with data acquisition but will result in accumulation of solids in downstream off-gas lines and equipment.

o The fractional efficiency of this scrubber can be estimated quite well from packed tower correlations.

o The overall DF is lower than that of a typical high energy wet scrubber but is expected for a scrubber of this design.

o No appreciable effect of scale on DF could be identified in these series of tests.

o Future tests should be performed with a scaled gas atomized scrubber to develop comparison data to full scale equipment at TNX.

Quality of Data

All data obtained was in accordance with the DWPS Quality Assurance Plan. Any applicable standard methods with any modifications to the standard were noted. Where necessary, certain data acquisition components have traceable performance characteristics and are identified as such. The data and development of equations used in this report may by obtained from SRL Notebook DPSTN 3383, pp. 79-91.

References

1. Stern, A. C., **Air Pollution**, Academic Press, NY, 1977, pg 276.

2. Sunberg, R. E., "The Prediction of Overall Collection Efficiency of Air Pollution Control Devices from Fractional Efficiency Curves", Journal of the Air Pollution Control Association, Vol 24, No. 8, August, 1974, pp. 758-764.

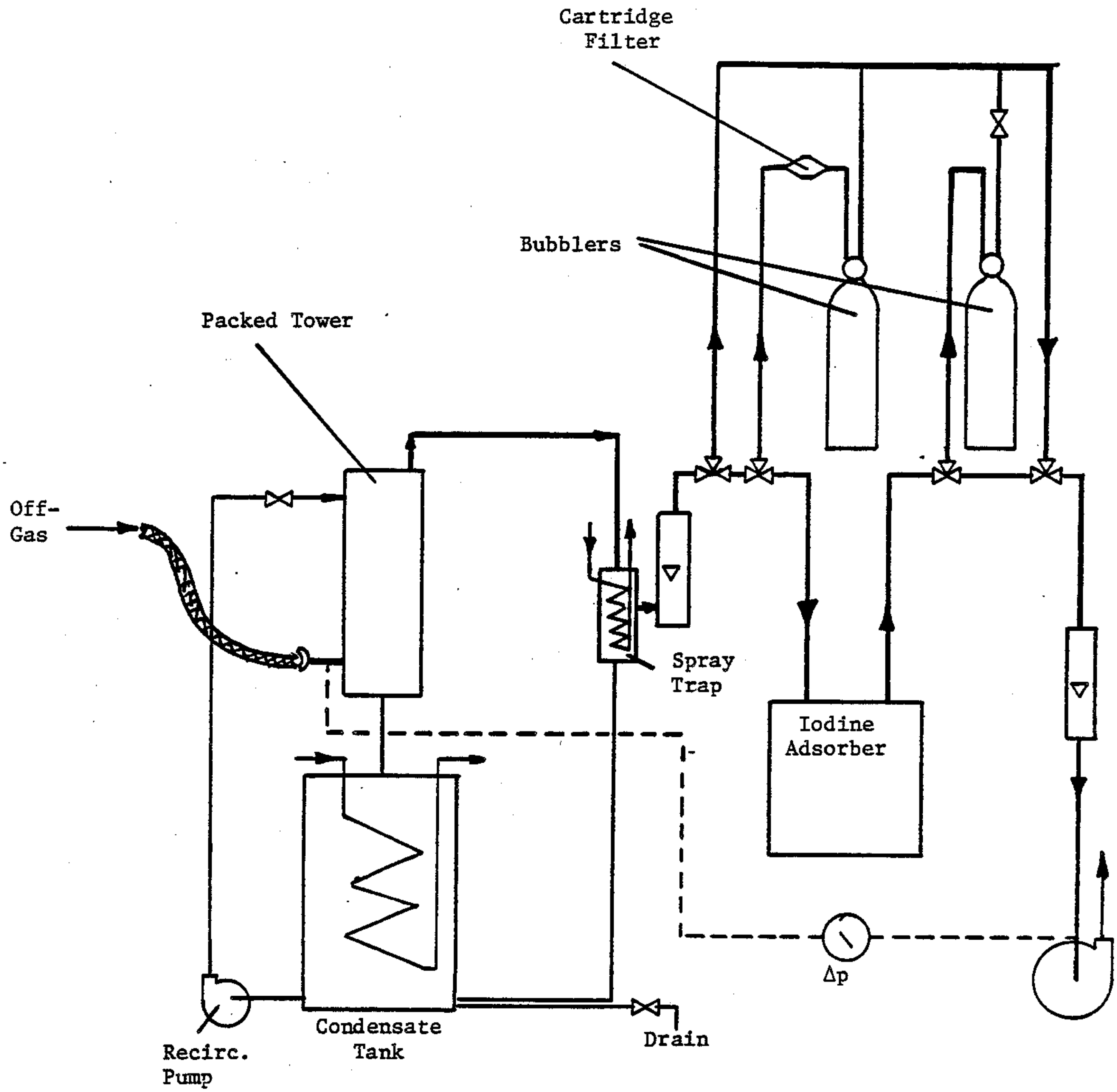

Figure 1: HLC OFF-GAS SYSTEM

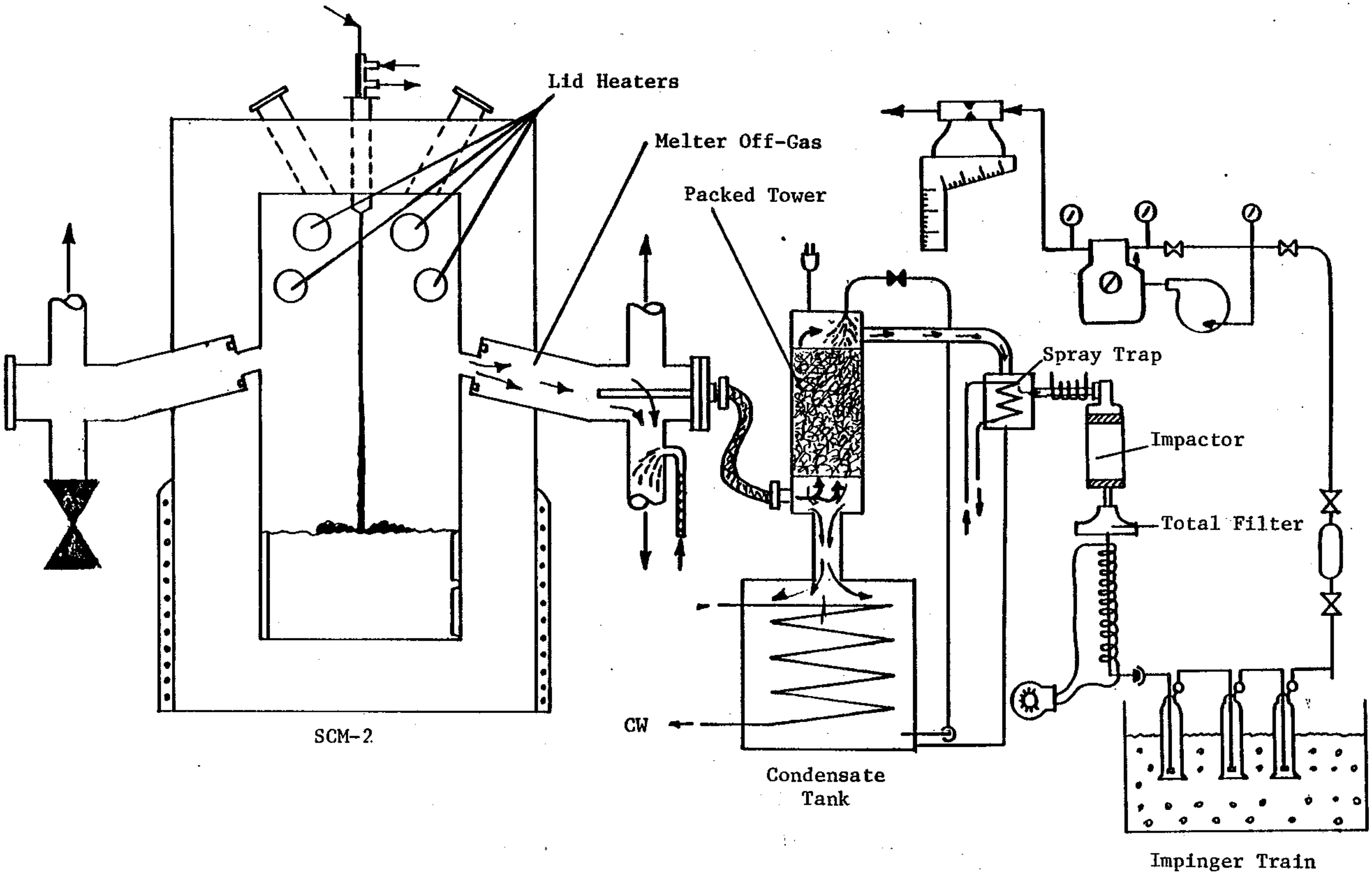

Figure 2. SET-UP FOR HLC OFF-GAS SYSTEM EVALUATION

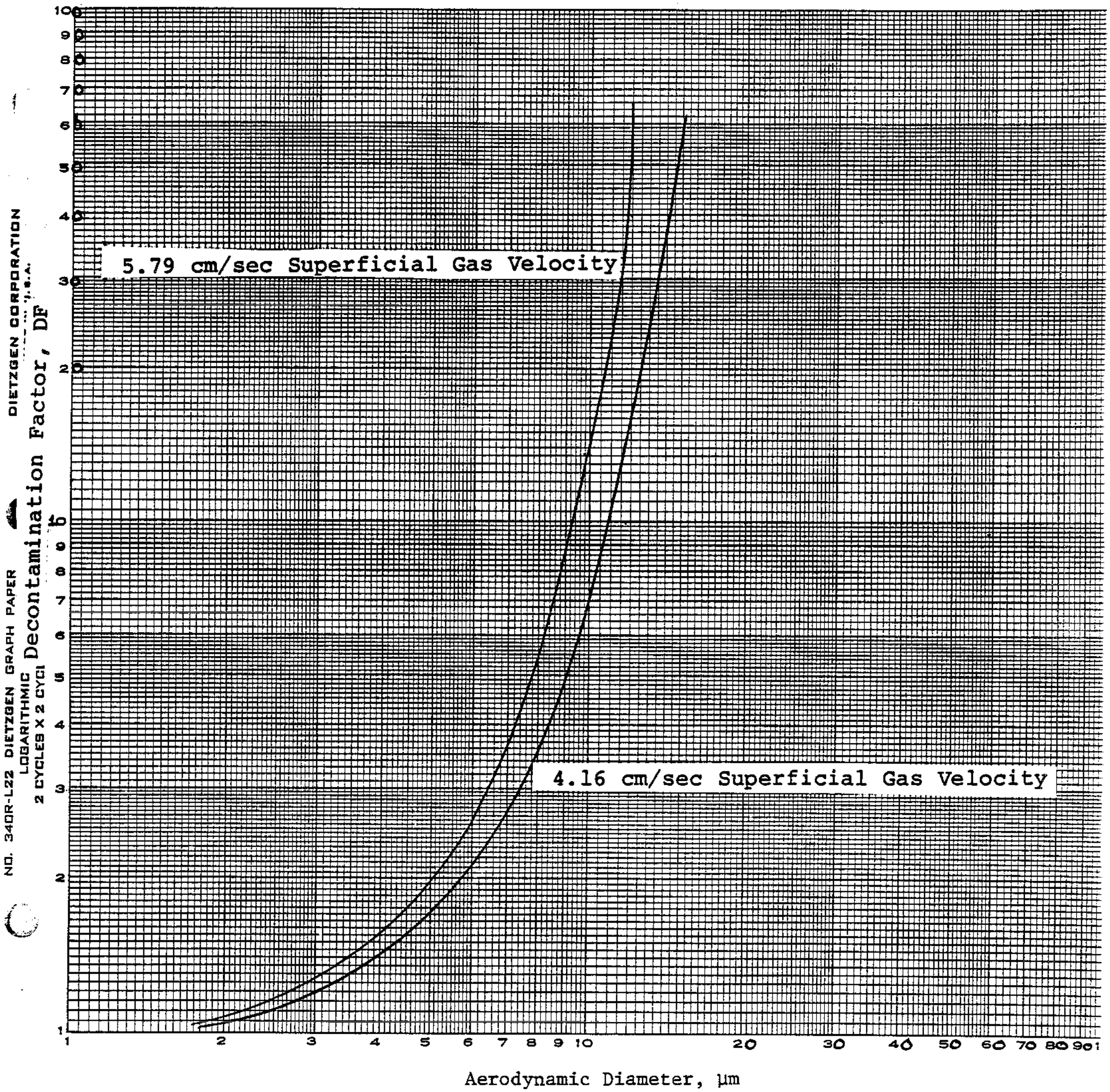

FIGURE 3. PREDICTED HLC OFF-GAS SCRUBBING PERFORMANCE

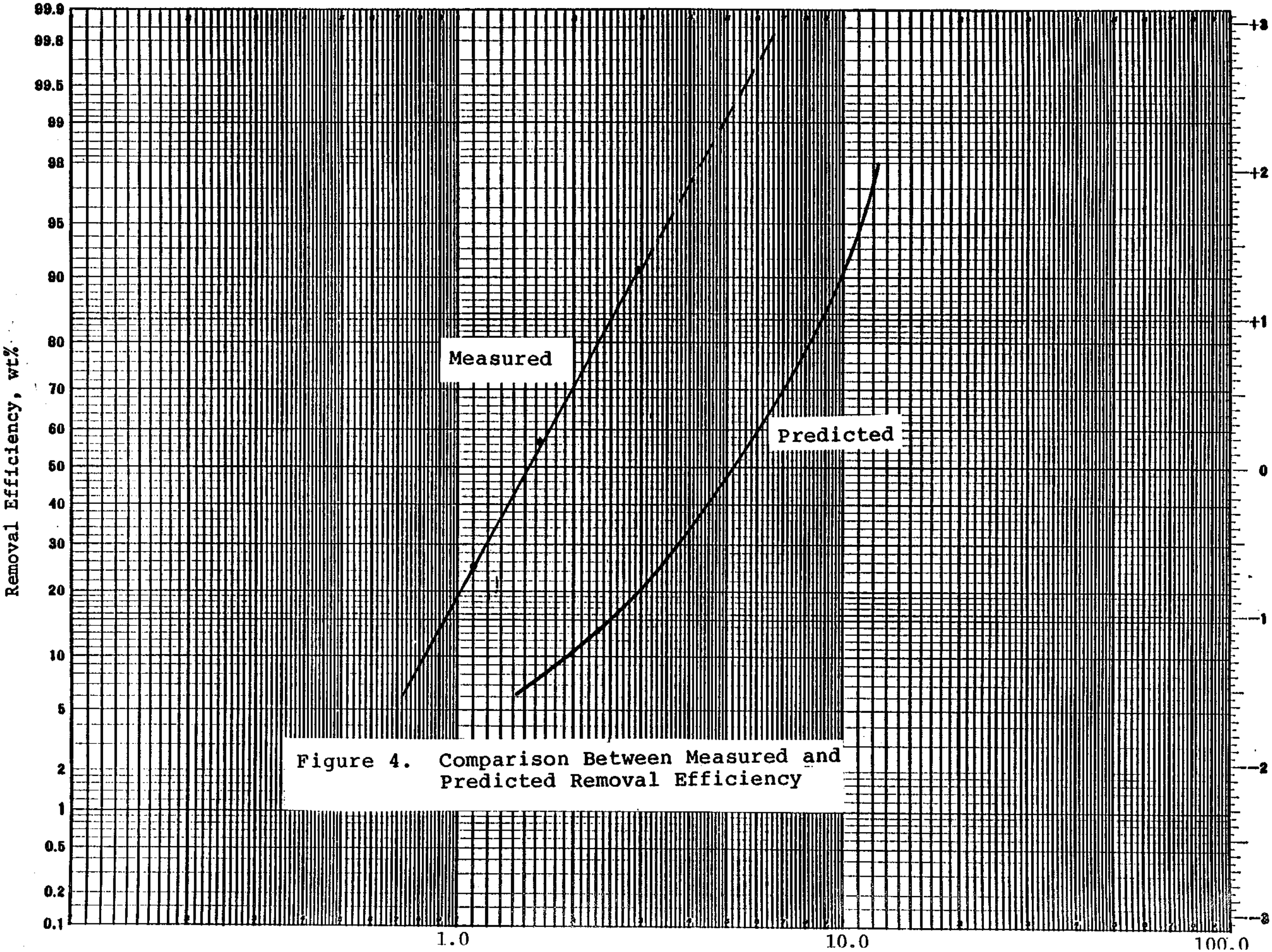

Figure 4. Comparison Between Measured and Predicted Removal Efficiency