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ODOR CONTROL BY SCRUBBING IN THE RENDERING INDUSTRY
Addendum

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ODOR CONTROL
BY SCRUBBING
IN THE RENDERING INDUSTRY
(Addendum)

by

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FOREWORD

A previous Report No. EPA-600/2-76-009 presented the results of experiments conducted at a rendering plant on the removal of odors from plant ventilating air using a plant-scale spray scrubber and a laboratory-scale packed bed scrubber.

This addendum to the previous report presents results of additional experiments at the rendering plant on the use of the laboratory-scale scrubber to remove high-intensity (5000 to 180,000 odor units) odors from a process air stream that normally goes to an incinerator.

This report covers investigations performed by the IIT Research Institute (IITRI), Project C8277, under contract with the Fats and Proteins Research Foundation, Inc.

Those who contributed to this project were: J. E. Huff, C. Swanstrom, L. Peckous, V. Ivanuski, T. Ripley, Dr. A. Dravnieks, and Dr. R. H. Snow of IIT Research Institute; and Dr. W. Boehme of the Fats and Proteins Research Foundation, Inc.; and Gene Rosendahl of National Byproducts Inc. Data are recorded in Logbooks C22333, C22334, C22335, C22336 and C22380.

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ABSTRACT

In the previous project, the performance of packed-bed scrubbers for high-intensity rendering plant odors (5,000 to 180,000 odor units) was investigated. In some cases, the removal was as high as 99%, but the average was only 85%. In this project, extensive performance data was obtained with an odor panel over a period of 8 weeks. Removal averaged 93% with 3 stages of sodium hypochlorite scrubbing even though each stage was designed to remove 99% of the odors based on its mass-transfer capacity.

The results were fitted to a regression equation, which showed that the important variables are the age of the solution and the relation of the inlet odor concentration to the previous history of exposure of the scrubbing solutions to high odor intensities. Chlorine concentration and pH also affect the results, and calcium hypochlorite is about 1.5 times more effective than sodium hypochlorite.

The experimental data could be explained by the assumption that approximately 85% of the odor was contributed by compounds that are oxidized by hypochlorite solutions, while the remaining fraction consists of compounds that are refractory to oxidation. Further efforts should be made to find scrubbing reagents that will remove the odorous compounds that are refractory to hypochlorite.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INVESTIGATION OF ODOR CONTROL IN THE RENDERING INDUSTRY - SCRUBBING OF HIGH-INTENSITY ODORS

1. INTRODUCTION - PREVIOUS WORK

The original thesis of this series of projects was that a reagent or combination of reagents could be found to react with the compounds responsible for rendering plant odors. Then, scrubbing systems to control rendering plant odors could be designed based on mass transfer principles, with no chemical reaction limitations. This thesis will have to be modified as a result of the present work.

In the first project (Report No. EPA-R2-72-088), the major compounds responsible for the odors were identified by a combination of gas chromatograph-mass spectrometer analysis, together with a computer regression of the strength of odorous air samples determined by an odor panel. Laboratory experiments with these pure odorants then showed that most of these compounds could be removed by reaction with strong oxidizers such as sodium hypochlorite.

The next step was a series of studies to determine the design of spray scrubbers and packed-bed scrubbers for rendering plant odor control, based on mass-transfer principles. In the previous project (Report No. EPA-600/2-76-009), scrubbing methods using alkaline sodium hypochlorite solutions were developed for both plant ventilating air (100 to 5,000 odor units) and for air that contains high-intensity odors (5,000-180,000 odor units) and normally goes to an incinerator. The use of a three-stage countercurrent blowdown system was demonstrated; first with the horizontal spray scrubber for plant ventilating air, and second with a packed-bed scrubber for the high-intensity air from the cooker. The plant odor scrubber averaged 92% removed, with an average outlet odor level of 64 odor units for a two-week period.

The report also included computer procedures for design of scrubbers based on mass-transfer principles, with coefficients established from the plant tests. The report also contained procedures for estimating the costs of scrubbing. For reasons discussed below, the design procedures should not be extrapolated beyond the conditions which were investigated experimentally.

These designs were checked by carrying out experiments using a plant-scale spray scrubber and a laboratory-scale packed bed scrubber at a rendering plant. The results for low-intensity plant ventilating air (100 to 5,000 odor units) confirmed the design predictions, as long as removals up to 90 percent were attempted. However, for control of high-intensity odors in process air from cookers (5,000 to 180,000 odor units) removals of 99% are needed. The 3-stage laboratory-scale scrubber was designed so that each stage should remove 90% of the inlet odor, and three stages should have been capable of removing 99.9% on a mass-transfer basis. Subsequently, the depth of packing was increased to raise the theoretical capacity to 99% for each stage. The results were inconclusive; in some cases removals of 99% were attained in short tests, but a 2-week test gave removals averaging 85%. It was thought that the conditions for complete reaction had not been maintained, and especially that pH above 11 was needed for complete reaction. On the other hand, there was evidence from the literature that lower chlorine concentration than the 0.2 wt % investigated could do as well at lower chemicals cost. The number of experiments done on the packed-bed scrubber was limited, and therefore the statistical reliability of the data could not be established.

The purpose of the present program was to determine the effect of pH and purge rate on the performance of high-intensity scrubbers. Determining the effect of chlorine concentration on performance was also an objective of this program. Many rendering plants operate scrubbers with chlorine levels in the parts per million range, while the previous program utilized chlorine levels of 0.17 to 1.0 wt % Cl_2.

2. SUMMARY

The present project was intended to obtain more data on the performance of the 3-stage packed-bed scrubber over a range of conditions of pH and chlorine concentration and purge rate of scrubber solutions. The depth of the packed bed in the 3 columns was 4 ft, so that on a mass-transfer basis each column should have been capable independently of lowering the odor concentration by 99%. The 6-in. diam columns were packed with 1/2-in. Intalox saddles. The air flow rate was 16.5 cfm. Experiments were done with 1, 2, and 3 columns in series. Chlorine concentration was varied from 0.005 to 0.25 wt %. pH was varied from 8 to 12.3. Scrubber solution purge rate was varied from 9 to 30 ℓ/hr, with either counter-current or separate purging of solution from each stage. Experiments were also done with calcium hypochlorite instead of sodium hypochlorite.

The experiments were carried out in a rendering plant in Iowa over a period of 8 weeks during July to September, 1975. The scrubber performance was evaluated using an odor panel with the dynamic forced-choice olfactometer method.

A multiple-regression analysis showed that the data could be fitted by either of two equations. The important variables are the inlet odor concentration, the history of previous exposure of the solution to odor and the number of hours of exposure, and the pH and available chlorine concentration of the reagent.

The results of these experiments showed that odor removals averaging 93% could be achieved. Removals of 99% were achieved only with fresh solutions. Calcium hypochlorite removed 1.5 times more odor than sodium hypochlorite at the same conditions

The experimental data could be explained by the assumption that approximately 85% of the odor was contributed by compounds that are oxidized by hypochlorite solutions, while the remaining fraction consists of compounds that are refractory to oxidation.

Removal of the reactive odorants is aided by high pH and high chlorine concentrations, within the range of these variables

studied. Removal of refractory compounds is highest in fresh solutions, which explains the removals of 99% achieved under some conditions. Variation of purge rate up to 30 ℓ/hr did not affect the results significantly, but theoretically an optimum purge rate should exist.

A long-term solution to the problem of scrubbing high-intensity rendering plant odors will depend on finding more effective reagents than hypochlorite.

3. CONCLUSIONS

A computer regression analysis resulted in the following equation to best fit the data:

$$\frac{\text{outlet}}{\text{inlet}} = 1.6\ \exp(-0.64\ \text{cols})\ \exp(0.41\ \text{reagent})\ \exp\ (-0.372\ \text{Cl}\cdot\text{pH})$$

$$\times\ \exp-\left(0.0253\frac{\text{inlet}}{1{,}000} - 0.0080\frac{\text{OU4}}{1{,}000} - 0.0046\frac{\text{OU1}}{1{,}000} - 0.0023\frac{\text{OU2}}{1{,}000}\right)$$

with a standard deviation of a factor of 1.95

where

- outlet is the outlet odor concentration, odor units
- columns is the number of scrubber columns in series
- Cl is the average concentration of available chlorine in the scrubber solutions
- pH is the average pH of the scrubber solutions
- inlet is the inlet odor concentration, odor units
- OU1, OU2, and OU4 are average inlet odor concentrations at the following previous times: 0-2 hrs., 2-4 hrs. and 10-15 hrs. respectively.
- Reagent = 1 for sodium hypochlorite
  = 0 for calcium hypochlorite
- Purge Rate = rate of flow of make-up and purge solution streams, liter/hr.

The results were also fitted by the following simpler equation:

outlet/inlet =

$$2.7e^{-0.622\text{columns}} \times e^{-0.284(\text{Cl}\cdot\text{pH})} \times \text{hours}^{0.246} \times \left[\frac{\text{inlet}}{1{,}000}\right]^{-0.737}$$

where

hours is the age of the scrubber solutions, or the number of hours they have been in use.

The experimental data could be explained by the assumption that approximately 85% of the odor was contributed by compounds that are oxidized by hypochlorite solutions, while the remaining fraction consists of compounds that are refractory to oxidation.

Results may vary depending on plant odorous composition. In fact, the response of a sulfur detector was found to vary by a factor of 5 over a cycle of 10 min, which corresponded to the period of an on-off raw material feeder to the continuous plant cooker. A sulfur detector has been found by others to be correlated to rendering plant odor level with a coefficient of 0.9. The figure of 85% represents an average for our tests.

Refractory compounds may be either present in the raw air stream, or they may be products of reactions of odorants with the scrubbing liquid. The rate of reaction of these refractory compounds is so slow that allowing the scrubber solution to stand a day does not affect the results. Apparently the refractory compounds have a limited solubility in water, so that removal of greater than 99% can be achieved with fresh solutions, but a purge rate much greater than 30 ℓ/hr would be needed to have a similar effect.

Removal of the reactive odorants is aided by high pH and high chlorine concentrations, within the range of these variables studied. Removal of the refractory compounds should be aided by high purge rate. Use of a high purge rate at high concentrations will result in high chemicals cost. To achieve constant chemicals cost, the purge rate can be increased while reagent concentration is lowered; some optimum must exist, but this was not investigated.

With the existing reagents, the best that can be done is to attempt to operate the scrubber near the optimum. A long-term solution to the problem will depend on finding more effective reagents than hypochlorite.

4. RECOMMENDATIONS

Further efforts should be made to find scrubbing reagents that will remove the odorous compounds that are refractory to oxidation by hypochlorite.

5. EXPERIMENTAL PROCEDURES

Modifications were made in the laboratory-scale scrubber system at the rendering plant of the National By-Products Company in Des Moines, Iowa. The purpose was to provide closer control of scrubbing conditions.

No gas chromatograph measurements were made on this project. The previous project has already presented GC data showing that certain compounds tend to build up in the scrubber solutions, and it was felt that further proof of this was not needed. (EPA Report 600/2-76-009, pages 6-8 to 6-11 and Tables 9-1 to 9-5.) Instead, it was thought best to concentrate on obtaining enough sensory data to establish the statistical reliability of the scrubber results.

An odor panel was set up in Des Moines, instead of shipping bag samples to IITRI's laboratory. Having a local panel allowed us to carry out sensory measurements daily, under direct control of project engineers.

A sulfur detector was installed to record the inlet concentration. This provided a measure of the time dependence of odor concentration. Others have previously shown a 0.9 correlation between sulfur detector response and odor units from a rendering plant.

In other respects the experimental procedures and equipment were similar to those described in the previous project (Report EPA-600/2-76-009.) Experiments were done with 1, 2, and 3 columns in series. Available chlorine concentration was varied from 0.005 to 0.25 wt %. pH was varied from 8 to 12.3. Scrubber solution purge rate was varied from 9 to 30 ℓ/hr, with either counter-current or separate purging of solution from each stage. The 6-in. diam columns were packed with 1/2-in. Intalox saddles. The depth of the packed bed in the 3 columns was 4 ft, so that on a mass-transfer basis each column should have been capable independently of lowering the odor concentration by 99%.

5.1 Equipment Modification

Before starting the experiments, two pH controllers were installed to control the pH of solutions in the second-and third-stage tanks. The controller opened a solenoid valve to allow caustic solution to flow into each tank. The solution in the first stage tank was manually controlled using one of the controllers as a pH meter. Equipment is shown in Figure 1.

Piping and liquid rotameters were installed between each stage so that the scrubbers could be operated either as a continuous counter-current blowdown system, or with separate make-up and blowdown of solutions in each stage.

5.2 Sulfur Detector

A Meloy Laboratory Flame Photometric Detector with a continuous recorder was set up, and a sample line was installed from the inlet air line to the detector. The sulfur detector was checked out at IITRI prior to shipping and found to be extremely sensitive; a concentration of 1 mg/ℓ of diethylsulfide gave a response of 90% of scale with the attenuator on 32×10^6. Calibration in terms of odor units is given in Section 6.

5.3 Odor Panel Measurements

To facilitate obtaining large amounts of odor data in an expedient way, the Dynamic Force-Choice Triangle Olfactometer owned by National By-Products was set up at Drake University in Des Moines. For this purpose, we used dynamic odor panel device similar to that used on the previous project {Dravnieks and Prokop, APCA Journal, 25(1): 28-35, 1975}.

Thirty panelists were screened for response to a sample of rendering air, under the supervision of Dr. Dravnieks. These panelists were then categorized into above- and below-average sensory perception. Two panelists were also asked not to participate any further because their sensory perception was very poor as compared to the other panelists. The panelists included high school students, college students, teachers, housewives, and

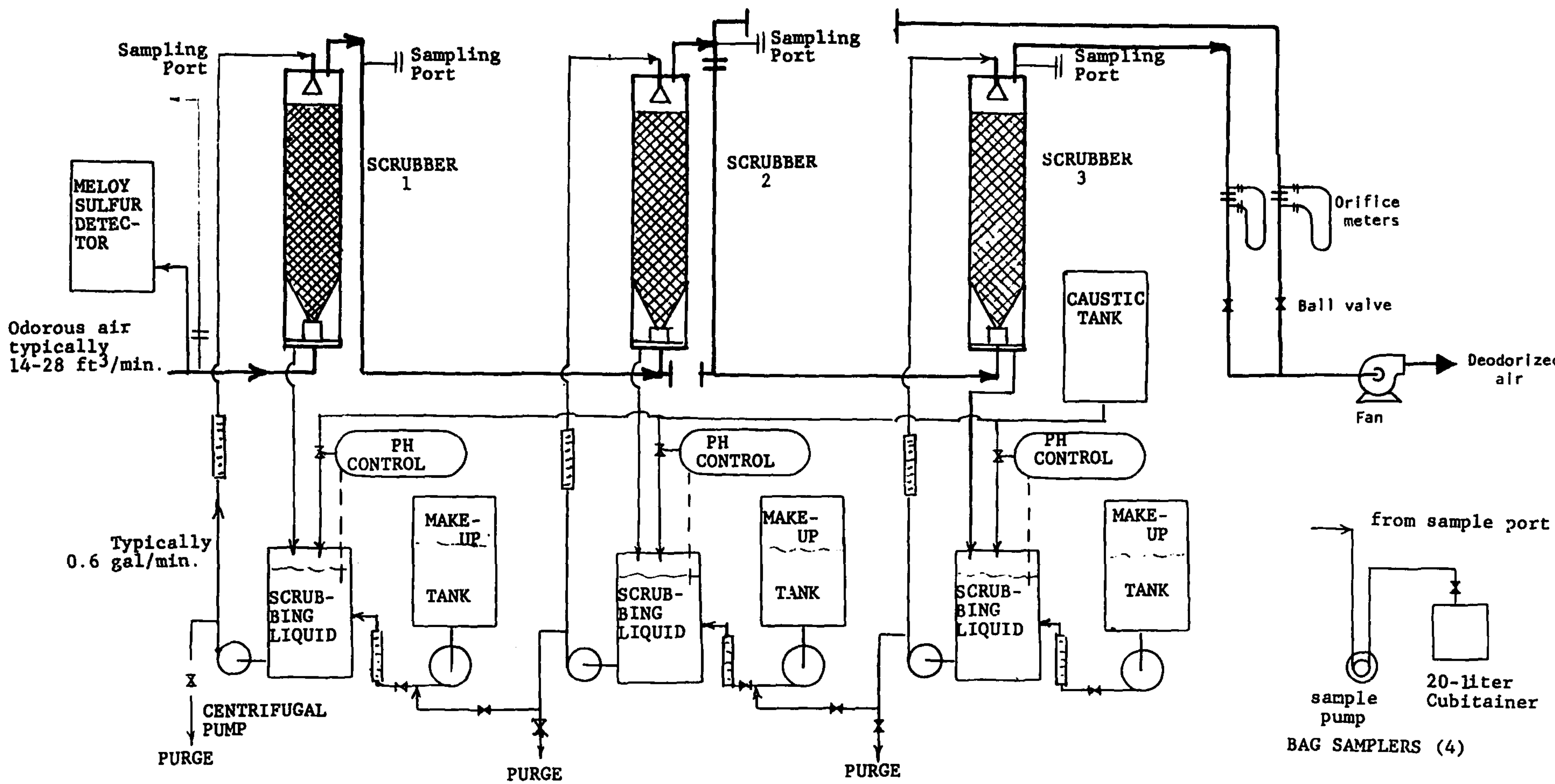

Figure 1

LABORATORY PACKED-BED SCRUBBER

several unemployed people. Panel sessions were arranged for Tuesday through Friday, one in the morning and one in the afternoon each day. Four or five bag samples were analyzed at each 2-hour odor session.

An experimental difficulty arose in the operation of the olfactometer. This instrument provides six levels of odorous air dilution. If several panelists detect the odor on the first, most dilute level, then a 27:1 diluter is inserted in the inlet line and the panel measurement is rerun. There should be an odor level at which the measurement can be made on-scale both with or without the diluter. It appears that there may be a systematic error when the diluter is inserted, because the measured odor is always higher with the diluter inserted, by a factor of 20 to 50%. More research would be needed to prove this and find the reason.

6. EXPERIMENTAL RESULTS

This section describes the sequence of experiments carried out, the objectives of each series of experiments, the experimental difficulties encountered and the methods used to overcome them. For an overall view of the effects of experimental variables on the scrubber performance, turn to the following chapter on statistical analysis of results.

6.1 Preliminary Single-Stage Experiments

Our plan was to conduct one week of exploratory experiments using two single-stage columns operated on the same air stream in parallel, in order to directly compare the effectiveness of high and low pH, chlorine concentration, and purge rate. The experimental system for these parallel-column experiments is shown in Figure 1.

For the first experiment, test 36, stage 2 was controlled at pH 10 and stage 3 was controlled at pH 12. The Cl_2 level in both stages was maintained between 0.15 and 0.20% and the blowdown rates were both 9 ℓ/hr. The results are presented in Table 1.

These results were contrary to what we had expected; pH 10 appeared to be more effective then pH 12. For experiment 37, the two scrubbing solutions were reversed; pH 12 was placed in stage 2 and pH 10 was placed in stage 3. Test 37 indicated that pH 12 removed more odor than pH 10. Alternatively, the results seemed to suggest that column 2 was considerably more effective than column 3, regardless of pH.

For test 38, fresh identical solutions were used in columns 2 and 3 to determine whether there was a difference in equipment performance. Since this was intended as a brief test to compare the difference in performance, no blowdown was used. The results are presented in Table 2.

Since stage 2 gave higher removals than stage 3 in all three tests, the results left little doubt that there was a significant performance difference between the stages.

TABLE 1

EFFECT OF pH ON PERFORMANCE

TEST NO.	AGE OF SOLUTION	INLET ED_{50}	pH 10 STAGE OUTLET ED_{50}	pH 10 STAGE % REMOVAL	pH 12 STAGE OUTLET ED_{50}	pH 12 STAGE % REMOVAL
			Stage 2		Stage 3	
36A	7	63,000	1,300	98	3,900	94
36B	9	47,000	390	99.2	2,700	94
36C	10	30,000	420	98.6	1,200	96
			Stage 3		Stage 2	
37A	15	81,000	19,000	76	390	99.5
37B	18	81,000	18,800	77	2,400	97
37C	20	57,000	18,000	68	5,900	90
AVERAGE	--	--	9,700	86	2,700	95

TABLE 2

ODOR REMOVAL BY SCRUBBING WITH SODIUM HYPOCHLORITE

Parallel Tests With Two Single Columns

TEST NO.	pH STAGE 2	pH STAGE 3	CHLORINE CONC WT % STAGE 2	CHLORINE CONC WT % STAGE 3	TEMP. °C STAGE 2	TEMP. °C STAGE 3	PURGE RATE ℓ/HR STAGE 2	PURGE RATE ℓ/HR STAGE 3	HOURS OF REAGENT USE	ODOR ED_{50} INLET	ODOR ED_{50} OUTLET COLUMN 2	ODOR ED_{50} OUTLET COLUMN 3	% REMOVAL COLUMN 2	% REMOVAL COLUMN 3
38A	10	10	.05	.05	23	23	0	0	1	23,000	410	4,800	98.2	79.
38B	12	12	.05	.05	22	22	0	0	2	25,000	760	2,000	97.	92.
38C	12	12	.20	.20	22	22	0	0	3	27,000	280	2,900	99.	89.
39	11	11	.05	.05	26	26	0	0	1	39,000	350	2,400	99.1	94.
40A	12		.18		24		9		3	48,000	240	not used	99.5	
40B	12		.18		23		9		4	43,000	430		99.0	
40C	12		.19		23		9		5	66,000	220		99.7	
41A	10.1	10.0	0.15	0.15		26	0	0	2	> 93,500	250	2,100	99.7	97.8
41B	10.1	10.0	0.20	0.15			0	0	4	> 133,000	2,200	2,400	98.3	98.2
42A	10.0	11.9	0.15	0.19	22.5	24.5	30	30	6	51,000	1,000	1,700	98.0	96.7

Prior to starting up the scrubbing system the following night, the system was:

- Checked for leaks in sampling lines - none found
- Cleaned the spray nozzles on both stages
- Checked the columns for vertical alignment. Both were off vertically 1-2 in. out of 6 ft. Straightened the columns so that they were vertical.

The parallel system was again checked for performance with fresh identical solutions in both stages. The results are given in test 39, Table 2, which again showed that stage 2 performed better than stage 3.

Before conducting test 41 in Table 2, the scrubbing liquid distributor nozzles on each column were checked, as well as the orifice plates used to measure the air flow rates. Column 2 again gave somewhat higher removals than column 3, although the difference was less than before.

Test 48 in Table 3 compares the results of sampling in different arrangements with no scrubbing solution being pumped over the packing. Test 48A shows that column 2 does indeed give a lower effluent ED_{50} than column 3 (8.200 odor units compared to 18,400). When the samplers were reversed in test 48B, column 2 still gave a lower result (14,000 odor units compared to 21,000). This indicates that the difference is not due to the sampling equipment, but something inherent in the column or the sampling port. Finally, test 48C was run with the two columns in series. The ED_{50} decreased as the air passed through the columns, from 36,000 to 13,000 to 8,850. This shows that the packing, which was still wet with scrubbing solution, was capable of removing some of the odor, even though the scrubbing liquor pumps were not turned on.

With the columns in series, both orifice plates for measuring gas flow were read simultaneously, to check whether the air flow measurement was the same. They agreed within 4% in pressure drop (1.04 in. water pressure vs. 1.08 in. water). This corresponds to only a 2% difference in flow rate, since flow depends on square root of pressure drop. Therefore, there

TABLE 3

TEST 48
COMPARISON OF PARALLEL AND SERIES COLUMN ARRANGEMENTS
Scrubbing Solution Pumps Not Turned On

TEST NO.	ODOR ED_{50}		
	OUTLET OF COLUMN 1	OUTLET OF COLUMN 2	OUTLET OF COLUMN 3
48A	Columns 2 and 3 in parallel		
	27,000	8,200	18,400
48B	Columns 2 and 3 in parallel, reversed samplers and shortened connections		
		14,100	21,000
48C	Columns 2 and 3 in series		
	36,000	13,000	8,850

was no significant difference in air flow in the parallel tests. By this time we were falling behind in our experiment plan, and it did not seem likely that we could discover the cause of the discrepancy without extensive further testing. There were 2 possible explanation but no evidence that either was correct: 1) column 2 actually removed more odor than column 3, or 2) the sampling system for one of the columns was introducting a bias, either by dilution or contamination.

Rather than deviate further from the project plan, we decided to proceed with the planned experiments using three columns in series, and to base the results on the output of column 3. This will give the most conservative interpretation of the results, since the output of column 3 showed a lower removal than the output from column 2.

6.2 Effect of Variables - Preliminary Experiments

From the preliminary tests, it was tentatively concluded that pH 12 is more effective than pH 10. Table 1 showed an average removal of 95% for pH 12, and 86% for pH 10, when results from both columns 2 and 3 are averaged. The effect of chlorine concentration and blowdown rate remained to be determined from the three-stage tests that followed.

The results of these preliminary experiments are further summarized in Table 4, where only the data from column 3 are extracted and presented. Inspection of the removals indicates that the two main variables are hours of operation with the same solution and pH of the solution. For solutions less than 10 hr old and with pH of 12, removals range from 89.3 to 98.2 for a single stage. (Note that the inlet air was also passing through column 1, which contained wet packing without any solution being pumped over the packing.) A high inlet odor may also contribute to a high removal. These data are included in computer regression of variables given in Section 8.

TABLE 4

COLUMN 3 -- SCRUBBING WITH SODIUM HYPOCHLORITE
(EXTRACTED FROM PARALLEL COLUMN DATA)*

TEST NO.	pH	CHLORINE CONC., WT %	TEMP., °C	PURGE RATE, ℓ/HR	HOURS OF REAGENT USE	ODOR ED_{50}		% REMOVAL
						INLET	OUTLET COLUMN 3	
36A	12.3	0.13	29	9	7	63,000	3,900	93.8
36B	12.0	0.16	27.5	9	9	47,000	2,700	94.3
36C	12.0	0.21	27	9	10	30,000	1,200	96.0
37A	9.0	0.25	26	9	15	81,000	19,000	76.5
37B	10.5	0.24	22	9	18	81,000	18,800	76.8
37C	10.5	0.19	21.5	9	20	57,000	18,800	67.0
38A	10.3	0.05	23	0	1	23,000	4,800	79.1
38B	12.1	0.10	22	0	2	25,000	2,000	92.0
38C	12.0	0.18	22	0	3	27,000	2,900	89.3
39A	10.9	0.028	26	0	1	39,000	2,400	93.8
41A	10.0	0.15	26	0	2	> 93,500	2,100	> 97.8
41B	10.0	0.15	--	0	4	> 133,000	2,400	> 98.2
42A	11.9	0.19	24.5	30	6	51,000	1,700	96.7

* The air passed through column 1. The packing of column 1 was wet, but the solution pump was off.

6.3 Two-Stage Scrubbing with Sodium Hypochlorite, Counter-Current Purge

From this point on, all tests were done with the columns in series. In the next group of tests (Table 5), reagent was pumped through only columns 2 and 3. From the results of test 48, we now know that column 1 was also removing some odor, even though solution pump No. 1 was turned off.

The purpose of these tests was to explore the effect of pH from 9.0 to 12, and of chlorine concentration from 0.005 to 0.3 wt %. Only one blowdown rate was used, 25 ℓ/hr. We had planned to try a lower rate as well, but since the odor removal was less than desired, it was felt that a lower rate would not help to achieve the desired removal. It appears from the table that age of solution, inlet ED_{50}, chlorine concentration, and possibly pH affect the removal. Computer regression will determine these relationships.

Test 52 was run in the same way as the other tests in Table 5, except that a fiberglass filter was packed into the top foot of column 1. The filter consisted of 16 6-in. dia. discs cut from fiberglass furnace filter material, weighing 47.0 g. The scrubber pump No. 1 remained off. Computer analysis may show an effect, but none is apparent from inspection of Table 3. The fiberglass filter was damp and odorous after exposure to the inlet air for 7 hr. After drying it in the sun, the filter weight was the same as before exposure within an accuracy of 0.1 g. Therefore, there is no evidence that particulates were affecting the scrubber performance.

In the tests following test 52, the same fiberglass was packed into the 4-in. dia. duct carrying the odorous air from the incinerator inlet to the lab scrubber. The purpose was to assure that no large quantities of particulates could enter the scrubber.

6.4 Three-Stage Scrubbing Tests - Sodium Hypochlorite, Counter-Current Purge

Since the odor removal in two stages did not reach our goal,

TABLE 5

ODOR REMOVAL BY SCRUBBING WITH SODIUM HYPOCHLORITE

Two Columns in Series, Continuous Countercurrent Purge

TEST NO.	pH STAGE 2	pH STAGE 3	CHLORINE CONC, WT % STAGE 2	CHLORINE CONC, WT % STAGE 3	TEMP, °C STAGE 1	TEMP, °C STAGE 2	TEMP, °C STAGE 3	PURGE RATE ℓ/HR STAGE 2	PURGE RATE ℓ/HR STAGE 3	HOURS OF OPERATION	ODOR ED_{50} INLET	ODOR ED_{50} OUTLET COLUMN 1	ODOR ED_{50} OUTLET COLUMN 2	ODOR ED_{50} OUTLET COLUMN 3	% REMOVAL COLUMN 2	% REMOVAL COLUMNS 2 & 3
43A	10.0	11.3	0.07	0.20	29.5	28	28	←	25	8.5	61,500		1,700	800	97.2	98.7
43B	9.8	10.9	0.18	0.26	25.5	26.5	27	←	25	11.5	40,000		2,300	2,500	94.3	93.8
43C	9.2	9.0	0.21	0.28	23	23.6	23.6	←	25	14.5	54,000		10,000	2,200	81.5	95.9
43D	10.3	12.0	0.31	0.15	23.5	25	25	←	25	19	8,300		6,900	1,700	16.9	79.5
43E	9.6	10.4	0.20	0.23	22.5	23.5	24	←	25	22	42,000		3,500	3,500	91.7	91.7
44A	9.1	9.9	0.18	0.11	--	--	--	←	25	25	13,800		--	4,200	--	69.6
44B	9.0	9.9	0.13	0.11	21.5	21.5	21.5	←	25	26.5	27,500		3,200	950	88.4	96.5
44C	11.1	11.9	0.07	0.065	24	24.5	23	←	25	30	22,400		3,500	3,300	84.4	85.3
44D	11.2	12.0	0.005	0.039	23	23	22.5	←	25	0.5	19,500		3,800	1,800	80.5	90.8
44E	11.5	12.0	0.005	0.046	23	23	22	←	25	1.5	10,200		6,500	2,600	36.3	74.5
52A	11.8	12.1	0.18	0.20	21.5	23	23	0	0	0.5	Filter	22,000	10,500	590	57	97.3
52B	12.1	12.3	0.19	0.20	21.5	22.5	22	0	0	2.5	Filter	25,700	13,100	2,001	49	92.2
52C	11.5	12.0	0.22	0.19	--	22.5	22.5	30	30	6.0	Filter	47,000	11,300	3,200	76	93.2

← INDICATES COUNTERCURRENT PURGE

the remaining tests used three stages of scrubbing. Our objective was to carry out a one-week test using the strongest and freshest reagents already tried in the preliminary tests. The conditions and results are given in Table 6, tests 45 to 50. The counter-current blowdown system was used. The pH was controlled from 10 to 13 in stage 1 and 12 to 13 in stages 2 and 3. Chlorine concentration was maintained from 0.2 to 0.3 in stage 3, 0.1 to 0.3 in stage 2, and 0.04 to 0.17 in stage 1.

The mean odor removal was 93% with a standard deviation of 3%. This was short of our goal of 99% removal. Results show that inlet odor ED_{50} and age of solution both affect the results. Results are included in the computer analysis in Section 6.

Experiment No. 45 was a blank run in that the scrubber was not connected to the incinerator inlet. The inlet air was drawn through 100 ft of 4-in. polyethylene tubing, which had become contaminated with grease and no doubt evolved the odor of 376 O.U. measured at the scrubber inlet. Fresh solutions were provided with counter-current purging for 1 hr. The outlet odor units of 55 to 91 probably result from odors desorbed from the inside surfaces of the scrubber air piping (which was constructed of 2-in. PVC pipe) as a result of previous exposure to high odor levels. These odor levels are smaller than those measured in the other tests, and indicate that the background does not represent a significant source of error.

Tests 49A and 49B of Table 6 made use of a low chlorine concentration in stage 3 (0.025 to 0.03 wt %) with higher concentrations of about 0.2% in stages 1 and 2. The purpose was to test the possibility that chlorine gas could be evolved from stage 3 and contribute odor to the scrubbed air; this should not be possible with a low chlorine concentration in stage 3. It is apparent that the removals of 69 and 90% are not better than the mean for the rest of Table 6, which is 93% removal.

In tests 51A and 51B of Table 6, the tanks were washed out and fresh solutions were provided. The removals were 98 and 98.6%.

TABLE 6

ODOR REMOVAL BY SCRUBBING WITH SODIUM HYPOCHLORITE
THREE COLUMNS IN SERIES, CONTINUOUS COUNTERCURRENT PURGE

TEST NO.	pH STAGE 1	pH STAGE 2	pH STAGE 3	CHLORINE CONC, WT % STAGE 1	CHLORINE CONC, WT % STAGE 2	CHLORINE CONC, WT % STAGE 3	TEMP, °C STAGE 1	TEMP, °C STAGE 2	TEMP, °C STAGE 3	PURGE RATE ℓ/HR STAGE 1	PURGE RATE ℓ/HR STAGE 2	PURGE RATE ℓ/HR STAGE 3	HOURS OF OPERATION	ODOR ED_{50} INLET	ODOR ED_{50} OUTLET COLUMN 1	ODOR ED_{50} OUTLET COLUMN 2	ODOR ED_{50} OUTLET COLUMN 3	% REMOVAL COLUMN 1	% REMOVAL COLUMNS 1 + 2 + 3
45	--	--	--	--	--	--	--	--	--	←	←	30	Blank	376	89	55	91	--	--
46A	11.6	11.9	12.0	0.04	0.11	0.23	25	24	23	←	←	30	1	14,300	4,000	2,200	830	72	94.2
46B	12.9	13.1	13.1	0.15	0.27	0.30	24	22.5	22	←	←	30	5	22,000			1,100		95.0
47A	12.1	11.6	12.1	0.17	0.15	0.14	27.5	27.5	26	←	←	30	9	30,000			1,100		96.3
47B	10.5	12.1	12.8	0.12	0.14	0.19	26	25	24	←	←	30	13	15,000	6,400	1,700	1,200	57.3	92.0
47C	10.7	12.6	13	0.11	0.14	0.23	--	--	--	←	←	30	16	11,000			1,400		87.3
47D	11.1	12.7	12.6	0.13	0.20	0.21	28	27	26.5	←	←	30	18	16,500			1,500		90.9
49A	11.5	12.6	12.2	0.17	0.19	0.03	--	--	--	←	10	← 20	20 (1)*	7,000		6,750	2,150		69.3
49B	11.0	12.5	12.1	0.19	0.18	0.025	--	--	--	←	10	← 20	21 (2)*	22,600			2,200		90.3
50A	10.2	11.0	12.1	0.17	0.19	0.21	30	28.5	27.5	←	←	30	23	34,000			1,850		94.6
50B	10.0	10.5	12.2	0.16	0.20	0.23	23.5	28.0	27.0	←	←	30	26	60,000		4,600	2,900		95.2
51A	11.7	11.7	11.9	0.18	0.17	0.19	23.5	23	22.5	0	0	0	0.4	23,500	5,900		510	74.9	97.8
51B	--	--	--	0.18	0.17	0.20	23	22.5	22	0	0	0	0.4	34,000	4,900		490	84.9	98.6
51C	--	--	--	0.18	0.20	0.22	--	--	--	←	←	30	2.2	32,500			790		97.6

* Tank 3

Computer regressions in Section 8 show that fresh solutions are the most effective in removing odor.

6.5 Three-Stage Scrubbing with Sodium Hypochlorite, Separate Purge of Each Stage

Since the removals were greatest with solutions only a few hours old, it was decided to conduct tests with separate purge of each stage. The conditions and results are shown in Table 7.

Through a misunderstanding, test 54 was conducted with separate purge, and test 55 reverted to counter-current purge. In test 56, the separate blowdown arrangement was restored, and the test was run long enough (48.5 hr) to assure that the purge solutions reached a steady state. Since the removal averaged 91% for Table 5, it does not appear that separate blowdown is the way to achieve 99% removal. Computer analysis including all the variables in Section 8 confirms this conclusion.

6.6 Supplementary Scrubbing Experiments

Additional experiments were conducted for the Fats and Proteins Research Foundation, Inc. These experiments were not part of the EPA project. The experimental procedures were described in Report No. IITRI-C8277-3, Appendix. The experimental data are contained in the computer analysis of results presented in Section 7. Experiment series 57 consisted of scrubbing with calcium hypochlorite, and experiments 58 and 59 consisted of scrubbing with the following three stages in series: 5% sulfuric acid with 200 ppm chlorine metered into the inlet air stream; dilute alkali at pH 10; and 5% sodium hydroxide.

TABLE 7

ODOR REMOVAL BY SCRUBBING WITH SODIUM HYPOCHLORITE
THREE COLUMNS IN SERIES, CONTINUOUS SEPARATE PURGES (EXCEPT TEST 55)

TEST NO.	pH STAGE 1	pH STAGE 2	pH STAGE 3	CHLORINE CONC, WT % STAGE 1	CHLORINE CONC, WT % STAGE 2	CHLORINE CONC, WT % STAGE 3	TEMP, °C STAGE 1	TEMP, °C STAGE 2	TEMP, °C STAGE 3	PURGE RATE ℓ/HR STAGE 1	PURGE RATE ℓ/HR STAGE 2	PURGE RATE ℓ/HR STAGE 3	HOURS OF OPERATION	ODOR ED_{50} INLET	ODOR ED_{50} OUTLET COLUMN 1	ODOR ED_{50} OUTLET COLUMN 2	ODOR ED_{50} OUTLET COLUMN 3	% REMOVAL COLUMN 1	% REMOVAL COLUMNS 1 + 2 + 3
54A	8	10.3	9.8	0.05	0.067	0.087	24	23	22.3	34	30	30	1	56,000	5,400	5,300	890	90.4	98.4
54B	9	9.8	10.2	0.027	0.070	0.055	23.5	22.5	22.5	30	30	30	7	86,000	13,100	8,800	2,800	84.8	96.7
55A	9.7	10.1	9.8	0.002	0.05	0.07	30	29	28.5	←	←	30	10.5	35,500			6,200		82.5
55B	9.8	9.7	9.9	0.003	0.054	0.06	29.5	28.0	27	←	←	30	14.0	25,500	18,500	10,900	4,000	27.5	84.3
55C	9.4	9.5	9.8	0.002	0.05	0.07	29	27.5	26.5	←	←	30	17.0	51,000			3,900		92.4
56A	9.6	10.0	10.0	0.037	0.071	0.082	25.5	25.0	24.5	30	30	30	20.8	51,000			6,000		88.2
56B	10.5	9.8	10.0	0.075	0.077	0.084	25	24	23	30	30	30	23.8	28,500	25,500	6,400	3,400	10.5	88.1
56C	10.2	9.9	10.0	0.027	0.062	0.066	23	23	22	30	30	30	26.5	58,000			5,800		90.0
56D	10.0	12.6	8.7	0.016	0.038	0.061				30	30	30	28.5	25,000			1,000		96.0
56E	10.0	9.5	10.0	0.028	0.059	0.073	20.5	22	20	30	30	30	32.0	34,500	23,200	3,200	4,300	32.8	87.5
56F	10.0	9.7	9.9	0.014	0.065	0.068	21	21.5	20.5	30	30	30	34.0	106,000			3,000		97.2
56G	9.5	9.8	9.5	0.022	0.057	0.055	20	20	19.5	3	30	30	37.5	44,500			1,250		97.2
56H	9.7	9.5	9.6	0.003	0.06	0.061				3	30	30	40.5	35,000			1,850		94.7
56J	10.7	10.0	10.1	0.061	0.061	0.096	22.5	22	21.5	30	30	30	43.5	8,000	2,100	1,700	1,600	73.8	80.0
56K	9.8	9.7	9.9	0.023	0.064	0.061	22.5	21.5	21.0	30	30	30	48.5	61,000			3,500		94.3

7. SULFUR DETECTOR AND INLET ED_{50}

During the first few weeks of the project, a Meloy Laboratories sulfur detector was operated whenever the incinerator inlet air was connected to the scrubber. Eventually. this system failed due to corrosion, and could not be repaired in the field. However, much useful data was obtained. Some data are compared with inlet ED_{50} values in Figure 2. This calibration is not absolute, because the response depends on the gas flow rate settings to the detector. It does show that for a given setting, the response varies directly with odor units.

Wahl, Duffee, and Marrone (EPA Report No. 650-2-74-008a) reported that output from this monitor was correlated with rendering odor units with a correlation coefficient of 0.91.

The object of these measurements was to have an on-line indication of odor level, so that periods of low inlet odor could be avoided. Figure 3 shows a segment of the sulfur detector recorder. Note the rapid fluctuations in output. Each peak occurs when the level control on the continuous cooker in the rendering plant causes the raw material feeder to start. Apparently, when this material contacts the hot oil in the cooker, its moisture content is boiled off, along with odorous compounds. This points out the need for sampling inlet and outlet gases of the scrubber at the same time and rate. Also, it suggests that the peaks in odor could be reduced by a proportional feeder controller, rather than an on-off controller.

The sulfur detector was put to a further use. The data presented above, for example in Table 7, indicate that the lowest odor removals are obtained when the inlet odor is low. For example, in Test 56J, the removal was 80% when the input level was 8,000 odor units. In Test 56F, it was 97% with an input of 106,000 odor units. Presumably, it is not the inlet odor level itself that is responsible, but the previous history of exposure of the scrubbing liquid to higher odor levels, which tend to saturate the solution with refractory compounds. This history of exposure cannot readily be determined by the odor panel tests, because these tests are made only intermittently. The sulfur detector gives a continuous record that can be used to determine the history of exposure of the solution, by calibrating the detector output with the odor panel tests made on the same day. This sulfur detector data was used for this purpose in the computer analysis of results given in Section 8.

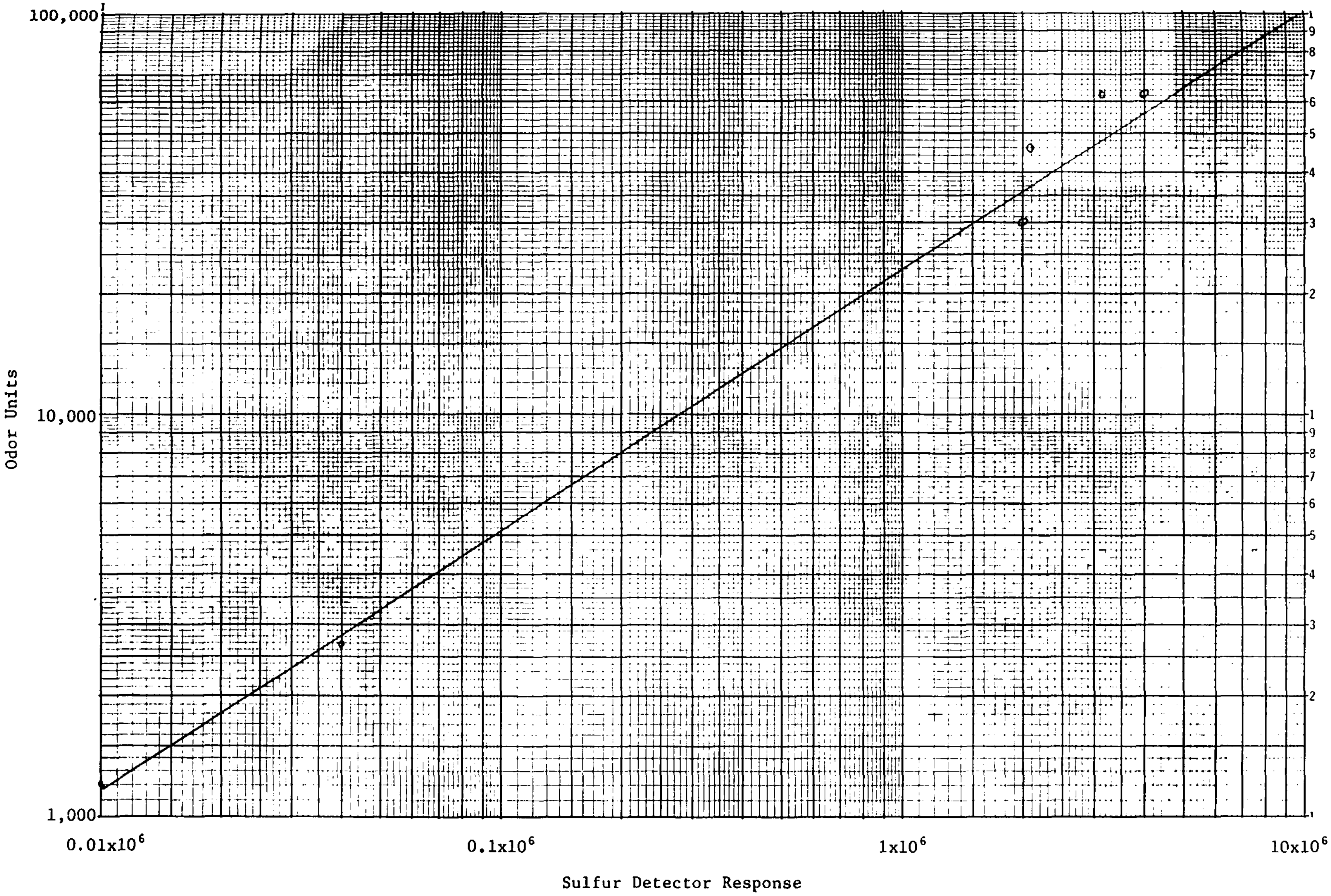

Figure 2

CALIBRATION OF SULFUR DETECTOR
WITH ODOR PANEL FOR EXPERIMENTS 36, 37, AND 38

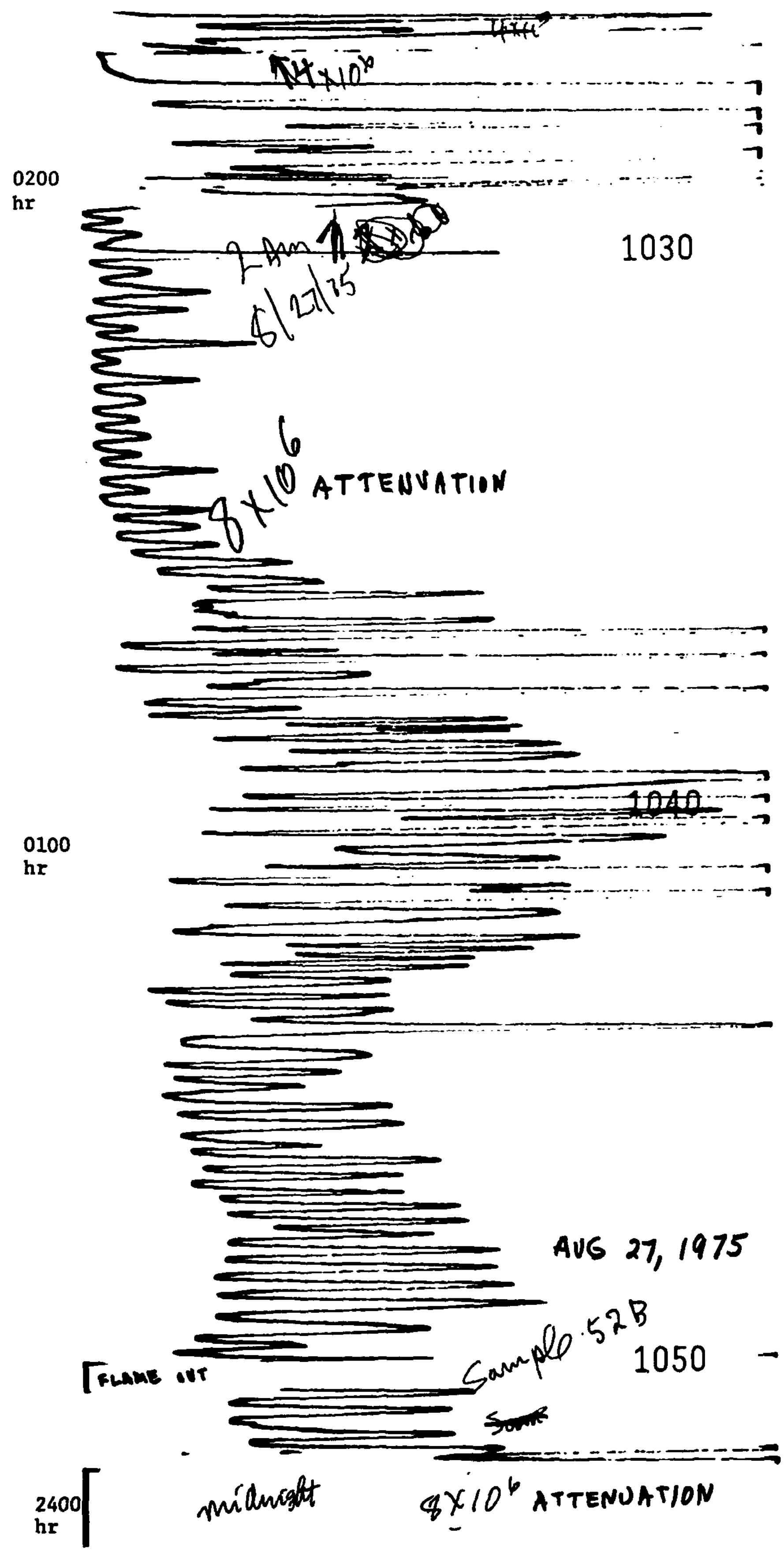

Figure 3

PORTION OF SULFUR DETECTOR RECORD
SHOWING CYCLICAL VARIATION RESULTING FROM INTERMITTANT
FEEDING OF CONTINUOUS COOKER

8. COMPUTER REGRESSION ANALYSIS AND EXPERIMENTAL RESULTS

One objective of this project was to obtain sufficient experimental data so that the statistical reliability of the results could be determined. Since a number of variables appeared to affect the results, the best way to achieve this objective was to subject the data to multiple regression analysis. This was done using an IITRI modification of the Biomed Program 02R, Stepwise Multiple Regression Analysis.

8.1 Input Data

All of the primary experimental data for all experiments is presented in Table 8. This consists of the data that were actually measured during the experiments. Table 9 contains additional variables that were computed from the primary data by coding added to the computer program. Not all of the variables included in the tables turned out to be important, but the statistical significance of all were considered by the program.

Some explanation of the tables is needed. Reagent type is identified as follows:

Type 1 -- Sodium hypochlorite
Type 0 -- Calcium hypochlorite
Type -1 -- Chlorine-acid/pH 10/alkali

Purge type is as follows:

Type +1 -- Separate make-up and blowdown of each stage
Type -1 -- Countercurrent blowdown

By coding discrete variables in this way, it is possible to include them in the regression program, which is intended to handle continuous variables.

In some of the experiments, two or three columns were used in series. In some cases, the outlet of an intermediate stage was also measured. These experiments are listed at the bottom of

TABLE 8

SUMMARY OF ALL SCRUBBING DATA

TEST NO.	REAGENT TYPE	NO. OF COLUMNS IN SERIES	INLET $ED_{50} \times 10^{-3}$	OUTLET $ED_{50} \times 10^{-3}$	ODOR UNITS HISTORY $ED_{50} \times 10^{3}$ OU1	OU2	OU3	OU4	HOURS OF REAGENT USE	PURGE TYPE	PURGE RATE	TEMP., °C	CHLORINE CONC., WT % STAGE 1	2	3	pH STAGE 1	2	3
43A	1	2	61.5	.6	61.	51.	100.		8.5	-1	25.	28.	.07	.20		10.	11.3	
43B	1	2	40.	2.5	40.	61.	54.	100.	11.5	-1	25.	26.5	.18	.26		9.8	10.9	
43C	1	2	54.	2.2	54.	40.	61.	75.	14.5	-1	25.	23.6	.21	.28		9.2	9.0	
43D	1	2	8.3	1.7	50.	54.	40.	61.	19.	-1	25.	25.	.31	.15		10.3	12.	
43E	1	2	42.	3.5	16.	8.	50.	45.	22.	-1	25.	23.5	.20	.23		9.6	10.4	
44A	1	2	13.8	4.2	18.	50.	15.	28.	25.	-1	25.	23.	.18	.11		9.1	9.9	
44B	1	2	27.5	.95	14.	18.	50.	12.	26.5	-1	25.	21.5	.13	.11		9.0	9.9	
44C	1	2	22.4	3.3	36.	14.	18.	35.	30.	-1	25.	24.5	.07	.065		11.1	11.9	
44D	1	2	19.5	1.8	0.	0.	0.		.5	-1	25.	23.	.005	.039		11.2	12.	
44E	1	2	10.2	2.6	19.	0.	0.		1.5	-1	25.	23.	.005	.046		11.5	12.	
52A	1	2	22.	.59	0.	0.	0.		.5	-1	0.	23.	.18	.20		11.8	12.1	
52B	1	2	25.7	2.	22.	0.	0.		2.5	1	0.	22.5	.19	.20		12.1	12.3	
52C	1	2	47.	3.2	26.	22.	0.		6.	1	30.	22.5	.22	.19		11.5	12.	
46A	1	3	14.3	.83	0.	0.	0.		1.	-1	30.	24.	.04	.11	.23	11.6	11.9	12.
46B	1	3	22.	1.1	22.	14.	0.		5.	-1	30.	23.	.15	.27	.30	12.9	13.1	13.1
47A	1	3	30.	1.1	30.	22.	14.		9.	-1	30.	27.	.17	.15	.14	12.1	11.6	12.1
47B	1	3	15.	1.2	15.	30.	22.	14.	13.	-1	30.	25.	.12	.14	.19	10.5	12.1	12.8
47C	1	3	11.	1.4	20.	15.	30.	18.	16.	-1	30.	25.	.11	.14	.23	10.7	12.6	13.
47D	1	3	16.5	1.5	11.	20.	15.	25.	[illegible]	-1	30.	27.	.13	.20	.21	11.1	12.7	12.6
49A	1	3	7.	2.15	36.	27.	11.	18.	20.	-1	20.	27.	.17	.19	.03	11.5	12.6	12.2
49B	1	3	22.5	2.2	7.	36.	27.	15.	21.	-1	20.	27.	.19	.18	.025	11.	12.5	12.1
50A	1	3	34.	1.85	22.	7.	36.	22.	23.	-1	30.	28.5	.17	.19	.21	10.2	11.	12.1
50B	1	3	60.	2.9	34.	22.	7.	30.	26.	-1	30.	23.	.16	.20	.23	10.	10.5	12.3
51A	1	3	23.5	.51	0.	0.	0.		.4	-1	0.	23.	.18	.17	.19	11.7	11.7	11.9
51B	1	3	34.	.49	0.	0.	0.		.4	1	0.	22.5	.16	.17	.20	11.7	11.7	11.9
51C	1	3	32.5	.79	34.	0.	0.		2.2	-1	30.	22.5	.18	.20	.22	11.7	11.7	11.9
54A	1	3	56.	.89	0.	0.	0.		1.	1	30.	23.	.05	.067	.087	8.	10.3	9.8
54B	1	3	86.	2.8	86.	56.	0.		7.	1	30.	22.5	.027	.070	.055	9.	9.8	10.2
55A	1	3	35.5	6.2	35.	86.	56.		10.5	-1	30.	29.	.002	.05	.07	9.7	10.1	9.8
55B	1	3	25.5	4.	25.	35.	86.	56.	14.	-1	30.	28.	.003	.054	.06	9.8	9.7	9.9
55C	1	3	51.	3.9	51.	25.	35.	71.	17.	-1	30.	27.5	.002	.05	.07	9.4	9.5	9.8
56A	1	3	51.	6.	51.	51.	25.	55.	20.8	1	30.	25.	.037	.071	.082	9.6	10.	10.
56B	1	3	28.5	3.4	29.	51.	51.	40.	23.8	1	30.	24.	.075	.077	.084	10.5	9.8	10.0
56C	1	3	58.	5.8	58.	29.	51.	45.	26.5	1	30.	23.	.027	.062	.066	10.2	9.9	10.
56D	1	3	25.	1.	25.	58.	29.	50.	28.5	1	30.	23.	.016	.038	.061	10.	12.6	8.7
56E	1	3	34.5	4.3	35.	29.	58.	40.	32.	1	30.	22.	.028	.059	.073	10.	9.5	10.
56F	1	3	106.	3.	106.	35.	25.	50.	34.	1	30.	21.5	.014	.065	.068	10.	9.7	9.9
56G	1	3	44.5	1.25	44.	106.	35.	37.	37.5	1	30.	20.	.022	.057	.055	9.5	9.8	9.5
56H	1	3	35.	1.85	35.	45.	106.	36.	40.5	1	30.	20.	.003	.06	.061	9.7	9.5	9.6
56J	1	3	8.	1.6	8.	35.	45.	75.	43.5	1	30.	22.	.061	.061	.096	10.7	10.0	10.1
56K	1	3	61.	3.5	61.	8.	35.	60.	48.5	1	30.	21.5	.023	.064	.061	9.8	9.7	9.9

TABLE 8 (CONT.)

SUMMARY OF ALL SCRUBBING DATA

TEST NO.	REAGENT TYPE	NO. OF COLUMNS IN SERIES	INLET $ED_{50} \times 10^{-3}$	OUTLET $ED_{50} \times 10^{-3}$	ODOR UNITS HISTORY $ED_{50} \times 10^{3}$ OU1	OU2	OU3	OU4	HOURS OF REAGENT USE	PURGE TYPE	PURGE RATE	TEMP., °C	CHLORINE CONC., WT % STAGE 1	2	3	pH STAGE 1	2	3
46A1	1	1	14.3	4.	0.	0.	0.		1.	-1	30.	24.	.04			11.6		
47B1	1	1	15.	6.4	15.	30.	0.		13.	-1	30.	25.	.12			10.5		
51A1	1	1	23.5	5.9	0.	0.	0.		.4	-1	0.	23.	.18			11.7		
51B1	1	1	34.	4.9	0.	0.	0.		.4	1	0.	22.5	.18			11.7		
54A1	1	1	56.	5.4	0.	0.	0.		1.	1	30.	23.	.05			8.		
54B1	1	1	86.	13.1	86.	56.	0.		7.	1	30.	22.5	.027			9.		
55B1	1	1	25.5	18.5	25.	35.	86.	56.	14.	-1	30.	26.	.003			9.8		
56B1	1	1	28.5	25.5	29.	51.	51.	40.	23.	1	30.	24.	.075			10.5		
56E1	1	1	34.5	23.2	35.	29.	58.	40.	32.	1	30.	22.	.028			10.		
56J1	1	1	8.	2.1	8.	35.	45.	75.	43.	1	30.	22.	.061			10.7		
36A	1	1	63.	3.9	95.	63.	0.		7.	-1	9.	29.	.13			12.3		
36B	1	1	47.	2.7	55.	95.	63.		9.	1	9.	28.	.16			12.		
36C	1	1	30.	1.2	42.	55.	95.	63.	10.	-1	9.	27.	.21			12.		
37A	1	1	120.	19.	92.	183.	42.	75.	15.	1	9.	26.	.25			9.		
37B	1	1	55.	18.8	120.	92.	183.	60.	18.	-1	9.	26.	.24			10.5		
37C	1	1	57.	18.8	57.	120.	92.	110.	20.	1	9.	26.	.19			10.5		
38A	1	1	23.	4.8	0.	0.	0.		1.	-1	0.	23.	.05			10.3		
38B	1	1	25.	2.	23.	0.	0.		2.	1	0	22.	.1			12.1		
38C	1	1	27.	2.9	25.	23.	.0.		3.	-1	0	22.	.18			12.		
39A	1	1	39.	2.4	0.	0.	0.		1.	-1	0	26.	.028			10.9		
41A	1	1	93.5	2.1	94.	0.	0.		2.	1	0.	26.	.15			10.		
41B	1	1	133.	2.4	133.	94.	0.		4.	-1	0.	29.	.15			10.		
42A	1	1	51.	1.7	55.	133.	94.		6.	1	30.	24.5	.19			11.9		
58A	0	3	57.	1.05	0.	0.	0.		.5	-1	30.	20.	.05	.048	.061	8.4	8.7	8.6
58B	0	3	74.	.7	74.	57.	0.		6.5	-1	30.	20.1	.0036	.031	.056	7.8	7.9	8.
59A	0	3	25.5	2.45	25.	74.	57.		10.2	-1	30.	20.	.026	.031	.062	8.5	8.1	8.2
59B	0	3	115.1	1.75	115.	25.	74.	57.	12.7	-1	30.	19.7	.016	.044	.060	8.1	8.2	8.2
59C	0	3	75.	1.	75.	115.	25.	65.	15.7	-1	30.	19.8	.012	.043	.053	8.2	8.3	8.3
59D	0	3	27.	.61	27.	75.	115.	45.	19.	-1	30.	21.7	.045	.053	.053	8.2	8.4	8.4
59E	0	3	29.5	1.2	30.	27.	75.	80.	22.3	-1	30.	21.7	.040	.047	.044	8.5	8.4	8.4
59F	0	3	51.5	2.15	52.	30.	27.	75.	25.	-1	30.	21.7	.017	.043	.056	8.2	8.3	8.2
59G	0	3	51.	3.2	51.	52.	30.	50.	27.5	-1	30.	20.1	.048	.048	.058	8.6	8.6	8.4
59H	0	3	30.5	2.2	31.	51.	52.	40.	30.5	-1	30.	20.2	.036	.061	.054	8.2	8.4	8.5
59J	0	3	33.5	1.6	34.	31.	51.	46.	32.	-1	30.	20.1	.023	.06	.06	8.3	8.4	8.6
58A1	0	1	57.	8.35	0.	0.	0.		.5	-1	30.	20.	.051			8.4		
59A1	0	1	25.5	12.4	25.	74.	57.		10.2	-1	30.	20.	.026			8.5		
59B1	0	1	115.1	8.4	115.	25.	74.	57.	12.7	-1	30.	19.7	.016			8.1		
59C1	0	1	75.	6.9	75.	115.	25.	65.	15.7	-1	30.	19.8	.012			8.2		
59E1	0	1	29.5	13.9	30.	27.	75.	80.	22.3	-1	30.	21.7	.04			8.5		
59F1	0	1	51.5	9.8	52.	30.	27.	75.	25.	-1	30.	21.7	.017			8.2		
59H1	0	1	30.5	11.5	31.	51.	52.	40.	30.5	-1	30.	20.2	.036			8.2		
57A	-1	1 3	50.	2.5	50.				1.5	-1	30.	27.	.02	.001			9.8	13.5
57B	-1	1 3	36.	2.7	36.	50.			6.5	1	30.	23.	.02	.002			10.4	13.5
57C	-1	1 3	50.	2.7	50.	36.	50.		9.5	1	30.	22.	.02	0.			10.3	13.
57D	-1	1 3	51.	1.9	51.	50.	36.	50.	12.3	1	30.	18.	.242	.002			10.	13.5
57E	-1	1 3	48.	3.1	48.	51.	50.	42.	14.3	1	30.	18.8	.25	.003			9.7	13.5
57G	-1	1 3	4.2	.8	4.2	79.	50.	50.	20.5		30.	16.	.202	.013			9.6	13.2
57H	-1	1 3	21.5	1.0	21.5	4.	75.	55.	25.5		30.	19.	.26	.007		4.	9.8	13.1

TABLE 9

LIST OF VARIABLES FOR EACH EXPERIMENT

LIST OF RESIDUALS

CASE NAME	CASE NUMBER	NTU, ln(INLET/OUTLET) EXPERIMENTAL Y X(21)	Y COMPUTED	RESIDUAL	REMOVAL X(33)	INLET/OUTLET X(31)	Cl · pH X(27)	OUI + 2 X(29)	ln(INLET) X(32)	ln(HOURS) X(23)
43A	1	4.3422	3.0304	1.3118	.9870	76.8750	1.4377	86.5000	4.1190	2.1401
43B	2	2.7726	2.0761	.6965	.9375	16.0000	2.2770	70.5000	3.6889	2.4423
43C	3	3.2005	2.5953	.6053	.9593	24.5455	2.2295	74.0000	3.9890	2.6741
43D	4	1.5856	1.6628	-.0772	.7952	4.8824	2.5645	77.0000	2.1163	2.9444
43E	5	2.4849	2.7502	-.2653	.9167	12.0000	2.1500	20.0000	3.7377	3.0910
44A	6	1.1896	1.7799	-.5903	.6957	3.2857	1.3775	43.0000	2.6247	3.2189
44B	7	3.3655	2.2552	1.1103	.9655	28.9474	1.1340	23.0000	3.3142	3.2771
44C	8	1.9151	1.7179	.1972	.8527	6.7879	.7762	43.0000	3.1091	3.4012
44D	9	2.3826	1.9278	.4548	.9077	10.8333	.2552	.0000	2.9704	-.6931
44E	10	1.3669	1.6218	-.2549	.7451	3.9231	.2996	19.0000	2.3224	.4055
52A	11	3.6187	2.7402	.8784	.9732	37.2881	2.2705	.0000	3.0910	-.6931
52B	12	2.5533	2.7728	-.2194	.9222	12.8500	2.3790	22.0000	3.2465	.9163
52C	13	2.6870	3.2530	-.5660	.9319	14.6875	2.4087	37.0000	3.8501	1.7918
46A	14	2.8466	2.8988	-.0523	.9420	17.2289	1.4989	.0000	2.6603	.0000
46B	15	2.9957	3.5656	-.5698	.9500	20.0000	3.1280	29.0000	3.0910	1.6094
47A	16	3.3059	3.2298	.0761	.9633	27.2727	1.8298	41.0000	3.4012	2.1972
47B	17	2.5257	2.7676	-.2419	.9200	12.5000	1.7700	30.0000	2.7081	2.5649
47C	18	2.0614	2.7079	-.6465	.8727	7.8571	1.9360	27.5000	2.3979	2.7726
47D	19	2.3979	2.9133	-.5154	.9091	11.0000	2.1840	21.0000	2.8034	2.8904
49A	20	1.1804	2.3706	-1.1901	.6929	3.2556	1.5730	49.5000	1.9459	2.9957
49B	21	2.3295	2.8976	-.5681	.9027	10.2727	1.5624	25.0000	3.1179	3.0445
50A	22	2.9112	3.3308	-.4196	.9456	18.3784	2.1090	25.5000	3.5264	3.1355
50B	23	3.0296	3.8495	-.8199	.9517	20.6897	2.1502	45.0000	4.0943	3.2581
51A	24	3.8303	3.3615	.4689	.9783	46.0784	2.1180	.0000	3.1570	-.9163
51B	25	4.2397	3.6414	.5983	.9856	69.3878	2.1572	.0000	3.5264	-.9163
51C	26	3.7170	3.5198	.1971	.9757	41.1392	2.3533	34.0000	3.4812	.7885
54A	27	4.1419	3.6321	.5098	.9841	62.9213	.6369	.0000	4.0254	.0000
54B	28	3.4247	3.8104	-.3857	.9674	30.7143	.4898	114.0000	4.4543	1.9459
55A	29	1.7450	2.6672	-.9222	.8254	5.7258	.4012	78.0000	3.5695	2.3514
55B	30	1.8524	2.1248	-.2724	.8431	6.3750	.3822	42.5000	3.2387	2.6391
55C	31	2.5708	2.5554	.0154	.9235	13.0769	.3890	63.5000	3.9318	2.8332
56A	32	2.1401	2.7107	-.5707	.8824	8.5000	.6249	76.5000	3.9318	3.0350
56B	33	2.1261	2.4261	-.3000	.8807	8.3824	.7945	54.5000	3.3499	3.1697
56C	34	2.3026	2.9461	-.6435	.9000	10.0000	.5184	72.5000	4.0604	3.2771
56D	35	3.2189	2.1136	1.1053	.9600	25.0000	.3999	54.0000	3.2189	3.3499
56E	36	2.0823	2.5003	-.4180	.8754	8.0233	.5244	49.5000	3.5410	3.4657
56F	37	3.5648	3.8713	-.3065	.9717	35.3333	.4835	123.5000	4.6634	3.5264
56G	38	3.5723	2.5226	1.0498	.9719	35.6000	.4288	97.0000	3.7955	3.6243
56H	39	2.9402	2.4605	.4796	.9471	18.9189	.3968	57.5000	3.5553	3.7013
56J	40	1.6094	1.7448	-.1353	.8000	5.0000	.7460	25.5000	2.0794	3.7728
56K	41	2.8581	2.9240	-.0659	.9426	17.4286	.4835	65.0000	4.1109	3.8816

TABLE 9 (CONT.)

LIST OF VARIABLES FOR EACH EXPERIMENT

CASE NAME	CASE NUMBER	NTU, ln(INLET/OUTLET) EXPERIMENTAL Y X(21)	Y COMPUTED	RESIDUAL	REMOVAL X(33)	INLET/OUTLET X(31)	Cl · pH X(27)	OUI + 2 X(29)	ln(INLET) X(32)	ln(HOURS) X(23)
46A1	42	1.2740	1.2340	.0400	.7203	3.5750	.4640	.0000	2.6603	.0000
47B1	43	.8518	1.4095	-.5577	.5733	2.3438	1.2600	30.0000	2.7081	2.5649
51A1	44	1.3820	2.0769	-.6949	.7489	3.9831	2.1060	.0000	3.1570	-.9163
51B1	45	1.9371	2.3423	-.4051	.8559	6.9388	2.1060	.0000	3.5264	-.9163
54A1	46	2.3390	2.2639	.0751	.9036	10.3704	.4000	.0000	4.0254	.0000
54B1	47	1.8817	2.4386	-.5568	.8477	6.5649	.2430	114.0000	4.4543	1.9459
55B1	48	.3209	.7135	-.3926	.2745	1.3784	.0294	42.5000	3.2387	2.6391
56B1	49	.1112	1.1434	-1.0322	.1053	1.1176	.7875	54.5000	3.3499	3.1355
56E1	50	.3968	1.1294	-.7325	.3275	1.4871	.2800	49.5000	3.5410	3.4657
56J1	51	1.3375	.4300	.9075	.7375	3.8095	.6527	25.5000	2.0794	3.7612
36A	52	2.7822	2.3040	.4782	.9381	16.1538	1.5990	126.5000	4.1431	1.9459
36B	53	2.8569	2.1296	.7273	.9426	17.4074	1.9200	102.5000	3.8501	2.1972
36C	54	3.2189	1.5731	1.6458	.9600	25.0000	2.5200	69.5000	3.4012	2.3026
37A	55	1.8431	3.1263	-1.2832	.8417	6.3158	2.2500	183.5000	4.7875	2.7081
37B	56	1.0735	1.7843	-.7108	.6582	2.9255	2.5200	166.0000	4.0073	2.8904
37C	57	1.1092	1.4670	-.3578	.6702	3.0319	1.9950	117.0000	4.0431	2.9957
38A	58	1.5669	1.4728	.0941	.7913	4.7917	.5150	.0000	3.1355	.0000
38B	59	2.5257	1.6758	.8499	.9200	12.5000	1.2100	23.0000	3.2189	.6931
38C	60	2.2311	2.0174	.2138	.8926	9.3103	2.1600	36.5000	3.2958	1.0986
39A	61	2.7881	1.7991	.9890	.9385	16.2500	.3052	.0000	3.6636	.0000
41A	62	3.7960	3.1875	.6085	.9775	44.5238	1.5000	94.0000	4.5380	.6931
41B	63	4.0149	3.7896	.2253	.9820	55.4167	1.5000	180.0000	4.8903	1.3863
42A	64	3.4012	2.2699	1.1313	.9667	30.0000	2.2610	121.5000	3.9318	1.7918
58A	65	3.9943	3.9992	-.0049	.9816	54.2857	.4540	.0000	4.0431	-.6931
58B	66	4.6607	3.8766	.7841	.9905	105.7143	.2386	102.5000	4.3041	1.8718
59A	67	2.3426	2.8708	-.5282	.9039	10.4082	.3279	62.0000	3.2387	2.3224
59B	68	4.1862	4.3786	-.1924	.9848	65.7714	.3267	127.5000	4.7458	2.5416
59C	69	4.3175	3.2678	1.0497	.9867	75.0000	.2976	132.5000	4.3175	2.7537
59D	70	3.5066	2.5727	.9338	.9700	33.3333	.4194	64.5000	3.2958	2.9444
59E	71	3.2021	2.4347	.7674	.9593	24.5833	.3683	43.5000	3.3844	3.1046
59F	72	3.1761	2.9037	.2724	.9583	23.9535	.3184	67.0000	3.9416	3.2189
59G	73	2.7687	3.0887	-.3200	.9373	15.9375	.4380	77.0000	3.9318	3.3142
59H	74	2.6293	2.7385	-.1092	.9279	13.8636	.4211	56.5000	3.4177	3.4177
59J	75	3.0415	2.7916	.2500	.9522	20.9375	.4020	49.5000	3.5115	3.4657
58A1	76	1.9208	2.7096	-.7888	.8535	6.8263	.4284	.0000	4.0431	-.6931
59A1	77	.7210	1.5510	-.8300	.5137	2.0565	.2210	62.0000	3.2387	2.3224
59B1	78	2.6176	3.0253	-.4077	.9270	13.7024	.1296	127.5000	4.7458	2.5416
59C1	79	2.3860	1.9136	.4723	.9080	10.8696	.0984	132.5000	4.3175	2.7537
59E1	80	.7525	1.1441	-.3916	.5288	2.1223	.3400	43.5000	3.3844	3.1046
59F1	81	1.6592	1.5571	.1021	.8097	5.2551	.1394	67.0000	3.9416	3.2189
59H1	82	.9754	1.4116	-.4362	.6230	2.6522	.2952	56.5000	3.4177	3.4177
59J1	83	.8102	1.4330	-.6228	.5552	2.2483	-.1909	49.5000	3.5115	3.4657
57A	84	2.9457			.9500	20.0000		50.0000	3.9120	.4055
57B	85	2.5903			.9250	13.3333		61.0000	3.5835	1.8718
57C	86	2.9188			.9460	18.5185		68.0000	3.9120	2.2513
57D	87	3.2900			.9627	26.8421		76.0000	3.9318	2.5096
57E	88	2.7398			.9354	15.4839		73.5000	3.8712	2.6603
57G	89	1.6582			.8095	5.2500		43.7000	1.4351	3.0204
57H	90	2.7316			.9349	15.3571		23.5000	3.0681	3.2387

the table with a suffix "1" added to the experiment number, to represent the performance of just the third stage in a multi-stage test.

Added to Table 8 is a section entitled "Odor Units History". For example, the data which is identified as OU1 represents the odor concentration in the two hours previous to the experiments. These data are obtained partly from sulfur detector measurements on the inlet odor stream, and partly from the odor panel measurements on the samples taken during the course of the experiment. The sulfur detector was in operation during about half of the experimental period. When it was operating, the sulfur detector gave a continuous record of the odor concentration during this preceeding period. The sulfur detector voltage was calibrated by comparing it to odor panel results at sampling times, and the comparisons during a given day were quite consistent.

During part of the time, the sulfur detector was not operating, and in this case, the odor concentration measured by the panel at the time of the experiment was taken as representative of the probable odor level during the previous two hours. This assumes that the odor concentration did not vary rapidly with time; analysis of the sulfur detector data shows that the inlet odor level is sometimes reasonably constant over two hours, and sometimes it changes rather suddenly, depending on rendering plant operations.

OU2 represents a similar measure of the average inlet odor for the period two to four hours before each experiment. OU3 represents the odor level for the period five to nine hours previous; and OU4 represents an average of the odor level for the period 10 to 15 hours previous. Of course, OU4 is zero for any test conducted in the first nine hours after startup with a fresh solution. Therefore, OU4 is strongly correlated with the age of the solution, as well as with the previous history of odor exposure of the solution. In fact, the correlation coefficient between OU4 and ln(hours) is 0.66. The coefficient for OU3 is

0.53; for OU2 is 0.44; and for OU1 is 0.37. A correlation coefficient of 1 means that the two quantities are directly related; a coefficient of 0 means that they are not related at all.

Table 9 includes a number of computed variables. The variable NTU (number of transfer units in mass transfer theory) represents ln(inlet/outlet odor units). It is a measure of the removal performance of the scrubber system. Another measure is the fraction removed, called Removal in Table 9. Another measure is the ratio Inlet/Outlet. By trial calculations, we found that the best fit of the data was obtained by using NTU as the measure of performance (the independent variable) in the computer analysis.

The variable Cl • pH is the product of the average available chlorine concentration times the average pH, averaged over the number of stages of scrubber used in each particular experiment. OU1 + 2 is a combination of OU1 and OU2. ln(inlet) and ln(hours) are the logarithms in the inlet concentration and the hours of use of the scrubbing solution, respectively.

8.2 Results of Regression

A number of combinations of variables in Table 8 were tried in a regression analysis, and the resulting best equation was found to be:

$$\ln \frac{\text{inlet}}{\text{outlet}} = 1.75 + 0.64(\text{Cols} - 2) + 0.0253\left(\frac{\text{inlet}}{1{,}000}\right) - 0.0080\left(\frac{\text{OU4}}{1{,}000}\right) - 0.0046\left(\frac{\text{OU1} + 2/2}{1{,}000}\right) + 0.372\text{Cl}\cdot\text{pH} - 0.41\text{Reagent} \pm 0.67 \quad (1)$$

Rearranging,

$$\frac{\text{outlet}}{\text{inlet}} = 0.625\exp(-0.64\ \text{cols})\ \exp(0.41\text{Reagent})\ \exp(-0.372\text{Cl}\cdot\text{pH}) \times \exp-\left(0.0253\frac{\text{inlet}}{1{,}000} - 0.0080\frac{\text{OU4}}{1{,}000} - 0.0046\frac{\text{OU1}}{1{,}000} - 0.0023\frac{\text{OU2}}{1{,}000}\right) \quad (2)$$

with a standard deviation of a factor of 1.95

where

outlet	is the outlet odor concentration, odor units	
columns	is the number of scrubber columns in series	
Cl	is the average concentration of available chlorine in the scrubber solutions	
pH	is the average pH of the scrubber solutions	
inlet	is the inlet odor concentration, odor units	
hours	is the age of the scrubber solutions, or the number of hours they have been in use	
Reagent	= 1 for sodium hypochlorite	
	= 0 for calcium hypochlorite	
	Reagent -1 was not included in the regression.	
Purge Rate	= rate of flow of make-up and purge solution streams, liter/hr	

An equation such as the above is useful to analyze the statistical reliability of the data and to express the effect of the variables on scrubber performance.

Table 10 lists the variables included in the equation and indicates their contribution to fitting the data. As each variable is added, the value of RSQ increases, showing that the equation accounts for an increasing fraction of the variance of the data. With all variables included in the equation, RSQ has a value of 0.6201.

Table 11 gives further statistics showing the importance of the variables in the equation. In the column headed P is listed the probability that the fit provided by each variable could have occurred by chance. The lower the value of P the better the fit provided by the variable, increasing the confidence that it is important in the equation. P ranges from essentially zero for Columns to 5% (95% confidence limit) for Reagent, to 9% for the variable OU1+2.

8.3 <u>Discussion of Results and Age of Solution</u>

Our attempt has been to define additional variables that have a physical significance, and to include these in a computer

TABLE 10

SUMMARY OF STEPS IN MULTIPLE REGRESSION

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	MULTIPLE RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE
1	COL1 4		.4893	.2395	.2395	25.5022
2	INLET 6		.6790	.4610	.2216	32.8867
3	OU 4 20		.7394	.5466	.0856	14.9205
4	CL.PH 27		.7662	.5870	.0404	7.6265
5	REAGNT 1		.7783	.6058	.0188	3.6637
6	OU1+2. 29		.7875	.6201	.0143	2.8664

TABLE 11

STATISTICS OF MULTIPLE REGRESSION EQUATION AND OF SCRUBBING VARIABLES

MULTIPLE R	.7875
DEGREE OF DETERMINATION	.6201
RESIDUAL STANDARD DEV.	6.70945-01

ANALYSIS OF VARIANCE

	DF	S.S.	M.S.	F	P
REGRESSION	6	5.5646358+01	9.307726+00	2.068+01	0.00
RESIDUAL	76	3.4212718+01	4.501673-01		

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F	P
(CONSTANT		1.75005+00)			
REAGNT	1	-4.09865-01	2.09838-01	3.8152+00	5.1643-02
CUL1	4	6.40043-01	8.18561-02	6.1139+01	0.0000
INLET	6	2.52682-02	4.18166-03	3.6513+01	2.5332-07
OU 4	20	-7.96719-03	2.79112-03	8.1480+00	5.5508-03
CL.PH	27	3.71796-01	1.02445-01	1.3171+01	6.2159-04
OU1+2.	29	-4.60527-03	2.72009-03	2.8664+00	9.0608-02

VARIABLES NOT IN EQUATION

VARIABLE		P CORR	TOL	F
PG TYP	2	.01412	.6616	.0149
COLMNS	3	.00000	.0000	.0000
EXP2	5	.22880	.6678	4.1432
HOURS	7	-.15821	.4331	1.9255
OUTLET	8	-.71135	.5437	76.8287
CL 1	9	-.10978	.1074	.9149
CL 2	10	-.01468	.3138	.0162
CL 3	11	-.19895	.4143	3.0910
PH 1	12	.13071	.2740	1.3036
PH 2	13	.07654	.1547	.4420
PH 3	14	-.29174	.1679	6.9774
PG RAT	15	-.26189	.5740	5.5227
TEMP F	16	-.04917	.5430	.1817
OU 1	17	-.05614	.0860	.2371
OU 2	18	.05614	.2652	.2371
OU 3	19	.07837	.5451	.4635
OUSE1	22	.09773	.5608	.7232
LN(HRS	23	-.25470	.3418	5.2029
OU4E	24	.06814	.1087	.3498
CL AV	25	-.08036	.0184	.4874
PH AV	26	.10967	.2011	.9130
OU3+4	28	.07837	.2041	.4635
OUE3+4	30	.10752	.2117	.8772
IN/OUT	31	.74194	.5261	91.8419
IN.	32	.10752	.0459	.8772
REMOVL	33	.70064	.5023	72.3167

regression equation. For example, the theory of mixing in solution tanks tells us that the rate of purging of the tanks with fresh solution affects the mean age of the solution in the tanks, where age is the length of time that the solution has been exposed to the odorous air stream. The age should also be affected by the method of purging, which was either a countercurrent purge method or a separate purge and make-up of solution in each tank. Furthermore, the history of exposure of the solution to odorous air of various concentrations should affect its remaining capacity to remove odors. This is explained by the following hypothesis: We postulate that the hypochlorite scrubbing solutions can oxidize most of the odorous components, and thus remove about 85% of the odorous compounds except those that are refractory to oxidation. Apparently, these refractory compounds are sparingly soluble in the solution. When the solution is fresh, the scrubber can dissolve enough of these refractory components to lower the odor level by 99%. As the solution is used, it becomes saturated with dissolved refractory components, and the overall odor removal decreases to 85 or 90%, as in Experiments 54A to 55 in Table 9. Furthermore, if the solution is exposed to an air stream of high odor concentration (e.g., 100,000 odor units in Experiment 56F) and then is used to scrub a stream containing only 8,000 odor units (in Experiment 56J), the odor removal may fall as low as 80%. In previous reports (EPA Report No. 600/2-76-009), we showed that when fresh air is passed through a scrubber containing used solutions, the effluent air will actually receive odor from the solutions, giving an outlet odor level of 30 to 100 odor units.

Further evidence for the existence of refractory but soluble odorants is given by the following observation. In defining the variables OU1, OU2, OU3, and OU4, we considered whether the refractory components might be oxidized during the time when the scrubber was not in operation. The scrubbing experiments were run at night while the rendering plant was operating, normally from 7 pm to 4 am. In many cases, the solution was left in the tanks during the day, and the experiment was started again the following evening. An attempt was made to allow for reaction of solution with dissolved odorants during this fallow period by setting the corresponding values of OU1, OU2, OU3, and OU4 equal to 0. However, this procedure gave a relatively poor fit by the regression equation. The fit was improved when the shut-down periods were ignored in defining OU1, OU2, OU3, and OU4. Evidently no significant reaction of dissolved odorants occurs during shut-down periods.

In Eq 2, the coefficient of the variable Inlet is 0.0253, while the sum of the coefficients of OU1 + OU2 + OU4 is only 0.0149. This could indicate that the variable Inlet has some effect in addition to its relation to saturation of the solution by exposure to previous odor history. However, this seems unlikely; mass transfer theory and chemical reaction rate theory indicates that lower inlet odors would less deplete the reagent and be easier to remove. It is possible that the strongest odors have a different composition; further study of the GC data in Report No. EPA-600/2-76-009 might give information on this point. But the most likely explanation is that the variables OU1, etc., were not exactly measured, because the sulfur detector was only working during half of the tests. During the rest of the tests, the variables OU1, etc., had to be estimated from the less frequent measurements of inlet odor units determined by odor panel samples. This incomplete data probably also explained why the variable OU3 did not improve the regression, and was excluded from Eq 2.

A satisfactory model of scrubbing should include the effect of purge rate. Purge rate should affect the results, because in-creasing the purge rate will result in a reduction of the effective age of the scrubber solution. However, we did not include purge rate in Eq 2 because Table 11 shows that the correlation of the purge rate (variable 15) with the odor removal has the wrong sign. The reason is that the purge rate is accidentally correlated with the hours of solution use, with a correlation coefficient of 0.55.

An attempt was made to include purge rate in the equation by multiplying the variables OU1, OU2, OU3, and OU4 by the function exp[-purge rate/(30 x number of columns in countercurrent purge)]. This function, based on the work of Levenspiel (Chemical Reactor Engineering, Wiley and Co., New York, 1962). expresses the age of solution in a tank when a purge stream is continuously mixed in.

This procedure did not improve the fit of the equation to the data. Purge rates of 0, 9, 25, and 30 liters/hour were used in the experiments and the effect was eithin the uncertainty of the effect of other variables on the results.

The experiments with fresh solutions could be considered equivalent to experiments with infinite purge rate; and these experiments resulted in significantly high removals, averaging near 99%. We had thought that 30 liters/hour was a high purge rate, but apparently a much higher purge rate is needed to significantly affect the results, at least for experiments lasting up to 48 hr. These results show that experiments at much higher purge rates are promising, but varying the purge rate within the range investigated was not as significant as starting with fresh solution.

Eq 2 represents a model that is reasonably successful in fitting the experimental results, but further study might result in a model that gives a better fit and reflects actual processes that govern the scrubbing behavior.

8.4 Effect of Reagent Type and Temperature

The variable Reagent was found to have a significant effect. The ratio of outlet/inlet is a factor of 1.5 less favorable when sodium hypochlorite is used than when calcium hypochlorite is used. In this comparison, the effect of different pH during the experiments is taken into account; the experiments with calcium hypochlorite used a pH between 8 and 9, whereas those with sodium hypochlorite mainly used a pH between 10 and 12. The equation implies that the factor of 1.5 improvement would be obtained if they were run at the same pH.

Even at the actual pH of the experiments, the calcium hypochlorite gave slightly better removals: calcium hypochlorite gave 96.3% removal with a standard deviation of 2.0 compared to sodium hypochlorite average removal of 93% with a standard deviation of 3.0%.

Temperature was found to have no sigificant effect upon the results.

When the experiments using Cl_2 gas in the air stream are included, the variable Cl • pH cannot be defined. In these experiments, the first column contained 5% H_2SO_4, the second column contained water adjusted to pH 9 with sodium hydroxide, and the third column contained 5% sodium hydroxide. In this case, the best fit was obtained by:

$$\frac{\text{outlet}}{\text{inlet}} = 2.2\ \exp(-0.705\text{columns})\ \exp(-0.00360\text{U1} - 0.00180\text{U2}) \times \text{hours}^{0.310} \times \left(\frac{\text{inlet}}{1{,}000}\right)^{-0.626} \qquad (3)$$

The statistics for this equation are given in Table 12. The coefficient RSQ is 0.6066, compared to 0.62 for Eq 2, which means the fit is nearly as good. However, the variable Hours of Reagent Use is of less practical value than the variables in Eq 2.

With Eq 3, the variable Reagent is not significant, according to Table 12. This means that scrubbing with Cl_2 gas added to the air stream is not significantly different from the other two reagents.

TABLE 12

STATISTICS FOR EQUATION 3
REGRESSION OF ALL DATA WITH THREE REAGENT TYPES

MULTIPLE R	.7789
DEGREE OF DETERMINATION	.6066
RESIDUAL STANDARD DEV.	6.52412-01

ANALYSIS OF VARIANCE

	DF	S.S.	M.S.	F	P
REGRESSION	4	5.5790298+01	1.394757+01	3.277+01	0.00
RESIDUAL	85	3.6179529+01	4.256415-01		

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F	P
(CONSTANT		6.28436-01)			
COL1	4	7.04834-01	8.00572-02	7.7513+01	0.0000
LN(HRS	23	-3.09550-01	6.38575-02	2.3498+01	1.2681-05
OU1+2.	29	3.63714-03	2.51663-03	2.0887+00	1.4809-01
LN(IN)	32	6.26339-01	1.41303-01	1.9648+01	4.8935-05

VARIABLES NOT IN EQUATION

VARIABLE		P CORR	TOL	F
REAGNT	1	.09612	.9267	.7834
PG TYP	2	-.07956	.9519	.5350
COLMNS	3	.00000	.0000	.0000
EXP2	5	.29621	.7752	8.0791
INLET	6	.07384	.1139	.4605
HOURS	7	.00563	.2002	.0027
OUTLET	8	-.79007	.5579	139.5265
CL 1	9	.23788	.9079	5.0386
CL 2	10	.27402	.7651	6.8196
CL 3	11	.04826	.6186	.1961
PH 1	12	.18178	.8821	2.8707
PH 2	13	.19820	.1963	3.4347
PH 3	14	-.25217	.1730	5.7044
PG RAT	15	-.24368	.5868	5.3029
TEMP F	16	-.04146	.9402	.1447
OU 1	17	.03900	.1042	.1279
OU 2	18	-.03900	.3153	.1279
OU 3	19	.00291	.6458	.0007
OU 4	20	-.07063	.5468	.4212
OU3E1	22	.02901	.6921	.0708
OU4E	24	-.02383	.6715	.0477
CL AV	25	.28445	.9302	7.3952
PH AV	26	.21448	.7536	4.0504
CL.PH	27	.29540	.9081	8.0309
OU3+4	28	-.03658	.4985	.1125
OUE3+4	30	-.00130	.6040	.0001
IN/OUT	31	.73048	.5494	96.1058
REMOVL	33	.71748	.5321	89.1183

8.5 Results of Previous Project

Since we now know that the inlet odor level and the previous exposure of the solutions to high odor intensities affect the scrubber performance, we can reexamine some of the performance data in the previous project (Report No. EPA-600/2-76-009). For example, Test 32 in Table 6-5 on page 6-10 of that report showed a two-stage laboratory scrubber having a very high (99.9%) removal with fresh solutions, and subsequent tests over a period of 24 hours of operation showed removals that were greatest for high inlet odor levels and less for low inlet odor levels. A similar effect is seen in Test 31 on page 6-7 of that report. (Note that the complete GC data is given in Appendix 7 of that report). Similarly, in Test 34, Table 9-1 on page 9-8 of that report, very poor removals of 32 and 59% were obtained with relatively low inlet concentrations, although the low pH between 9.3 and 10 was an additional factor as was pointed out in that report. A more quantitative analysis of these results is difficult since we do not know the odor exposure of the solutions during the hours between each test sampling.

8.6 Prediction of Scrubber Performance by Regression Equation

In Report No. EPA-600/2-76-009, computer models were developed to design scrubbers based on mass transfer equations, calibrated with the experimental measurements available at that time. Those models included calculations of costs and sizing of the equipment. They are still valid for those purposes, including the performance predictions for plant ventilating air. For high-intensity (5,000 to 180,000 odor units) air, the statistical regression Eq 2 may be used to predict performance. Since it is based on experiments rather than theory, Eq 2 can only be used within the range of the variables measured during the experiments upon which the equation is based. For example, it cannot be used to predict the effect of using higher purge rates than 30 ℓ/hour at low reagent concentrations, even though we suspect that such a procedure would yield better results at the same cost. To permit predictions outside the range of experimental data, an equation must have some theoretical basis. Such theoretical predictions would be useful to determine whether further experiments are promising to improve scrubber performance.

Eq 2 was used to compute the predicted performance of scrubber systems under various conditions, and the results are presented in Table 13. The removal percent is in the high nineties when the inlet concentration approaches 100,000 odor units. It is generally in the 90% range when the inlet is 5,000 to 25,000 and the previous inlet was higher than the present inlet, especially with three stages or with the highest chlorine and pH (0.2 and 12). Poor removal (60% or less) is found with only one stage, when the inlet concentration is lower than previous inlets, and chlorine and pH are low (0.02 and 10, respectively). The use of three stages gives a safety factor to maintain removal close to 90% when the previous inlet concentration was as high as 100,000 odor units.

Table 11 also compares calculated and experimental results for the conditions of each experiment.

8.7 Conclusions

The data from this investigation are sufficient to define the performance of hypochlorite packed-bed scrubbers under a range of typical operating conditions. The problem of rendering plant odor control is not completely answered, however, since removals of 99% cannot be attained under most conditions listed in Table 13. The problem is not one of equipment design. since the scrubber has been shown to have more than enough mass transfer capacity. The problem is that hypochlorite reagents will not remove all the odorants, and the limitation is one of chemical reactions. Thus, a more effective scrubbing reagent is still needed.

TABLE 13

SCRUBBING PERFORMANCE PREDICTED BY REGRESSION EQUATION

VALID ONLY WITHIN RANGE OF EXPERIMENTAL DATA

(60% < REMOVAL < 99.4%)

NO. OF COLUMNS	INLET ED_{50}	PREVIOUS INLET HISTORY OU1, OU2, OU4	CL · pH	OUTLET* / INLET	% REMOVAL
3	75,000	0	0.20 x 12	0.0056	99.4
			0.02 x 10	0.0128	98.7
			0.01 x 9	0.0133	98.7
	75,000	75,000	0.20 x 12	0.017	98.3
			0.02 x 10	0.039	96.1
			0.01 x 9	0.041	95.9
	25,000	0	0.02 x 10	0.045	95.5
		75,000		0.138	86.2
	5,000	0	0.02 x 10	0.075	92.5
	5,000	25,000		0.109	89.1
2	75,000	0	0.02 x 10	0.024	97.1
	25,000	0		0.085	91.5
	25,000	75,000		0.261	73.9
1	75,000	0	0.02 x 10	0.046	95.4
	25,000	0		0.162	83.8
	25,000	75,000		(0.495)	(50.4)
3	25,000	75,000	0.2 x 12	0.061	93.9
2				0.116	88.4
1				0.219	78.1

* Multiply by 1.5 for sodium hypochlorite reagent.
Standard deviation is a factor of 1.95.
Values in ( ) are outside experimental range.

TECHNICAL REPORT DATA
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16. ABSTRACT The report gives results of a study extending an earlier project during which an investigation of the performance of packed-bed scrubbers for high-intensity rendering plant odors (5000 to 180,000 odor units) showed that, although in some cases the removal was as high as 99%, the average was only 85%. In this study, extensive performance data was obtained with an odor panel over a period of 8 weeks. Removal averaged 93% with three stages of sodium hypochlorite scrubbing even though each stage was designed to remove 99% of the odors based on its mass-transfer capacity. The results, fitted to a regression equation, showed that the important variables are the age of the solution and the relation of the inlet odor concentration to the previous history of exposure of the scrubbing solutions to high odor intensities. Chlorine concentration and pH also affect the results, and calcium hypochlorite is about 1.5 times more effective than sodium hypochlorite. The experimental data could be explained by assuming that about 85% of the odor was contributed by compounds that are oxidized by hypochlorite solutions, while the remaining fraction consists of compounds that are refractory to oxidation. Further efforts should be made to find scrubbing agents that will remove the odorous compunds that are refractory to hypochlorite.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Sodium Hypochlorite	Air Pollution Control	13B	07B
Industrial Plants	Calcium Hypochlorite	Stationary Sources		
Fats	Chlorine	Rendering Plants	06A	
Oils	pH	Odor Panels		07D
Scrubbers			07A	
Odor Control				

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