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COMPARISON OF TWO CONDENSER-ABSORBER DESIGNS
FOR NITROGEN OXIDE RECOVERY

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COMPARISON OF TWO CONDENSER-ABSORBER DESIGNS
FOR NITROGEN OXIDE RECOVERY

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INTRODUCTION

Improved and more economical means are being sought for the downdraft condenser recovery of nitrogen oxides from the Purex Plant dissolvers. The tests described below compared the performance (absorption efficiency, pressure drop) of the existing externally finned tube design to a lower cost alternate with Raschig ring packing outside the cooling water tubes.

SUMMARY AND CONCLUSION

The following experimental results were obtained on single tube downdraft absorber-condensers operating on simulated dissolver off-gas under equivalent cooling water flow and condensing side cross sectional area:

1. Single tube downdraft condenser tests indicate that substitution of plain (unfinned) tubes surrounded with Raschig rings for the currently installed longitudinal finned tubes will result in approximately the same mass and heat transfer characteristics.
2. The packed condenser tests showed that an appreciably higher gas side pressure drop will occur. For example, at 9.0 scfm gas inlet flow, equivalent to 4600 scfm for a plant scale unit, the differential pressure was negligible for the externally finned system, and 6.0 pounds per square inch for the externally packed plain tube test.

TEST EQUIPMENT AND PROCEDURE

The experimental equipment for the two tests is shown in Figure 1, and the dimensions for the towers are detailed in Figure 2 (plain tube-raschig ring test) and Figure 3 (finned tube tests). The equipment duplicated the reactant side free cross sectional area for a single tube in the dissolver tower, 0.02 square feet. The cooling water rate was regulated to give a water velocity in the tube of 5.5 feet per second. The differences in the volumetric rates (Table 1) are due to differences in the annular areas formed by the tube and the dummy inner tube.

Each test was begun by adjusting the cooling water rate to its selected value. Air, steam, NO, and NO₂ flow rates were then adjusted to the specified rates for the test. About 20 minutes was required to reach a thermal steady state in each test and it was assumed that mass transfer steady state had also been reached by this time. Temperatures and the exit liquid flow rate were then measured and two exit gas samples were taken. An exit liquid sample was also taken to measure the acid concentration of the tower product.

The two exit gas samples were absorbed in premeasured quantities of potassium permanganate and water and titrated with standard base and standard oxalic acid solution respectively, to evaluate the NO and NO₂ content of the exit gas stream. The measurements were not self consistent, placing doubt on the accuracy of the technique, however, for comparison purposes, the total nitrogen oxides concentration of the exit gas was calculated and is presented in Table 2 to give an indication of the relative concentrations of acid vapors in the exit gases. Acid recovery rates were calculated from liquid sample acid titrations and the observed liquid rates.

Summaries of the test conditions and observations are presented in Tables 1 and 2. Seven sets of test conditions were investigated for the plain tube with external raschig ring packing. Four of these were found to be of sufficient interest to warrant study for the finned tube case and were duplicated to evaluate the reproducibility of the test method.

Figure 4 illustrates how the unit differential pressure varied with air and saturated steam inlet rates for the packed tower test. Cooling water was maintained at the same flow rate for this test as for the other packed tower tests. No measurable differential pressure was observed for any of the finned tube tests.

DISCUSSION

Literature reports^{1,2,3,4} for the system of nitrogen oxides, air (oxygen), and water suggest that rapid absorption of the oxides of nitrogen is controlled primarily by reaction kinetics rather than by diffusion mechanisms. Nitric oxide is also generated in the liquid phase by the absorption and reaction of nitrogen dioxide in water, and is transferred back into the gas phase by desorption from the liquid. Oxidation of nitric oxide to nitrogen dioxide occurs in both liquid and gas phases and is relatively slow in either case. All these effects accent the effect of residence time for the reactants in the condenser-absorber. Also, the reaction rate is dependent upon the oxygen concentration in the gas and liquid, and low air rates or high NO₂ concentrations over a saturated liquid can further limit the absorption process. The experimentally determined behavior of the two units are explained accordingly.

Table 2 summarizes the observations. There was very little difference in absorption efficiency for the two condenser-absorber designs. The exit gas concentrations show a slightly better nitrogen oxide removal efficiency by the packed-plain tube design, as predicted by its greater surface area for gas-liquid contact and liquid holdup. The improvement is small, however.

Heat transfer capability was generously large in both designs as illustrated by the usually equal product and cooling water exit temperatures in co-current flow. Heat transfer was so rapid that the bare outer shell of the test assembly (before applying the laggin) was cool to touch about three feet below the reactant inlet level at steam and air rates slightly higher than used during the experiments, and at the specified cooling water rate.

Pressure differential across the packed tower was appreciable but was too low to measure during the finned tube experiments. The differential pressure graph for the packed design is self explanatory. Inlet pressures were measured from zero to 9 scfm air rate at several constant inlet steam rates.

References

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2. M. S. Peters and E. J. Koval, "Nitrogen Oxide Absorption in an Agitated Reactor," Ind. and Eng. Ch., 51, 4, pp. 577-580. April 1959.
3. M. S. Peters, C. P. Ross, and J. E. Klein, "Controlling Mechanism in the Aqueous Absorption of Nitrogen Oxides," AIChE J., 1, 1, pp. 105-111. March 1955.
4. A. B. McKeown and F. E. Belles, "Nitric Acid - Nitrogen Dioxide - Water System," Ind. & Eng. Ch., 47, 12, pp. 2540-2543. December 1955.

TABLE 1
TEST OPERATING CONDITIONS

Test No.	NO Mole %	NO ₂ Mole %	Air Mole %	Steam Mole %	NO Lb./Hr.	NO ₂ Lb/Hr.	Air Lb/Hr.	Air Lb/Ft ² -Hr	Steam Lb/Hr.	Total Lb/Hr.	Superficial Noncondensable Gas Velocity Ft/Sec.
1	2.	8.	9.	81.	0.9	5.5	3.8	190.	21.4	31.6	.68
2	10.	10.	9.	71.	4.5	6.9	3.8	190.	18.7	33.9	.68
3	5.	25.	9.	61.	2.1	17.0	3.8	190.	16.2	39.1	.68
4	2.	8.	19.	71.	0.9	5.5	8.1	405.	18.7	33.2	.63
5	8.	2.	9.	81.	3.6	1.4	3.8	190.	21.4	30.2	.68
6	9.	20.	67.	4.	3.9	13.8	28.4	1420.	1.1	47.2	5.16
7	8.	1.	86.	5.	3.6	0.9	36.6	1830.	1.3	42.4	6.63

Cooling water rates to give 5.5 feet per second annular water velocity:

Plain tube packed tower test

4.58 gpm

Finned tube tests

4.01 gpm

Absorption side equivalent cross sectional area = 2.9 in.²/tube = 0.02 ft.² tube

Superficial gas inlet velocity = 7.73 ft/sec (before condensation and absorption)

TABLE 2
EXPERIMENTAL OBSERVATIONS

<u>Test</u>	<u>Inlet Water Temp. °C</u>	<u>Outlet Water Temp. °C</u>	<u>Outlet Reactants Temp. °C</u>	<u>Outlet Reactants Lb/Hr.</u>	<u>Acid Recovery Rate, As Lb/Hr. 100% HNO₃</u>	<u>Recovered Acid Conc. Wt. %</u>	<u>% Acid Recovery</u>	<u>Exit Gas Nitrogen Oxides Concentration, Total Mole %</u>
1 Plain	--	--	23	29.4	3.75	12.8	39.7	0.3
1 Fin, #1	19	25	23	31.7	3.2	10.1	33.9	1.2
1 Fin, #2	19	25	25	26.6	3.4	12.8	36.0	1.7
2 Plain	--	--	28	32.6	7.42	22.8	39.2	2.0
2 Fin, #1	19	25	25	28.4	5.2	18.3	27.5	4.0
2 Fin, #2	19	24	24	26.2	5.9	22.5	31.2	6.2
3 Plain	--	--	24	34.2	11.5	33.6	41.5	3.0
4 Plain	--	--	20	24.5	3.2	13.1	33.9	1.1
4 Fin, #1	19	24	27	24.8	3.0	12.1	31.7	0.6
4 Fin, #2	19	24	24	22.0	3.0	13.6	31.7	1.1
5 Plain	--	24	24	40.4	7.61	18.8	80.5	3.5
5 Fin, #1	19	26	26	36.5	9.8	26.8	103.7	4.9
5 Fin, #2	19	25	25	31.9	10.2	32.0	107.9	4.3
6 Plain	--	19	19	5.1	1.86	36.5	8.9	0.6
7 Plain	--	--	19	7.5	2.71	36.1	30.7	2.4

FIGURE 1
TEST ARRANGEMENT

FIGURE 2
PACKED TUBE TEST

FIGURE 3
FINNED TUBE TEST

Inlet Pressure as a Function of Air and Steam Rates

FIGURE 4

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