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A STUDY OF MULTISTAGE/MULTIFUNCTION COLUMN FOR FINE
PARTICLE SEPARATION

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Principal Author(s): Dr. Shiao-Hung Chiang

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Submitting
Organization(s)

Dr. Shiao-Hung Chiang
Chemical and Petroleum Engineering Department
University of Pittsburgh
Pittsburgh, PA 15261

Name & Address

(1)

(2)

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ABSTRACT/EXECUTIVE SUMMARY

Wastewater treatment tests program was conducted during this quarter. Preliminary tests showed that the multistage column had superior performance to conventional column. In both batch and continuous operations, the oil removal efficiencies were higher than 90%. The results were also compared with data reported in the open literature.

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1.0 INTRODUCTION

The overall objective of the research program is to explore the potential application of a new invention involving a multistage column equipped with concentric draft-tubes (hereafter referred to as **the multistage column**) for fine coal cleaning and other fluid/particle separation processes. The research work will identify the design parameters and their effects on the performance of the separation process. The results of this study will provide an engineering basis for further development of this technology in coal cleaning and in the general areas of fluid/particle separation.

In the last quarter, we initiated the **wastewater treatment tests program** to verify the multifunction features of the multistage column. The set-up of the test equipment and analytic instrument were completed. During this period, we performed a series of oily water cleaning tests. Table 1.1, the project schedule, shows work accomplished to date.

Table 1.1 Project Schedule

Tasks	1994			1995			1996			1997			
	7	9	12	3	6	9	12	3	6	9	12	3	6
1. Project Planning	■												
2. Equipment		■						■					
3. Hydrodynamic Tests				■									
4. Separation Tests							■				■		
5. Conventional Column Tests				■			■				■		
6. Data Analysis				■			■				■		
7. Reports	□	□	□	■	□	□	□	□	■	□	□	□	●

Notes: □ Quarterly Technical Progress Report; ■ Annual Report; ● Final Report.

2.0 RESULTS AND DISCUSSION

2.1 Task 1: Project Planning

This task was completed in September 1994^[1].

2.2 Task 2: Equipment Design and Construction

Currently, the objective is to modify an existing multistage column system in our lab for general use in wastewater treatment. This unit includes a multistage flotation column, a gas supply system and associated ancillaries. The equipment modification was completed in the previous quarter^[2].

2.3 Task 3: Hydrodynamic Tests

The objective of this task is to pursue a basic understanding of the hydrodynamic behavior and to characterize the flow and mixing conditions in the multistage separation column. This task was completed in December 1995^[3-5] for the previous version of the agitated column for solid-solid separations. The hydrodynamic tests for the newly constructed column for liquid-liquid separation is to be performed in the next quarter.

2.4 Task 4: Separation Tests

To demonstrate the multifunction features of the multistage column, the separation tests in Task 4 have focused on the investigation of wastewater treatment since April 1996. The goal of this phase of the study is to examine the potential application of the column to the general areas of fluid/particle separation and evaluate the effectiveness of the multistage column in these processes.

The detailed description of the technical progress for this quarter is presented below.

2.4.1 Objective and Scope

The objective of this phase of our study is to explore the potential application of the multistage column for wastewater treatment. The experimental work focused on identifying the effect of operating parameters on the column performance as a wastewater treatment device and demonstrating its multifunctional features in the removal of contaminants (such as dispersed oil) from wastewater.

2.4.2 Experimental Setup and Procedure

The experiments were performed in a three-stage non-agitated flotation column. The column configuration was reported in the last report^[2].

A simulated wastewater sample was prepared by adding a pre-determined amount of a light mineral oil (LMO) with a density of 874 kg/m^3 at 25°C . The oil/water mixture was emulsified in a 50 gallon feed tank by pumping and recycling through a static mixer for about 60 minutes. Based on our previous experience, the oil-water emulsion prepared in this manner was stable and no coalescence of oil droplets was expected. The initial oil concentration in water was set to be about 500 mg/L. 2-Ethyl-1-hexanol (2-EH) was used as frother. The superficial gas velocity varied over a range up to 4.0 cm/s and liquid feed rate was tested up to 5 liter/min.

The oily water was fed to the top of column and water level was adjusted to keep the overflow rate to be less than 5% of the feed one. Gas bubbles were generated by a vertical perforated metal sparger (mean pore size of $10 \mu\text{m}$), which was located at the bottom of the column. Gas bubbles passed through each contactor upward in contact with the down-flowing oily

wastewater simulant stream. The gas-lift action caused a circulation (or loop flow) of fluids around each draft tube. The treated water left the bottom of the column via the clean water discharge line, while the oil-laden foam overflowed into the foam discharge tank. Clean water samples were collected and analyzed for oil content using an OCMA-220 oil content analyzer.

2.4.3 Preliminary Oily Water Treatment Tests

Tests were performed in the multistage column of given geometry^[2] to study the effects of various operating conditions on the oily water clean-up performance. The oil removal efficiency, η , is the performance criterion and defined as

$$\eta = \frac{C_o - C_f}{C_o} \times 100\% \quad (2.4.1)$$

where C_o and C_f are the initial and final oil concentrations, respectively.

2.4.3.1 Batch Operation

When oily water feed rate was zero, the clean up process was a batch operation. A comparison of oil removal efficiency (ORE) between the multistage column and a conventional open column was plotted in Figure 2.4.1. The superficial gas velocity was chosen to be 2.9 cm/s and frother dosage was 15 ppm.

Test results showed that oil removal was much faster and more complete in the multistage column than in the open column. Within 5 minutes flotation time, the oil removal efficiency achieved 90% in the multistage column, contrasting to 80% oil removal at 25 minutes in a conventional column. The results obtained in the batch tests provided information on choosing feed rate for further investigation of continuous operation.

Figure 2.4.1 Comparison of Oil Removal Efficiency between MSTLFLO and Open Column in Batch Operation

2.4.3.2 Continuous Operation

Continuous operations of the multistage column were conducted at feed rates ranging over 1-5 liter/min. Typical results were shown in Figure 2.4.2. In all cases, the oil content in the clean water stream is less than 40 ppm (which is equivalent to 92% oil removal).

In both low and high feed rate cases, higher superficial gas velocity favored the oil removal. This was primarily due to the facts that higher superficial gas velocity corresponded to higher gas holdup. In the presence of frother, the gas bubbles were sizing uniformly and didn't change much with the increasing gas flow rates. Therefore, higher holdup implied higher interfacial area which had significant positive influences on oil removal. The only exception was found at low feed rate (1 liter/min) and high superficial gas velocity (>3 cm/s) which led to a decrease in oil removal. Experimental observation indicated the liquid circulation in the first stage was poor in the low feed rate case at high superficial gas velocities because the both the central region and the annular region were occupied almost entirely by gas so that the driving force for liquid circulation was greatly diminished. Similar phenomena were observed when investigating the oil contents of samples withdrawn from different stages at low feed rates (see Figure 2.4.3).

It was seen in Figure 2.4.2 that at feed rate of 4 liter/min, the oil removal efficiency was as high as 92%. Considering the total volume of the column and its gas holdup, the average residence time of the feed liquid at 4 liter/min was only 3-5 min at high superficial gas velocities. This shows that the oil clean up performance in the continuous operation is comparable to that of the batch operation.

Figure 2.4.2 Oil Content vs. Superficial Gas velocity in Continuous Operations

Figure 2.4.3 Oil Content in Difference Stages

Figure 2.4.4 Comparison with Data from Literature

A comparison of oil removal efficiencies with other reported data in open literature is shown in Figure 2.4.4. It was found that the separation efficiency of the multistage column is superior to the conventional columns not only for the dispersed air flotation operation^[6] but also for the dissolved air flotation^[7].

The excellent performance of the multistage flotation column in emulsified oil clean up again verified the original multistage separation design concept. More importantly, it reveals the broad potential applications of this novel column in the general areas of fluid/particle separations.

2.5 Task 5: Conventional Column Tests

In this quarter, only batch tests were carried out in the conventional column and the results were reported in section 2.4.3.1.

2.6 Task 6: Data Analysis

Experimental results were analyzed and discussed qualitatively in section 2.4. Mathematical treatments will be presented after more hydrodynamic data are collected.

3.0 CONCLUSION AND WORK FORECAST

In this quarter, efforts were mainly devoted to the oily water clean up tests in the new multistage column for liquid - liquid separations.

Both batch and continuous tests were carried out. In the batch tests, the oil removal efficiency was as high as 95% at 5 minutes flotation time. In the continuous tests, at low feed rate (1 liter/min), oil removal efficiency was over 95% at the superficial gas velocity being 2.9 cm/s and at high feed rate (4 liter/min), the oil removal efficiency was also higher than 90% at high superficial gas velocities.

The excellent performance of the multistage column was resulted from the favorable hydrodynamic conditions it created.

In the next quarter, a systematic study of hydrodynamics in the column will be conducted to provide an engineering basis for further process developments. Work will include the following:

- (1) The effect of operating conditions on gas holdups, both overall and local;
- (2) The effect of operating conditions on liquid circulation behavior;
- (3) Measurements of gas bubble sizes and distribution.

4.0 REFERENCES

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