A THREE-STAGE COUNTER CURRENT LEACHING RIG FOR THE SENIOR LABORATORY

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N.S.W. Australia, 2006

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LABORATORY WORK IS regarded as a vital part of the unit operations course at the University of Sydney. Exposed to the real world of the laboratory, students discover the importance of concepts other than the mathematical models that tend to be taken as the be-all and end-all of understanding. Students apply their ideas to a complex plant which must be approached with preparation and respect. In planning and executing their activities, they are inculcated with a sense of discipline and leave the sessions with a feeling of accomplishment. Properly done, the laboratory can also be a lot of fun.

With this in mind, the department has built a three-stage counter current leaching rig designed by the author. The new rig was intended to overcome the problems of previous models which were beset by poor performance and frustrating breakdowns. Its design contains a number of attractive features which help to make the laboratory both satisfying and instructive.

DESIGN PHILOSOPHY

Previous models of the leaching rig had several unattractive features. Motors and bearings suffered from exposure to wet and dusty conditions around the mixers and settlers. Underflow was removed by valves which were either fully on or fully off, with the resultant discontinuity of flow leading to frequent blockages. The conventional overdriven impellers in each mixer could not be restarted if they were submerged under sedimented solids, and there was virtually nothing instructive to see because the vessels were opaque. The new rig is designed around a translucent acrylic panel which separates both mixers and settlers (the "wet side") from the motors, pumps, bearings, and electrics (the "dry side") (see Figure 1). This panel also acts as a convenient diffuser for a backlight so that the behaviour of the slurry in the vessels can be clearly seen. The vessels are a "flat cell" design in order to simplify construction and to simulate the usual cross-sectional view of such apparatus seen in texts and on the chalkboard. Mixers employ externally mounted centrifugal pumps situated on opposite sides of the acrylic panel (see Figure 2). When the pumps are started with settled solids in the vessel,

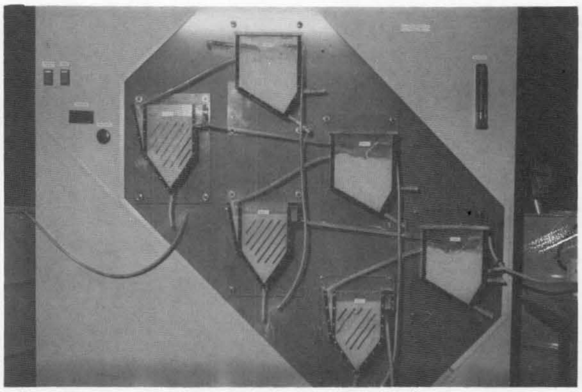
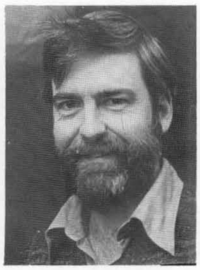


***FIGURE 1.** The whole rig. Three sets of mixer/settlers are connected by tubing to create countercurrent solid/liquid flow. Feed slurry enters the bottom mixer (RHS). Leached solids are pumped from the base of the top settler (LHS). Feed water enters the top mixer and the strong product solution emerges from the overflow of the bottom settler. Underflows are conveyed upwards by pumps mounted behind the acrylic panel.*



Wayne Davies spent two years as a lecturer in the department where he had previously received both his bachelors and PhD degrees. Apart from his interest in undergraduate teaching using the practical "hands-on" approach, he is also interested in applications of both conventional and novel unit operations to the processing of biological products and their long-term storage and stability.

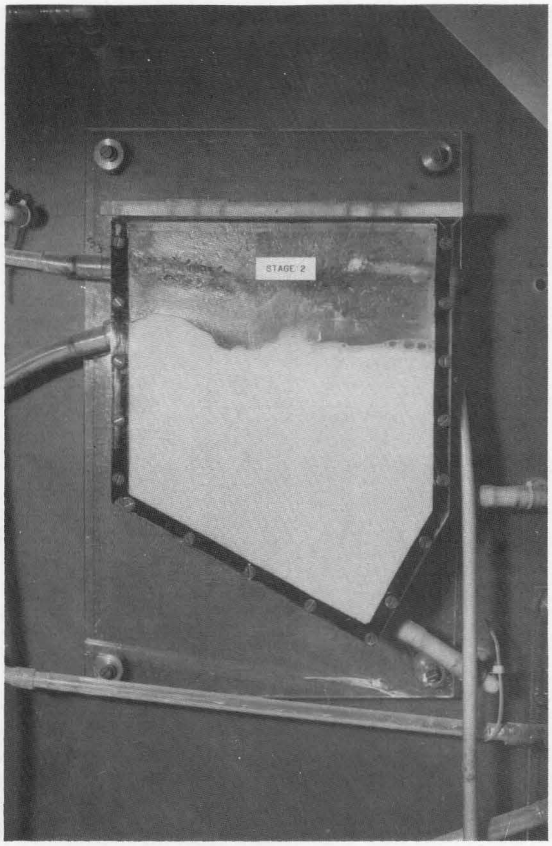


FIGURE 2. Stage 2 mixer showing pentagonal shape. Slurry to the external pump agitator leaves the vessel about halfway up on RHS. Slurry returns from the pump via the angled tube at the bottom. Incoming overflow is via the top tube (LHS), incoming underflow is via top tube (RHS) and mixed slurry leaves the vessel via overflow tube (LHS).

clear supernatant initially enters the pump and the return flow fluidises the sediment. After a short time the entire contents are fully resuspended. The pentagonal shape of the mixers encourages turbulent conditions everywhere in the vessel and the motors are overrated in order to cope with concentrated slurry (up to 35% v/v settled solids). The settlers are designed similarly. Natural consolidation of the sediment occurs in the steep V-bottomed shape of the vessel (see Figure 3) and the inclined parallel plates increase the effective surface area by a factor of about three over that of the air/water interface. A perforated plate delivers feed to the parallel plate settling section to help smooth pulsations in feedrate.

Almost continuous removal of the underflow is achieved by peristaltic pumps situated on the dry side of the acrylic panel. These are driven by a common shaft from a variable speed gearbox and motor. Because timing belts connect the shaft to the pumps, there is no slip, and each pump delivers almost exactly the same volumetric flowrate. The excellent pumping characteristics obtained allow the underflow pumps to do dual service, and they also convey the underflow up to the next mixer stage (Figure 1). All other flows can gravitate from one vessel to the next by tubing whose angles of fall were chosen to avoid blockages by solids build-up. Thus the solids-rich streams from mixer to settler are angled at 28° while the solids-poor settler overflows are angled at only 8.5°. Instrumentation includes an electronic tachometer on the underflow pump shaft in order to reproduce flowrates and a variable area flowmeter for the feed water which is delivered from a constant head tank.

OPERATION

Routinely, feed consists of a slurry of alumina (average particle size 65 μm) in water containing about 40 ppm fluorescein as the solute. The slurry is continuously mixed in a 200 litre tank, and a peristaltic pump delivers the feed to the first stage mixer where it meets the overflow from the second stage settler. Overflow from this mixer moves to the first stage set-

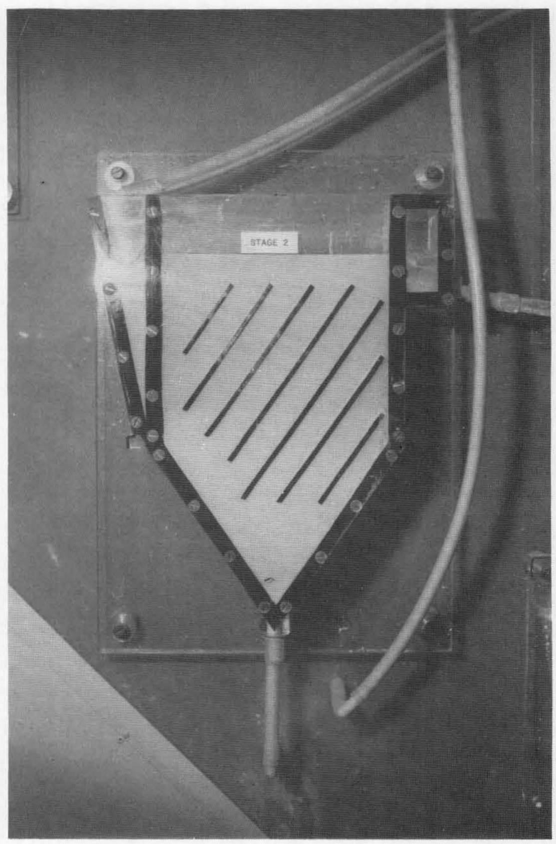


FIGURE 3. Inclined plate settler showing wedge-shaped inlet chamber (LHS), underflow removal tube (bottom) and overflow (RHS) as well as vertical tube conveying underflow to next mixer stage above.

tler, which separates the solids-rich underflow, which moves to the second stage mixer. The process is repeated over three identical stages. A stream of solute-poor solids emerges from the third stage settler, and the strong product solution emerges as overflow from the first stage settler. The leached solids are collected in a 200 litre receiver tank. When full, this tank is simply interchanged with the now-empty feed tank and extra dye is added. Feeding slurry instead of solid avoids the need to dry the material between laboratory sessions, which was far too laborious and time-consuming.

Set up this way, the operation is strictly described as counter-current washing since the solute dye is already in solution and not combined with the solid. True leaching can be performed by feeding real mineral solids directly. Dye concentration is simply determined from its absorbance at 491 nm. Solids concentrations are most conveniently expressed as the volume fraction of the wet sediment after centrifuging (5 min, 1000 xg). A correlation between mass fraction and volume fraction is obtained experimentally by students.

Choosing the operating parameters follows a set logic which is determined by the design limits of the equipment. The best way to start is to select the feedrate of slurry and its concentration, which may be in the range 3 to 26 ml/sec and 20% to 60% (v/v wet solids), respectively. The feedrate of solids then dictates the minimum underflow rate from the settlers. The absolute upper limit of solids in the underflow has been found experimentally to be 85% (v/v), as any limit greater than this will stall the pumps. For reliable operation, a practical limit of 75% offers a margin of safety.

The minimum water flowrate is determined as the amount necessary to prevent solids concentration exceeding the design limit of the mixer pumps, which has been found to be about 35% (v/v). This is done by a mass balance around the third stage mixer. Once these minimum requirements have been found, greater values for water flowrate may be set without problem and the underflow rate can be increased to the point where its volumetric flowrate just equals the combined volumetric flowrates of the feed water and the feed slurry. Naturally enough, optimal conditions usually mean that the underflow is as thick as possible.

PERFORMANCE

In the two years that the rig has been in service, it has logged over one hundred hours of operation without any problems. Most experimental runs are based on conditions of constant flowrates and compositions, the performance of the rig being determined at steady state. For most runs starting with no dye or solids in the system, this takes about fifty minutes to achieve within reasonable error, much less if run parameters are allowed to change dynamically.

Table 1 shows the results of two runs which demonstrate typical extremes of operation. In Run 1 the feed flowrate is modest and the water flowrate is fairly generous, whereas Run 2 operated close to the design limit of both mixer and underflow pumps, with high feed flowrate and minimal water flowrate. Run 1 achieved almost total (99%) recovery of the solute but at relatively low concentration (15.7 ppm). In Run 2 the recovery was less (95%) but the product concentration was more than double (34.7 ppm). The solids concentration in the underflows was fairly thick in both runs (72% v/v), and the settlers were still producing a workable underflow with sedimented solids up to 150 mm deep. In Run 2 the mixers were close to their design limit for solids concentration (32% v/v), but in Run 1 the mixers were hardly stressed at only 13% (v/v). Because of its greater water flowrate, Run 1 achieved a relatively clean washed solid with only 0.86 ppm solute in the accompanying solution. Under nearly all conditions studied so far, the rig returns better than 2.5 ideal stages, or 83% stage efficiency.

TABLE 1
Performance Data

	RUN 1	RUN 2
Feed		
Solids Concentration (% v/v)	22	19
Flowrate (ml/sec)	7.0	13.4
Dye Concentration[1] (ppm)	40	44
Water Flowrate (ml/sec)	10.6	6.5
Underflow		
Solids Concentration (% v/v)	72	72
Flowrate (ml/sec)	2.9	5.9
Dye Concentration (ppm)	0.86	6.1
Product Stream		
Flowrate (ml/sec)	13.5	13.5
Dye Concentration (ppm)	15.7	34.7
Recovery[2] (%)	99	95
Mixers		
Solids Concentration (% v/v)	13	32

1. Dye concentration is expressed in the supernatant.
2. Based on a balance of the dye in the feedrate less the amount in the underflow.

DISCUSSION

The leaching rig described here offers students a worthwhile laboratory experience due to its reliable and predictable performance. As long as a few preliminary calculations are done to set the operating parameters correctly within design limits, the run can be expected to proceed without a hitch. Failure to observe a simple set of logical rules will inevitably lead to disaster, with wasted hours of misery in unblocking underflow tubes awaiting the unprepared.

Experimental tasks using the rig can be made simple or sophisticated to suit the ability of the group. As most experiments attempt to demonstrate performance at steady state, one task set can be to show that steady state has been achieved within experimental error. More advanced questions involve adding economic constraints, *e.g.*, students may be told that the solute stream is the valuable product and that overall profitability of the operation is improved by the total recovery of the solute but is diminished as the stream becomes more dilute. Additional constraints may be that the operating costs of the operation increase as some function of the feedrate. With these considerations in mind, students are asked to perform an optimisation of the operation and then to make the rig work accordingly.

CONCLUSIONS

The apparatus described here represents the result of an integrated approach to design with an emphasis on teaching. The rig is functional, fits well with theory, and needs little maintenance. Its ultimate utility is limited only by the imagination of the user.

ACKNOWLEDGEMENTS

I would like to thank the staff of the department, especially Mr. D. Trevaskis, who helped with many invaluable suggestions during the design and construction of the rig. I am also indebted to Mr. P. Kamlade for the experimental results which he obtained as part of his graduation thesis and to Associate Professor D. Bagster for critical review of the manuscript.

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ALTERNATIVE APPROACH

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the needs of a diverse group of students given the present economic and social climate. A survey of the students who took this course reveals that while six have jobs related to product development, only four of the twenty-eight (four are undecided) have accepted jobs which directly involve work on chemical processes. One has accepted a job as a financial analyst with a major New York investment bank. The rest are either going to graduate school (three in chemical engineering, one in law, and one in business), the naval officer program, or will work for firms that specialize in business systems and consulting. Clearly, the present format offered more to this particular group of students than would a course which included only topics traditionally considered as process design.

All indications are that the course was successful in meeting the intended goals. However, it must be noted that this was due in large part to the effort of the students. They worked hard for the first part of the semester to finish the design project. They also exerted significant effort through the end of the semester to make the product design project worthwhile, even though most of them had already accepted jobs.

The structure of the present course may break too far from tradition for the personal taste of many chemical engineering faculties. However, the time could be right to reconsider the content and structure of process design courses which were conceived when the majority of chemical engineers were employed in developing and operating large chemical processes.

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