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A MECHATRONICS APPROACH TO SOLID/LIQUID SEPARATION

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SUMMARY

It is shown how a mechatronics approach can improve a traditional unit operation. The basic principles of the task are outlined and the example of a pressure leaf filtration system is chosen to illustrate how the approach yields flexible apparatus. The experimental apparatus, which incorporates full computer control and hardware to provide pseudo-tomographic images of filter cakes, is described. Data are presented to illustrate the benefit of its use in both constant pressure and constant flow modes.

INTRODUCTION

Since the 1980's there has been a veritable explosion in the use of microprocessor-based products such as micro- & personal computers (PC's) and process logic controllers (PLC's). Initially extolled for their number crunching capabilities, these devices have since been employed in countless applications from systems and data handling to data presentation and control. The pace of development is such that the combination of modern technologies with more traditional engineering requirements has spawned whole new philosophies. One of these philosophies has become known as mechatronics[1].

Mechatronics integrates electronics engineering and computer technology with applications requiring the control of mechanical systems and processes. Most mechatronic applications are inherently diverse and necessitate that a practising engineer has a firm understanding of many technologies and an ability to combine them coherently. By its nature, pressure filtration is a transient process which, in the past, has been performed with varying degrees of operator interference. To be able to control and correctly interpret the filtration process, and the post-filtration washing and dewatering operations which complete a filter cycle, a new approach must be taken where operator interference is minimised.

JUSTIFICATION FOR A MECHATRONICS APPROACH

In cake filtration, the relationship between filtrate volume and time is commonly expressed through a modified form of D'arcy's Law, known as the filtration equation[2]. Although this equation is widely used to interpret filtration data, to give specific cake resistance and a measure of filter medium resistance, its validity has been challenged[3]. When compressibility is present in the forming cake, the cake properties are continually changing with time and the filtration equation becomes potentially less reliable. Moreover, the cake resistance changes with height throughout the cake and the need to know the variation becomes more important at higher cake compressibility[4]. The situation is often further complicated by interactions between the cake and the filter medium which change the manner of cake formation.

When a filter cake has been formed it is often post-treated by gas dewatering and/or displacement washing[5]. In the former a pressurised gas is introduced above the cake to force liquor through the cake interstices, whilst washing requires the displacing liquid to remove solute contaminant(s). The tortuous nature of all filter cakes induces dispersion of the displacing fluid and may subsequently lead to reduced efficiency. Problems can become extreme when channelling occurs. Here, certain areas of a cake exhibit a significantly lower resistance to fluid flow and a high

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proportion of the displacing fluid preferentially passes through a channel leaving the remainder essentially untouched.

The need to understand, acquire and display (real-time) data throughout all phases of a filter cycle is imperative if the phenomena described are to be understood in the context of solid/liquid separation. The ability to interrogate particle/fluid motions during a separation is a prerequisite to this, as is the ability to provide a test rig which removes as much operator interference as possible. Such an approach has been taken in the current work whereby a computer controlled rig, capable of taking scanned images of a filter cake, has been constructed and successfully commissioned.

DESCRIPTION OF EXPERIMENTAL APPARATUS

The filter cell and the principle hardware for evaluating in-situ filter cake properties are shown schematically in Figure 1. The system comprised a 43 cm long, dead-end pressure filter cell and circuitry capable of taking electrical resistance measurements. The filter cell, constructed from stainless steel (s/s) and plastics, contained 16 horizontally oriented rings of electrodes situated at various heights above the filtering surface. Each ring contained 16 electrodes spaced evenly around its periphery such that all the electrodes protruded 5 mm from the internal wall of the cell to prevent tracking of the electrical signal. The cell had a filtration area of 80 cm^2 and was able to operate at internal pressures up to 1000 kPa.

For suitable resistance measurements to be taken each electrode was able to either generate an electrical current (termed pulsed), receive a current (termed earthed) or be neither pulsed nor earthed (termed floating). The co-ordination of the electrodes was performed using a number of printed circuit boards designed with the aid of Easy-PC Professional™ CAD software. A distribution board and 16 daughter boards were developed in conjunction with a mimic display board and two interface circuit boards. The combination of these boards allowed data transfer to, and from, a driving computer fitted with PCL-812PG and PCL-860 add-on cards provided by Fairchild™. A digital signal, supplied to the master and daughter boards, determined which electrodes were switched to the pulsed or earthed states. This procedure allowed an alternating electric current, provided by a 2 kHz square wave generator, to pass between the chosen pair of electrodes in the cell. The voltage generated was measured and calibrated to the suspension concentration using a combination of the add-on cards installed in the computer and the driving software.

The remainder of the experimental rig has been described in detail previously[6-8] but essentially comprised two s/s storage vessels, used for storing the feed suspension and wash water respectively, connected by s/s piping to the filter cell. Compressed air at pressures up to 800 kPa was supplied to the control valves on the rig pipework and also fed to the storage vessels/filter cell via an electronic regulator. In this manner the driving forces for all phases of a filter cycle were provided. A heater/cooler system regulated the temperature of the filter cell and the storage vessel contents by continuously passing water through their surrounding jackets. If a washing phase was included in a filter cycle, liquor samples were taken using a 20 interval rotary table situated directly below the filter cell. An electronic balance, also situated below the filter cell, enabled liquor transport rates to be continuously monitored. Air flow rates were monitored during dewatering using an electronic flowmeter. All components related to data acquisition and rig operation were sequenced by the computer through dedicated computer software.

RESULTS AND DISCUSSION

The experimental apparatus was commissioned using 10% v/v, aqueous based, calcite suspensions. A series of experiments were performed at constant pressure over the range 100-600 kPa to ensure that the rig was functioning correctly and giving reliable and repeatable results.

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Representative samples of the data obtained are shown in Figures 2 & 3. Figure 2 illustrates a standard plot of cumulative filtrate volume vs. time for six different applied pressures; the filter cycles in these cases involved filtration and subsequent dewatering phases. Such data, and the corresponding time/volume vs. volume data[7], illustrate that by using computer controlled and sequenced apparatus, reliable and accurate filter cycle data can be obtained, repeatedly, without the need for excessive operator interference. Figure 3 shows that by switching series' of diametrically opposite electrodes within the filter cell, transients solids concentration profiles can be measured. In the example shown, data were obtained for a fixed filtration pressure of 400 kPa over four vertical planes, where each plane was at a 45^o rotation to the previous one. The scanned profiles clearly show progressive cake growth at the filtering surface and the homogeneous nature of the ~110 mm deep filter cake.

To illustrate the potential of the experimental apparatus some further data are shown in Figures 4 & 5. Here, an initial attempt was made to control the pressure applied during a filtration in order to maintain a constant filtrate flow rate of 1 $cm^3\ s^{-1}$ (and hence mimic a positive displacement pumping operation). A number of control methodologies were tried, ranging from relatively simple proportional control to the more complex proportional-integral-derivative (PID) control. The controller gains in each case were determined using a method attributed to Ziegler-Nichols[9] and the values are shown in Table 1. Figure 4 shows a typical result obtained for proportional control. It can be seen that a reasonable level of control was achieved in a relatively short period of time, but (usually) at the expense of an offset, or flow error, and some oscillation. Figure 5 shows that for a PID controller the flow error and oscillation could usually be eliminated. However, for the experimental conditions employed a delay of 140s was observed before the desired 1 $cm^3\ s^{-1}$ flow rate was reached.

CONCLUSIONS

The continuing emergence of the mechatronics philosophy has opened many new avenues to research workers. Whilst most of these have yet to be exploited, the data shown in this paper serve to highlight the potential of a mechatronics approach to solid-liquid separation research. Now that the benefits of a computer controlled experimental rig have been proven, future work should realise the facility for constant pressure, constant flow and variable pressure/flow tests within one experimental apparatus. Suspensions can be introduced to a filter in a consistent manner through control of the delivery pressure, thus mimicking pumping operations. Ultimately, the approach taken here could lead to the development of intelligent controllers for filtration equipment, whereby data are acquired and interpreted in real time and then utilised to improve an ongoing separation process.

ACKNOWLEDGEMENT

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REFERENCES

1. C. Fraser and J. Milne, 1994, *Integrated Electrical and Electronic Engineering for Mechanical Engineers*, pp.1-7, McGraw-Hill, London.

2. D.R. Sperry, 1916, *Met. Chem. Eng.*, **15**, 198.

3. A. Rushton, 1976, *Filt. and Sep.*, **13** , 573.

4. S.A. Willmer, E.S. Tarleton and R.G. Holdich, 1995, *Proc. Filtech Conference*, pp.149-159, Filtration Society, Karlsruhe, Germany, October.

5. R.J. Wakeman, 1975, *Filtration Post-Treatment Processes*, Elsevier, Amsterdam.

6. E.S. Tarleton and D.L. Hancock, 1995, *Proc. Filtech Conference*, pp.117-126, Filtration Society, Karlsruhe, Germany, October.

7. E.S. Tarleton and D.L. Hancock, 1996, *Proc. IChemE Research Event*, Leeds, in press.

8. E.S. Tarleton and D.L. Hancock, 1995, *Proc. colloquium 'Innovations in manufacturing control through mechatronics'*, pp.63-65, IEE, Newport, UK, November.

9. C.A. Smith and A.B. Corripio, 1986, *Principles and Practice of Automatic Process Control*, pp.210-234, Wiley, New York.

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FIGURES AND TABLES

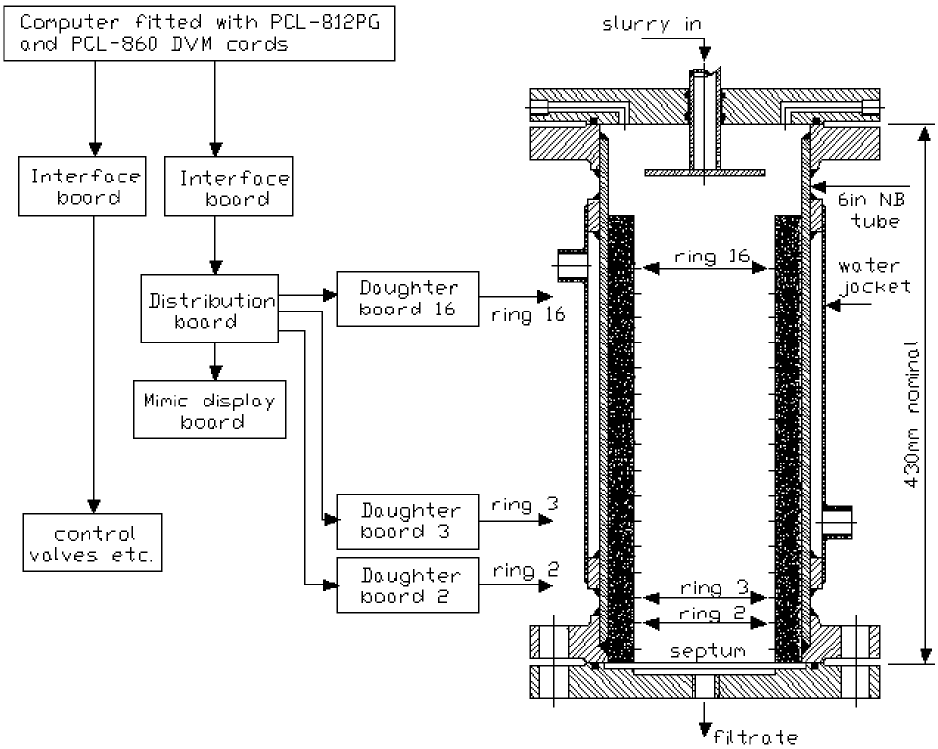

Figure 1: The pressure filter cell and a schematic diagram of the electrode control hardware.

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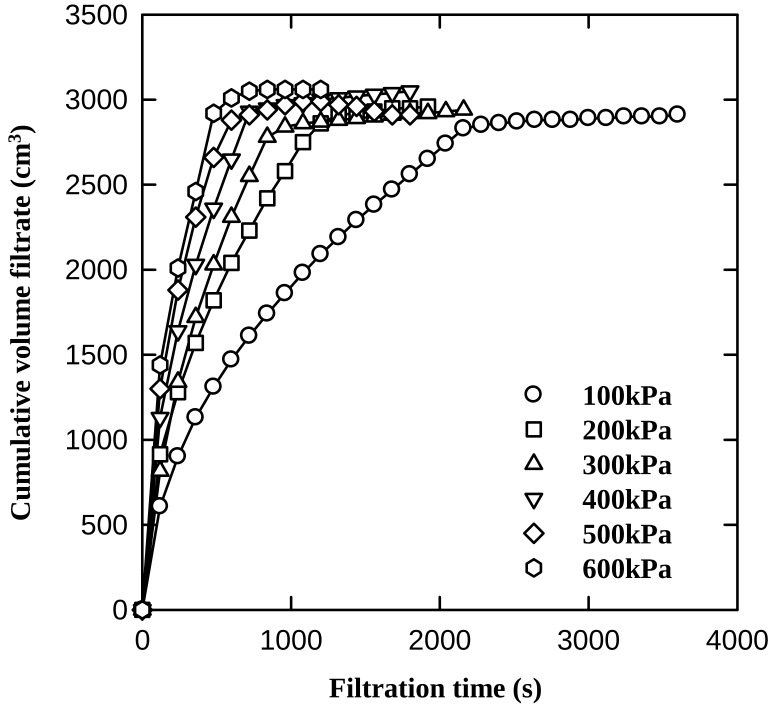

Figure 2: Cumulative volume vs. time for the filtration of 10% v/v calcite suspensions.

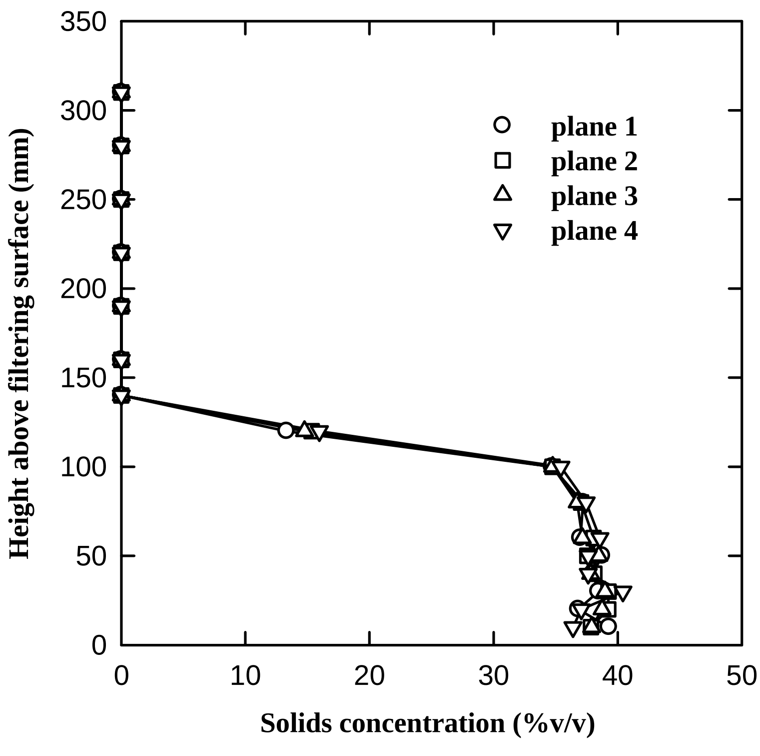

Figure 3: Solids concentration profiles during cake formation.

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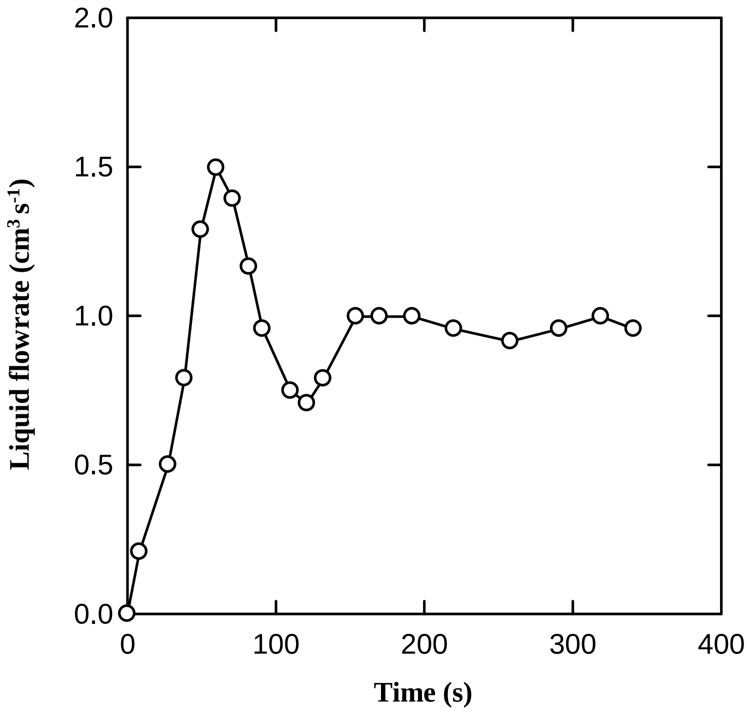

Figure 4: Proportional control of the filtration rig.

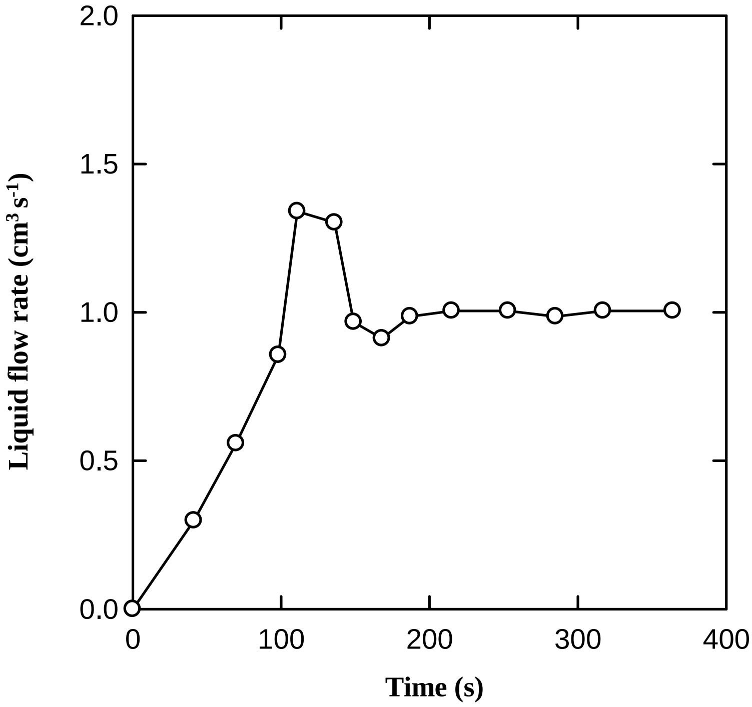

Figure 5: Proportional-integral-derivative control of the filtration rig.

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Controller type	Proportional gain	Integral gain	Differential gain
Proportional	1	-	-
PID	0.1	0.015	0.25

Table 1: Controller gains determined by Ziegler-Nicols method.

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