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Pressure filtration: Bench-scale evaluation and modeling using multivariable regression and Artificial Neural Network

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A B S T R A C T

Pressure filtration offers the opportunity to produce solids (filter cake) that can be stacked or mixed with the coarse refuse, and water (filtrate) that can be recirculated in the plant. In this study, the bench-scale pressure filtration testing was performed to dewater coal refuse slurry, which was obtained from the thickener underflow stream of a coal preparation plant, and was being discharged into a slurry impoundment. A flexible fractional factorial design was developed to determine the effects of pressure, pH, and solids concentration on the performance of filtration, which was measured in terms of filtrate flux. The results indicated that the pH had a maximum effect on the filtrate flux followed by the pressure and solids concentration. Additionally, a linear regression model and an Artificial Neural Network (ANN) model were developed to predict the filtrate flux based on the test variables. Both models were able to fit the data well, with R^2 values of 0.986 and 0.991 for the linear regression model and the ANN model respectively. It was also found that the test dataset had a mean squared error of 0.2 for the ANN model, while it was 3.99 for the regression model.

1. Introduction

Filtration is commonly used for dewatering across many industries such as biotechnology, chemical, food, brewing, ceramic, and mineral processing (Tarleton and Willmer, 1997). It has also been employed to treat waste water, process dairy products, remove macromolecules (e.g., proteins), and refine beer (Nimhurchu et al., 2006). In mineral processing, slurries are commonly dewatered using vacuum or pressure filters. In the latter case, filtration is carried out at pressures greater than atmospheric.

Since the failure of a coal slurry impoundment in Kentucky in 2000, where the dam failed and released about 300 million gal. of coal refuse slurry into the Big Sandy River, handling of coal refuse slurry has become one of the major interests in coal utilization in the U.S. (Lovan, 2010). Coal refuse slurry that is being directed to impoundments typically has about 20–30% solids (by weight), therefore it can be regarded as a candidate for pressure filtration, which has been used to dewater coal and coal refuse slurries under various conditions (Prat, 2012; Patwardhan et al., 2006; Verma and Klima, 2010; Klima et al., 2013). If the pressure filtration is implemented, the dewatered solids can often be stacked or combined with coarse refuse, while the recovered water could be recirculated in the plant. This not only reduces the surface area requirement for waste storage, but also reduces the overall water consumption of the plant. Thus, filtration can result in improved water conservation, minimized environmental impact, safer operation, and reduced area requirements for disposal (Alam et al., 2011).

In this study, an experimental design was developed to study the effects of applied pressure, slurry pH, and feed solids concentration on the filtration performance for dewatering of the thickener underflow slurry using a bench-scale unit. Meanwhile, the experimental data were then used to develop a linear regression model and an Artificial Neural Network (ANN) model.

2. Experimental approach

2.1. Sample acquisition and analyses

The coal slurry sample was obtained in twelve 5-gallon buckets from the thickener underflow of an operating bituminous coal cleaning facility in Pennsylvania, United States. To prepare the samples for the bench-scale testing, each 5-gallon bucket was circulated via a pump in a closed circuit, and sub-sampling was performed by collecting the slurry from the discharge line. These slurries were then used to determine the solids concentration, particle size distribution, ash values and sulfur contents of the samples. The slurry was dried overnight in a convection oven at approximately 100 °C, and the dried solids were wet screened on a 500 U.S. Mesh (25 μm) screen to separate the −25 μm particles. The +25 μm particles were dried overnight in the oven, and dry screened using a Ro-Tap sieve shaker. The −25 μm material was dried and sized down to 0.3 μm using a Microtrac S3500 particle size analyzer.

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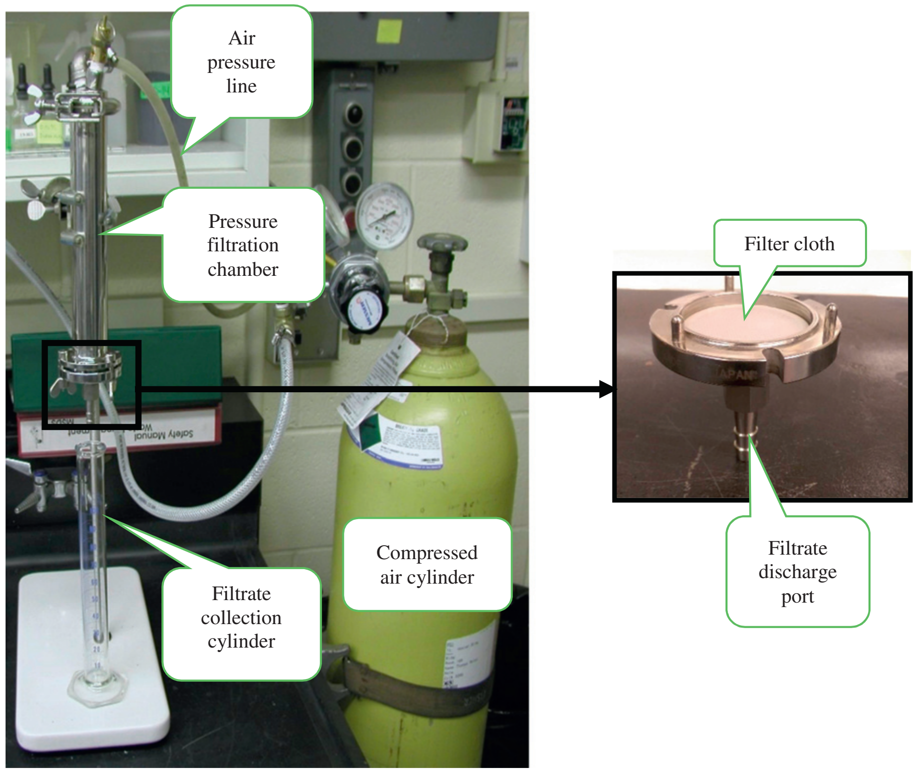

Fig. 1. Bench-scale pressure filtration setup.

The ash value for each sieve size fraction and the sulfur content of the total solids were determined.

2.2. Pressure filtration testing

The pressure filtration testing was performed using a bench-scale unit (Fig. 1). The unit consists of a stainless-steel pressure chamber, which is 203 mm (8 in.) long with a diameter of 35 mm (1.375 in.). The upper cap is attached to a compressed air cylinder, and the bottom cap contains the filtrate discharge port. Woven polypropylene cloth with a 120 μm pore size was used as the filter medium. This filter cloth is placed on a support screen, which retains the solids and supports the formation of the cake while passing the filtrate. The filtrate was collected in a graduate cylinder via the filtrate discharge port. The pressure regulator was set to the desired test pressure, with a maximum pressure of approximately 827 kPa (120 psi). It was observed that a 45 min filtration time was necessary, as ultrafine refuse particles typically offer higher resistance to moisture removal.

About 90 mL of slurry was used for each test. The slurry was mixed with a mechanical stirrer at 500 RPM for a minimum of 5 min. The pH of the slurry was adjusted during the mixing stage using 37% hydrochloric acid (HCl) or 5 M sodium hydroxide (NaOH) until the desired pH was attained. The slurry was then immediately transferred to the chamber followed by the closing of the upper cap. The pressure valve was then opened, and the filtrate was collected for about 45 min, continuously recording the filtrate volume as a function of time.

Table 1
Size, ash, and sulfur analyses of the feed material.

Size interval, μm	Weight, %	Total ash, %
+300	9.3	43.3
−300 + 150	16.5	36.3
−150 + 75	14.7	38.9
−75 + 37	14.5	42.6
−37 + 25	4.0	48.7
−25	41.0	66.6
Total	100	52.0
Sulfur form		**Sulfur, %**
Total		1.90
Pyritic		1.17
Sulfate		0.08
Organic		0.65

Table 2
Particle size distribution from sieve and Microtrac analysis.

Size (μm)	Cumulative % passing
841	100.0
595	99.2
400	95.8
300	90.7
210	82.7
150	74.2
105	66.2
75	59.5
53	48.4
37	45.0
25	41.0
18.5	40.8
13.1	39.7
9.3	36.9
6.5	32.3
4.6	27.0
3.3	21.7
2.3	16.5
1.6	11.9
1.2	7.9
0.82	5.0
0.58	3.0
0.41	1.6
0.29	0.6