Application of a Pilot-Scale Plate Filter Press in Dewatering Coal Slurries

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ABSTRACT

A plate filter press provides a potential option for dewatering ultrafine clean coal and refuse slurries, which could benefit plant operations through reduced product moistures, improved handleability of the dewatered products, and increased amount of water that is available for reuse in the cleaning facility. In this study, a series of tests was carried out with a pilot-scale plate filter press to evaluate its effectiveness in dewatering various coal slurries. The filter press consisted of a single set of 0.4 m × 0.4 m plates and was equipped with a hydraulic system, which operated the filter plates and feed pumps. Primary dewatering was carried out at a slurry feed pressure of approximately 860 kPa (125 psi) and additional dewatering was done using an air-blow system that provided compressed air of approximately 620 kPa (90 psi). The feed slurries were obtained from four bituminous coal cleaning facilities and included an effluent from a screen-bowl centrifuge dewatering a flotation product, a clean coal froth product, and three thickener underflow slurries. Filter cake moistures ranged from 20% for the clean coal product to approximately 30% for the thickener underflow material, though in one case, cake formation did not occur. Solids recoveries around 99% were obtained for all tests.

INTRODUCTION

Improved dewatering of both the clean coal and refuse material can provide various benefits to the plant operator. For example, when producing a clean coal product that must meet a specified heating value, a reduction in the product moisture content could be offset by increasing the amount of higher ash value material in the product so that the desired heating value is the same. This approach would increase the overall clean coal yield (Mohanty et al. 2012). In other cases, ultrafine material that was discarded because it could not be dewatered sufficiently could be recovered as a product, also increasing the clean coal yield. Likewise, refuse slurry could be dewatered to produce material that could be mixed with the coarser refuse for disposal. This would eliminate the need for a slurry impoundment and its potential environmental liabilities. Moreover, improved dewatering increases the amount of water that can be reused in the coal cleaning facility. The result is that less makeup water is needed and possible environmental effects associated with the treatment of additional water is reduced.

One technique with the potential for improving product dewatering is pressure filtration.

Pressure filtration involves separating solids from the liquid under pressures higher than atmospheric. The slurry is presented to a filter medium, which retains the dewatered solids (filter cake) while passing the liquid (filtrate). The pressure difference across the across the filter cake forces the filtrate from the slurry. The pressure is typically produced by pumping the slurry into the filter chamber. Typically, higher pressures will produce drier filter cakes; though for compressible filter cakes, higher pressures can decrease cake permeability, resulting in a lower filtration rate (Tiller 1975). In general, pressure filtration is used when dewatering slurries containing large percentages of ultrafine particles typically at feed solids concentrations greater than 10% solids (by weight). In the case of coal slurries, product moistures less than 25% are not unusual using a plate filter press (Patwardhan et al. 2006; Verma and Klima 2010a, 2010b).

Plate filter press operation is a batch process characterized by a total cycle time, which includes loading of the filter cavity with slurry, a ramping pressure period in which cake formation and filtrate production begin, constant pressure operation, and discharge of the cake. Prior to cake discharge, additional processing is often done to increase moisture removal. This may include the use of flexible membrane units that squeeze moisture from the cake, but this is more frequently accomplished through post-filtration air blowing. However, dewatering by air blowing may be limited by high capillary forces encountered with small pore sizes (Buscall and White 1987). Typically, air blowing is effective for cakes with permeabilities of 10^{-11} to 10^{-15} m^2 (Carleton and Salway 1993). The air must be applied at sufficient pressure so that the cake entry pressure is exceeded, at which point pore liquid is removed. Liquid in the pores first exits the cake through plug flow and then the remaining particle surface moisture is removed by the air. Evaporation effects are also present but desaturation by evaporation is often minimal unless given extensive blowing time, which is not typical in industry (Carleton and Salway 1993). After a period of blowing, an equilibrium or residual saturation is reached at which time the driving pressure differential and capillary forces of the cake are balanced so that an irreducible amount of moisture exists within the pores. The residual saturation is dependent on porosity as much as cake pore structure (Hosten and San 2002).

Large commercial plate filter press units may contain more than 100 plates, with plate areas over 2 m^2. Feed pressures can range from 700 kPa to well over 1,500 kPa. Moreover, a plate filter press minimizes or eliminates the need for additional flocculant as might be required for other pressure filtration devices (Prat 2012). In this study, the performance of a pilot-scale plate filter press was evaluated for dewatering bituminous coal slurries. This included slurries containing different amounts of −38 μm material and with a range of ash values and feed solids concentrations.

EXPERIMENTAL APPROACH

Sample Collection and Characterization

Slurry samples were obtained from four bituminous coal cleaning facilities located in the United States and Canada. Plant 1 samples were collected by plant personnel in 55-gallon drums from the effluent of a screen-bowl centrifuge, which had been thickened in a clean-coal thickener. The centrifuge was treating the clean coal product from a froth flotation circuit. Samples of the clean coal froth product were obtained from Plant 2 in 5-gallon buckets (Sample 2a) as well as from the thickener underflow (Sample 2b). Thickener underflow samples from the other two facilities were collected by plant personnel in 5-gallon buckets (Plant 3) and 55-gallon drums (Plant 4). At the laboratory, the material in each drum was mixed and then split into 5-gallon buckets to facilitate transferring the slurry to the filter press feed tank. The mixing/splitting approach ensured that the material in each bucket was representative of the entire drum. Each plant sample was characterized for solids concentration, size distribution, and ash values.

Filter Press Testing

Tests were carried out using a pilot-scale, plate filter press manufactured by Tecnicas Hidraulicas.

The filter press (Figure 1) consists of a 100-L feed tank with a variable-speed mixer, a set of two (0.4 m × 0.4 m) filter plates equipped with a hydraulic system for opening and closing the plates and powering diaphragm feed pumps, and a filtrate collection tank. Each plate is covered with a polypropylene cloth having a pore size of 0.051 mm. The filtrate collection tank is equipped with a conductivity probe, which can be raised or lowered to control the filtration time. The filtration time is the time during which the slurry is fed continuously to the filter press. The filtration cycle will stop if the probe is exposed before the maximum filtration time is reached, which would occur when the filtrate discharge rate decreases sufficiently. When the filtration cycle ends, compressed air at approximately 620 kPa is used to provide additional dewatering by blowing the air through the filter cake voids. The air-blow time can be adjusted as required. More detail on these operations can be found elsewhere (Verma 2009; Prat 2012).

For each test, the appropriate slurry sample was added to the feed tank in approximately 19-L batches. The operating variables, including maximum filter time and air-blow time, were set prior to the start of each test. For all tests, the conductivity probe height was lowered to the minimum height to maximize the filtration time. The filter plates were closed, and the feed pumps began filling the filter chamber. The filtrate began discharging into the collection tank. During the filtration cycle, the feed pressure was approximately 860 kPa. As the solids loading in the filter chamber increased, the filtrate rate decreased. The filter cycle ended either when the filter time was reached or when the filtrate rate decreased such that the conductivity probe was exposed in the collection tank. At that point, the air-blow cycle started and continued until the maximum air-blow time was reached. Prior to cake discharge, a valve was opened to drain slurry from the feed line to avoid diluting the filter cake during cake discharge. When the filter plates opened, the cake discharged by gravity, completing the cycle.

For each test, the filtrate was collected and weighed over timed intervals during the filter and air-blow cycles. The filter cake was collected and weighed. Samples of the filter cake were taken from several locations in the cake and were used for moisture determination.

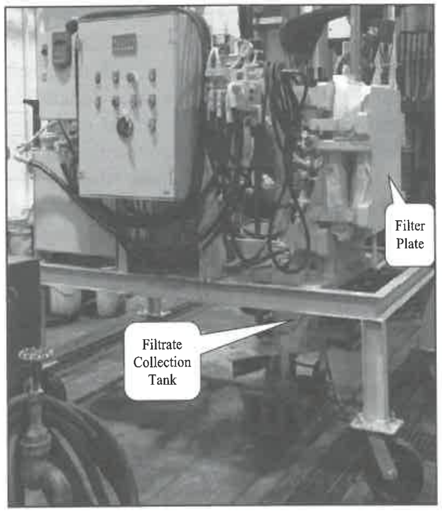

Figure 1. Pilot-scale plate filter press

RESULTS AND DISCUSSION

Sample Analyses

Table 1 summarizes the results from the size and ash analyses for the feed material. Plant 1 material (centrifuge effluent) had a solids concentration of 9.7% (by weight) and an ash value of 11.6% on a dry basis. Over 90% of the material was finer than 38 μm, which had an ash value of 11.7%. Plant 2a material (froth product) had a solids concentration of 17.5% and an ash value of 7.1%. Nearly 52% of the material was finer than 38 μm, which had an ash value of 10.6%. Plant 2b material (thickener underflow) had a solids concentration of 10% and an ash value of 45.6%. Approximately 84% of the solids were finer than 38 μm, which had an ash value of 45.7%. Plant 3 material (thickener underflow) had a solids concentration of 12.4% and an ash value of 54.3%. For this material, 70% of the material was finer than 38 μm, which had an ash value of 66%. Plant 4 material (thickener underflow) had a solids concentration of 22.8% and an ash value of 40.3%. Approximately 79% of the material was finer than 38 μm, though the ash value was 34.5%, which was lower than the other two underflow samples.

Table 1. Summary of the feed analyses and test results for the plant samples

Size Interval, μm	Plant 1		Plant 2 (Sample A)		Plant 2 (Sample B)		Plant 3		Plant 4	
	Wt.,%	Ash,%	Wt.,%	Ash,%	Wt.,%	Ash,%	Wt.,%	Ash,%	Wt.,%	Ash,%
+150	1.19	51.9	4.81	4.0	6.56	54.8	8.79	46.7	11.15	64.5
–150 + 75	1.93	7.35	22.67	2.8	3.39	58.3	9.26	20.0	5.95	62.0
–74 + 38	6.30	3.75	20.64	3.7	6.14	26.7	11.72	18.8	3.76	55.7
–38	*90.58*	*11.7*	*51.88*	*10.6*	*83.91*	*45.7*	*70.23*	*66.2*	*79.14*	*34.5*
Total	100	11.6	100	7.1	100	45.6	100	54.3	100	40.3
Feed solids concentration,%	9.7		17.5		10.0		12.4		22.8	
Filter cake moisture,%	25.3		20.4		29.5		NA*		29.3	
Unit capacity, kg/hr/m^2	146		245		49.6		NA*		161	

*No filter cake was formed.

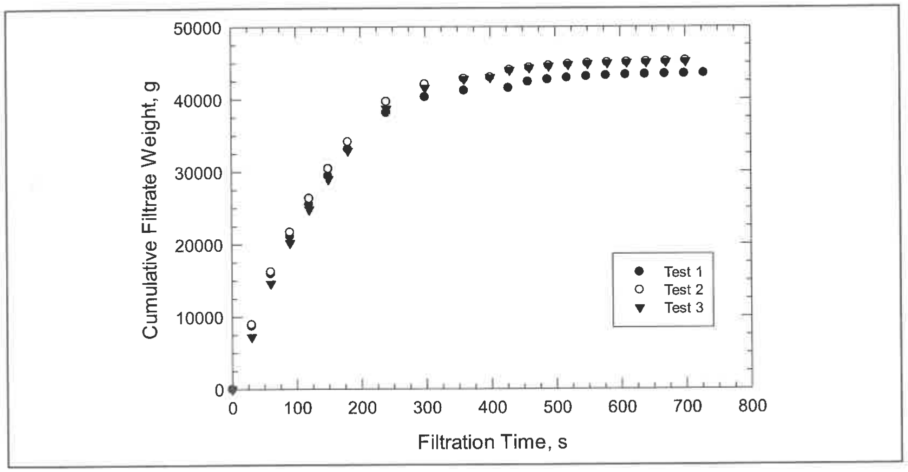

Figure 2. Reproducibility testing for Plant 1 material

Filter Press Testing

Plant 1

The screen-bowl effluent is currently being thickened and recycled in the plant, though this is being done inefficiently at best. Increased recovery of this material is desired as it has a relatively low ash value and could be sold as a coking coal if the moisture could be reduced sufficiently. Several tests were conducted with this material to evaluate different aspects of the filtration process. The normal filtrate and air-blow filtrate samples were collected in timed increments and then weighed. This process was repeated for two additional runs to evaluate the reproducibility of the process. These results are shown in Figure 2. Very similar results were obtained for all three tests. As expected, the rate of filtration was the greatest over the first 300 seconds and then decreased at the longer times. After 450 seconds, there was a slight increase in the filtration rate when the air-blow cycle started. Similar results were observed in previous testing using both anthracite and bituminous coal slurries (Verma and Klima 2010a, 2010b).

Figure 3 shows a typical filter cake for this material. The cake was approximately 50 mm thick, which was the depth of the filter cavity. The cake discharged easily from the filter cloth by gravity when the filter plates opened. At the start of the filter cycle, the filtrate was slightly turbid.

Figure 3. Filter cake using Plant 1 material

However, the clarity quickly improved as the solids collected on the cloth, with the cake acting as the filter medium.

Using the data from Test 1, an overall solids and water balance was performed. These results are shown in Table 2. The reconstituted solids concentration and ash values compare well with the values from the feed sample analysis given in Table 1. Approximately 99% of the total solids were recovered in the filter cake. This value is similar to those obtained in previous testing with this unit (Verma and Klima 2010a, 2010b). Analysis of the filtrate solids indicated that 89% of the material was finer than 25 µm and had an ash value of 13.5%, which was similar to the ash value of the feed solids.

Another filtration test was conducted, and the results were used to determine the change in cake moisture with time (Figure 4). As with the other tests, the recovered filtrate increased with increasing filter time, while cake moisture decreased (and the solids concentration increased). For example, the cake moisture decreased from 90% (10% feed solids concentration) to about 40% after the filter cycle ended at 450 seconds. During the air-blow cycle, additional filtrate was removed, reducing the final cake moisture to 25%.

The filter unit capacity was estimated by Equation 1.

Table 2. Solids and water balance for Plant 1 material

	Filter Cake	Filtrate (Filtration Cycle)	Filtrate (Air Blow Cycle)	Reconstituted Feed
Weight of Water, g	1626.6	41491	2011	45128.6
Weight of Solids, g	4757.4	55.3	1.3	4814.0
Distribution of Solids.%	98.82	1.15	0.03	100.00
Solids Concentration, wt.%	74.52	0.13	0.03	9.64*
Ash%, dry basis	11.19	12.75	65.01	11.22*

Size Interval, µm	Wt.,%	Ash,%
+150	0.81	39.55
+150–75	1.85	5.64
+75–38	6.89	3.86
+38–30	8.70	3.12
–30	81.75	12.78
Total	100.	11.41

*Values compare well with feed sample analysis.

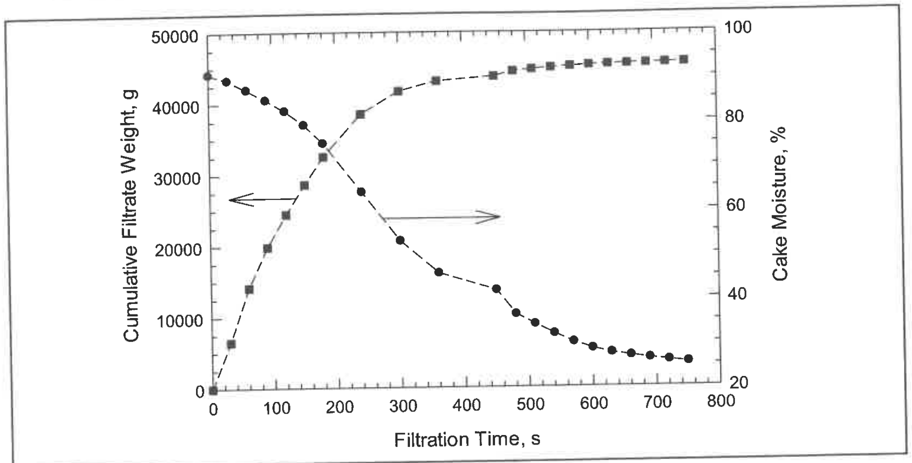

Figure 4. Variation of filtrate weight and cake moisture with filtration time for Plant 1 material

$$\text{Unit Capacity} = \frac{\text{Final Dry Cake Weight (kg)}}{\text{Cycle Time (hr)} \times \text{Filter Plate Area (m}^2\text{)}} \qquad (1)$$

The cycle time is the sum of the filter and air-blow times, which was 750 seconds for this test. This gave a unit capacity of 146 kg/hr/m^2. Higher unit capacities would be associated with higher filter cake moistures. For example, in a previous study using the same test unit, it was found that the unit capacity increased from 60 to 210 kg/hr/m^2 with an increase in filter cake moisture from 17% to 26% (Verma and Klima 2010a). In this case, anthracite slurry from a thickener underflow was processed. This material was 61% finer than 38 µm and had an ash value of almost 68%.

Plant 2

For the froth product material (Sample 2a), the filter cycle lasted for 176 seconds at which time the air-blow cycle began. This occurred because the flow of filtrate was very slow and essentially no material was being pumped into the filter cavity. The air-blow cycle continued for an additional 300 seconds. The filter cake discharged from the filter cloth with no difficulty and was very dry to the touch. There was less than a 1% loss of solids to the filtrate over the entire filter cycle. The final cake moisture was 20.4%, and the calculated unit capacity was 245 kg/hr/m^2. The high unit capacity was not surprising considering that this was a clean coal product and would be expected to dewater well.

For the thickener underflow material (Sample 2b), a very long filtration time was used to maximize water removal. After 40 minutes, the filter cycle stopped when the conductivity probe was exposed. The air-blow cycle continued for an additional seven minutes. Analysis of the filtrate indicated that that approximately 99% of the feed solids were recovered in the filter cake. After the air-blow cycle, the plates opened and the cake discharged by gravity with no difficulty.

Figure 5 shows the cake moisture as a function of air-blow time. Before the air-blow cycle began, the cake moisture was about 38%. At this point, the filter cycle ended due to the very low filtrate flow. However, during the air-blow cycle, additional filtrate was removed. After only 60 seconds, the cake moisture was reduced over four percentage points and nearly six percentage points after 120 seconds. An additional two percentage points of moisture were removed over the remainder of the air-blow cycle, and a final

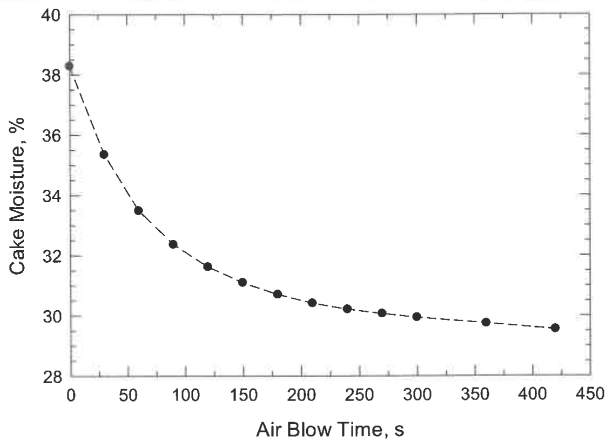

Figure 5. Variation of filter cake moisture with air blow time for Plant 2 (Sample 2b) material

moisture content of 29% was obtained. The unit capacity was 49.6 kg/hr/m^2 due to the relatively long cycle time.

Plant 3

For this material, no cake was formed during filtration. As the slurry was pumped into the filter chamber, the filter cloth became coated with a fine layer of solids, blinding the cloth and preventing filtration. This test was repeated and the same result occurred. Although only a thin film of solids was recovered, this material was dried, and the solids concentration was approximately 20% in both cases compared to 12.4% solids in the feed. In previous testing with this unit, filter cakes were formed in all cases (Verma and Klima 2010a, 2010b). It was likely that the presence of ultrafine clays in the Plant 3 material led to the filter cloth blinding, preventing filter cake formation.

Plant 4

A filter time of 720 seconds and an air-blow time of 120 seconds were used for this test. The recovered filtrate and cake moisture as a function of filtration time are shown in Figure 6. As was seen for the other tests, the filtration rate was the highest initially and then decreased at the longer times. As more filtrate was removed, the cake moisture decreased from 80% moisture to a final value of 29.3% after a total time of 840 seconds. Based on these results, the unit capacity was estimated to be 163 kg/hr/m^2, with an overall solids recovery of 98.5%.

Estimation of Filter Cake Moisture

In an attempt to estimate the moisture contents for the various filter cakes, a simple regression model was developed based on the percentage of –38 µm material in the feed and the corresponding ash value for the four tests in which a filter cake was produced. Another data point was also used, which was obtained from previous testing using the same filter press (Verma and Klima 2010b). The regression equation is given by

$$M = 0.174A + 0.115B + 9.694 \qquad (2)$$

where M is the filter cake moisture (%); A is the % of –38 µm in the feed material; and B is the ash value (%) of the –38 µm material. Figure 7 compares the actual and calculated moistures for the five tests. The fit was relatively good considering the variation in feed materials that were used. The adjusted r-squared value was 0.775. It has been shown that for some dewatering devices (i.e., screens, centrifuges, and vacuum filters) the product moisture could be related to the percentage of –75 µm material in the feed (Arnold 1999). Further work will be needed to develop better relationships between final cake moisture and properties of the material to be dewatered, taking into account, perhaps, particle shape and a measure for overall average particle size.

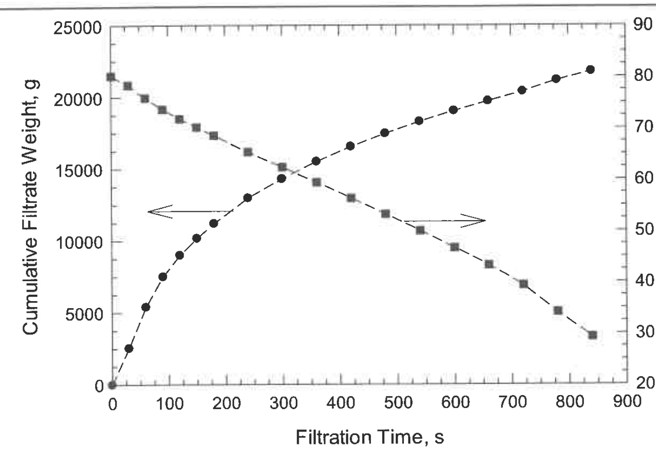

Figure 6. Variation of filtrate weight and cake moisture with filtration time for Plant 4 material

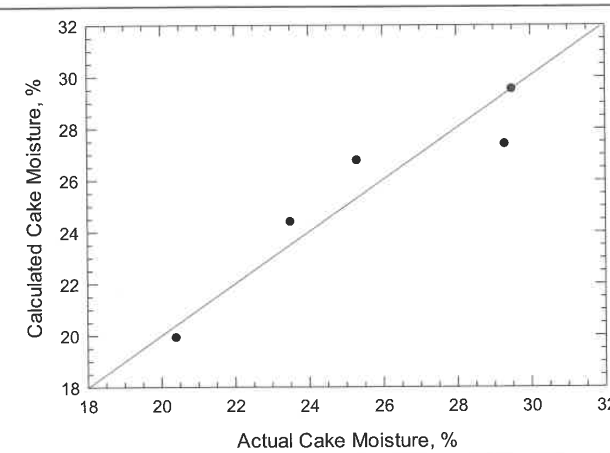

Figure 7. Comparison of the actual and calculated cake moisture contents

SUMMARY AND CONCLUSIONS

Five bituminous coal slurries were evaluated using a pilot-scale plate filter press. One sample was obtained from the effluent of a screen-bowl centrifuge, which was dewatering clean coal from a froth flotation circuit. Starting with a slurry solids concentration of 10%, a filter cake with approximately 42% moisture was obtained after a filter time of 400 seconds. Following an additional 300 seconds of air blowing, a final cake moisture of approximately 25% was obtained. Based on the dry cake weight and cycle time, a unit capacity of 146 kg/hr/m^2 was determined. The froth flotation product was dewatered to a final moisture content of 20.4% with a unit capacity of 245 kg/hr/m^2.

The other three coal slurries were obtained from thickener underflow streams at different processing facilities. For two of the samples (Plants 2 and 4), the final cake moistures were approximately 29%, with unit capacities of 49.6 and 163 kg/hr/m^2, respectively. On the other hand, a suitable cake could not be formed with the Plant 3 material. The type of clays in this material likely blinded the filter cloth, preventing cake build up and subsequent filtration. Overall it appears that a plate filter press provides an option for dewatering various clean coal and/or refuse slurries. This would benefit plant operations through reduced product moistures, improved handleability of the dewatered products, and an increased amount of water available for reuse in the cleaning facility. Moreover, additional chemical treatment would likely only be needed for materials that would blind the filter cloth.

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