ABSTRACT

Marble dust was separated from a water slurry at various constant feed pressures (40, 50, 60, 75, 80, and 90 psia) using a plate and frame filter.The volume of the remaining slurry mixture was recorded as a function of time for each trial run and plots of time/volume vs. volume were generated for each trial. The plots were then used to calculate the specific cake resistance and filter medium resistance for each trial. The filter medium resistance was determined to be 1.16×10^9, 6.24×10^9, 6.85×10^9, 7.47×10^9, 6.44×10^9, 6.32×10^9, and 6.59×10^9 ft^{-1} for 75, 40, 60, 80, 90, 50, and 50 psia, respectively. The specific cake resistance was determined to be 2.60×10^8, 1.01×10^8, 1.85×10^8, 2.72×10^8, 6.67×10^8, 2.24×10^8, and 1.86×10^8 for 75, 40, 60, 80, 90, 50, and 50 psia, respectively. The degree of compressibility was determined to be 0.9, which indicated that the cake filter was highly compressible.

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INTRODUCTION

Filtration is the removal of solid particles from a fluid through a filtering medium, or septum, on which the solids are deposited and the solids suspended in the mixture are retained by a porous filter which allows the cleared liquid to flow out of the filter.[1] It is a widely employed separation technique in industrial processes and these industrial filtrations range from simple straining mechanisms to highly complex separations. Fluid flows through a filter medium due to a pressure differential across the filter medium. The fluid flowing through a filter can be a gas or a liquid, and the valuable product of filtration may be the fluid recovered, the solids collected, both, or sometimes neither (for example, in the case of waste collection before disposal). In industrial filtration, solid content in the feed stream ranges from trace amounts to very high percentages.[1] Also, the feed may need to be modified by heating, recrystallization, or addition of filter aids to improve filtration rate. Many types of filters have been developed due to the wide variety of materials and different conditions needed for filtration processes.

At the start of cake filtration, solid particles are trapped when they enter the pores of the filter medium, as shown in Figure 1. Thereafter, the cake layer created in the filter performs the filtration, not the septum, hence the name cake filtration.[1] The pore size of the septum is usually smaller than the solid particle size to prevent solid from freely passing through the filter. Cake filters separate large amounts of solids as a cake of crystals or sludge which can often be

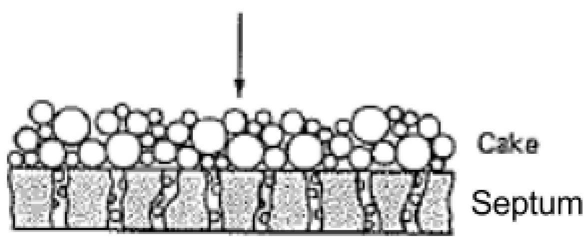

Figure 1: Mechanism of Cake Filtration[1]

collected and washed or dried by removing some of the liquid content from the solid before discharge.

Cake filtration can be carried out in a plate and frame filter press, which is a set of plates designed to provide a series of chambers where solid particles are collected as they pass through (Figure 2).[1] Plates contain a filter medium and, when slurry is pumped into the chambers under pressure, filtrate emerges from the medium and is discharged, while a wet cake of solids is left behind. Filtration continues until filtrate no longer flows out of the discharge or the filtration pressure suddenly rises, both occurring when the press is full of solid and no more slurry can pass through. The performance of the filter press can then be characterized by analyzing the flow rate of filtrate over time Cake filtration can be carried out in two modes: a constant-pressure mode where the feed pressure is held constant and the filter cake builds in the filter and increases the resistance to flow correspondingly and a constant-rate mode where the feed pressure is steadily increased to overcome increasing flow resistance to maintain a constant flow rate. This experiment investigates cake filtration under conditions of constant pressure to determine the

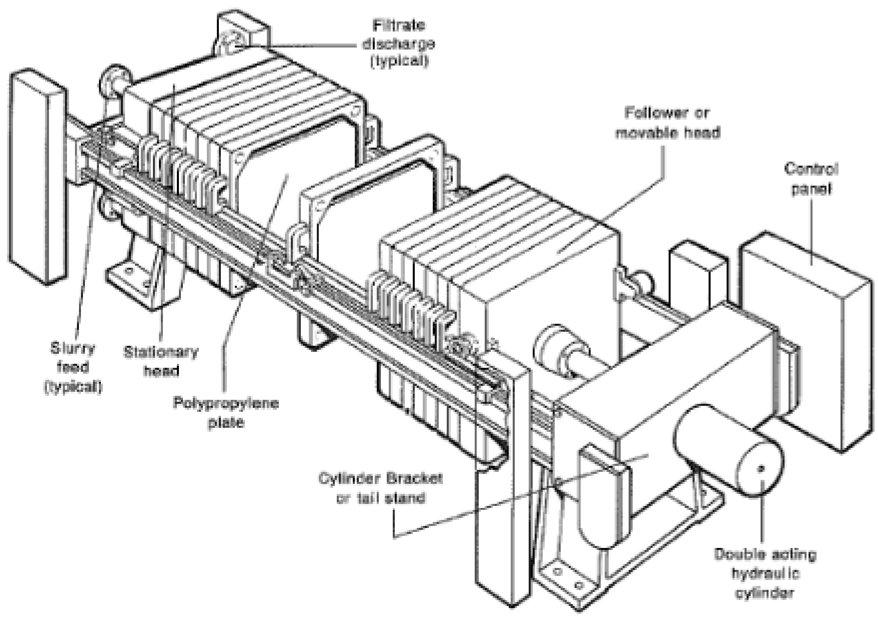

Figure 2: Parts and Assembly of a Filter Press[1]

filter medium resistance, specific cake resistance and compressibility coefficient.[2] Filter medium resistance is the resistance to the flow of feed through the filter provided by the filter medium alone before build up of cake while specific cake resistance expresses the resistance provided by the filter cake as a function of particle shape, mean particle size, polydispersity, cake porosity and particle density.[3] The degree of compressibility is a measure of how compressible a filter cake is on a scale of 0 to 1, with 0 meaning incompressible and 1 meaning very compressible.

In cake filtration, resistance to flow occurs because of the filter medium and the cake layer. The filter resistance remains constant throughout and once a cake layer is formed, the cake is responsible for most of the filtration. The cake resistance increases with increasing cake layer thickness, from an initial thickness of zero. The estimated drop in pressure across the cake can be determined by considering the fluid flow through a bed of solids. The individual channels through which feed flows through the filter cake are approximated to be straight tubes. This flow is modelled by the Hagen-Poiseuille equation[1] (i) for laminar flow through straight tubes:

$$\frac{\Delta p}{L} = \frac{32 v \mu}{g_c D^2} \qquad \text{(i)}^1$$

where:
Δp = the pressure drop across the bed of solids (lb_f/ft^2)
L = length (ft)
v = average fluid velocity (ft/s)
μ = absolute viscosity (lb/ft-s)
g_c = gravitational constant (32.174 ft-lb_m/lb_f-s^2)
D = tube diameter (ft)

Further development[1] of this equation by using the average fluid velocity, the nominal particle diameter and a correction factor, *K,* applied to the pressure drop through a filter cake result in the following relationship:

$$\frac{dp}{dL} = \frac{K\mu u(1-\varepsilon)^2(s_p/V_p)^2}{g_c\varepsilon^3} \qquad \text{(ii)}^{1}$$

Where:
dp/dL = the pressure gradient at cake thickness L
u = the linear velocity of the filtrate, based on filter area (ft/s)
ε = the porosity of the cake
s_p/V_p = specific surface area of a single particle (ft^{-1})

The linear velocity u is given by the following equation:

$$u = \frac{dV/dt}{A} \qquad \text{(iii)}^{1}$$

Where
t = time (s)
V = volume of filtrate collected from start of filtration to time, t (ft^3)
A = Area of the filter(ft^2)

Since the filtrate passes through the entire cake, V/A is the same for all layers of cake along L and thus u is independent of L. The volume of solids in the layer is A(1-ε)dL[1], and mass of solids is dm in each dL layer of cake

$$dm = \rho(1-\varepsilon)AdL \qquad \text{(iv)}$$

Where ρ= density of particles

Using (iv) to eliminate dL from (ii) gives the following equation:

$$dp = \frac{K\mu u(1-\varepsilon)(s_p/V_p)^2}{\rho A g_c\varepsilon^3}dm \qquad \text{(v)}$$

All the factors on the right-hand side of (v) except m are independent of L and therefore (v) is integrable directly, over the thickness of the cake.[1] Taking m_c to be the total mass of solids in the cake, and integrating the left side of (v) over the pressure drop across the cake, Δp_c and the right hand side from 0 to m_c

$$\int_{p_0}^{p_0+\Delta p_c} dp = \frac{K\mu u(1-\varepsilon)(s_p/V_p)^2}{\rho A g_c \varepsilon^3} \int_0^{m_c} dm \quad \text{(vi)}$$

This integration yields the pressure drop across the cake, Δp_c

$$\Delta p_c = \frac{K\mu u(1-\varepsilon)(s_p/V_p)^2 m_c}{\rho A g_c \varepsilon^3} \quad \text{(vii)}$$

The structure of the bed of solids determines the compressibility of the filter cake.

Incompressible cakes have a resistance that is independent of filtration pressure, thus a specific cake resistance for incompressible cakes may be defined as:

$$\alpha \equiv \frac{\Delta p_c g_c A}{\mu u m_c} \quad \text{(viii)}^2$$

$$\text{Where } \alpha = \frac{K(1-\varepsilon)(s_p/V_p)^2}{\rho \varepsilon^3} \quad \text{(ix)}^2$$

Defining a pressure drop across the filter medium Δp_m, the filter-medium resistance R_m[1] can be defined as:

$$R_m \equiv \frac{\Delta p_m g_c}{\mu u} \quad \text{(x)}^1$$

When R_m is treated like an empirical constant, it also includes resistance to flow that may exist in pipes leading to and from the filter. The total pressure drop then becomes:

$$\Delta p_c + \Delta p_m = \frac{\mu u}{g_c}\left(\frac{m_c \alpha}{A} + R_m\right) \quad \text{(xi)}^1$$

It is convenient to express the linear velocity of the filtrate, *u* as a function of V, using equation (iii). Also, if c is the mass of particles deposited in the filter per unit volume of filtrate, the mass of solids in the filter at time *t* is the product of V and c. Thus,

$$m_c = V^*c \qquad \text{(xii)}^1$$

Substituting these relations for *u* and m_c into (xi) gives

$$\frac{dt}{dV} = \frac{\mu}{Ag_c\Delta p}\left(\frac{\alpha c V}{A} + R_m\right) \qquad \text{(xiii)}$$

For constant pressure filtration, the only variables in (xiii) are *V* and *t*. When t = 0, V = 0 and $\Delta p = \Delta p_m$, (xiii) becomes

$$\left(\frac{dt}{dV}\right)_0 = \frac{\mu R_m}{Ag_c\Delta p} = \frac{1}{q_0} \qquad \text{(xiv)}^1$$

Equation (xiii) can therefore be written as:

$$\frac{dt}{dV} = K_c V + \frac{1}{q_0} \qquad \text{(xv)}^2$$

Where: $$K_c = \frac{\mu c \alpha}{A^2 \Delta p_c g_c} \qquad \text{(xvi)}^1$$

When (xv) is integrated for constant pressure conditions, between the limits (0,0) and *(t,V)* the following relationship is obtained:

$$\frac{t}{V} = \left(\frac{K_c}{2}\right)V + \frac{1}{q_0} \qquad \text{(vii)}^2$$

Therefore, a plot of t/V versus V may be developed from the t-V data collected during each cake filtration experiment and the specific cake resistance (α) and the filter medium resistance (R_m) may be calculated from the slope and intercept values.

For incompressible cakes, empirical equations such as (viii) below may be fitted to data obtained

.

$$\alpha = \alpha_0(\Delta p_c)^s \qquad \text{(viii)}^{1}$$

Where s = the compressibility coefficient

s and α_0 are empirical constants. The compressibility coefficient is zero for incompressible cakes and positive for compressible ones, typically between 0.2 and 0.8.[1] From the calculated values of alpha, a plot of log(α) vs. log(Δp_c) can be made developed to give s as the slope of the trendline obtained.

EXPERIMENTAL PROCEDURE

The feed tank (Sii Snyder #997176) was filled with water and approximately 112 lb of marble dust (10% marble on a w/w basis). Since the filtrate collection tank was slightly filled at the start, some of the filtrate from the feed tank went into the drain to avoid overfill of the filtrate collection tank. The filter apparatus, as seen in Figure 3, was arranged in an alternating sequence the one and three dot plates to ensure proper alignment of the filter.[2] Once the plates were aligned with one another, the hydraulic ram was pumped to approximately 4000 psi to seal the filter.

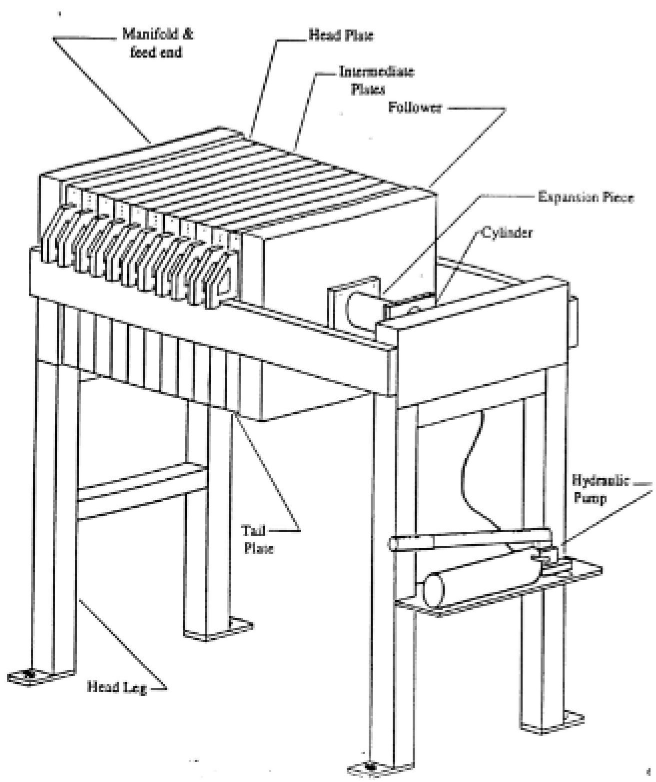

Figure 3 - Diagram of the filter apparatus[2]

The feed tank valve was then opened and the three way valve was set to point towards the feed stream. The inlet valve to the filter was opened, and the pneumatic filter feed pump was set to about 25 psi and run for about two minutes to release all the discharge from the filter run. Then, the bottom manifold valves were opened and the feed pressure was set to the desired value. The time and level of the feed tank were measured initially and at 30-60 second intervals. Data were collected until the feed level was down to 10-20 cm, then the pump was turned off and the filter inlet and feed tank discharge valves were closed. The manifold valves were closed except for the bottom manifold valve closest to the filter feed pump. The air supply was slowly opened to blow down the filter and discharge liquid in the filter assembly.

The filter cake was collected in a tray by releasing the pressure from the hydraulic ram and then carefully removing the filter cake from the plates. The filter cake and tray were weighed, and then three small samples of the filter cake were taken and weighed. These samples were weighed again after letting them dry for 24 hours in an oven.

The remaining filter cake was mixed into the filtrate collection tank, which is now the feed tank for the next run. The filter and filter assembly was rinsed and the experiment was repeated for another desired feed pressure.

RESULTS

With the filter at a hydraulic pressure of 4000 psi, eight experiments were done: 40, 50, 60, 75, 80, and 90 psia. Three experiments were performed at 50 psia since the first 50 psia experiment had poor results and two more trials were deemed necessary. The data for the changes in volume with time during each experiment was recorded at regular intervals and are presented in Appendix I.

A sample analysis and calculation of the data on Trial 4, which had a desired feed pressure of 60 psi, is shown in this section. The area of the tank from the tank diameter was first calculated. The diameter of $35\,\frac{6}{16}$ inches was converted to ft and then used to calculate the area:

$$\textit{area of tank} = \textit{diameter}^2/4 \, * \, \pi \, = \, 6.83\,ft^2$$

The volume displaced was then calculated from area of tank* height displaced.

For example, at 60 seconds, volume displaced= $6.83\,ft^2 \, * 0.30\,ft = 2.02\,ft^3$. Then t/V was calculated in seconds/ft^3, and the data tables for each trial can be found in Appendix I.

A plot of t/V vs Volume was generated from the data, and a linear regression was performed.

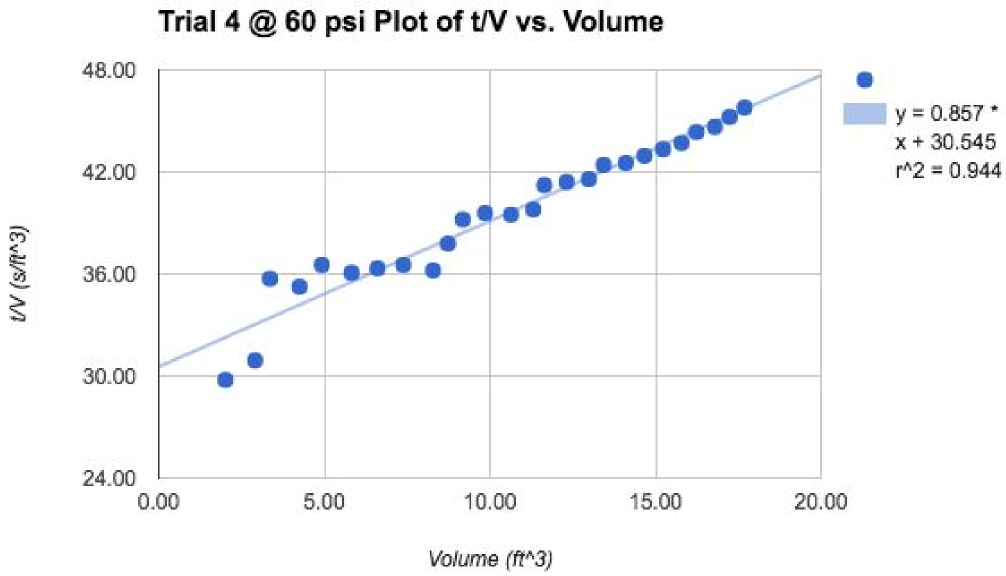

Figure 4: Plot of t/V vs Volume for Trial 4

From the linear regression, the slope and intercept were determined; the slope should be $\frac{Kc}{2}$ and the intercept should be $\frac{1}{q_0}$. K_c can then be used to find α (the cake resistance) and $\frac{1}{q_0}$ can be used to find R_m (the filter resistance). In this sample calculation, $\frac{Kc}{2}$ = 0.857 s/ft^6 and $\frac{1}{q_0}$ =30.545 s/ft^3 from the trendline.

From the marble cake recovered in the experiments, samples were weighed and used to determine the moisture content of the cake, shown in Appendix III, and the weight of the dried cake was determined for each trial. Then using the total volume displaced, the mass of particles deposited in the filter per unit volume of filtrate, c (dry cake density), was determined.

Sample calculation for Trial 4:

$$weight\ of\ cake = weight\ of\ wet\ cake * (1 - \%\ moisture) = 32\ lb * 0.780 = 24.96\ lb$$

$$c = weight\ of\ cake\ /\ volume\ displaced$$

$$c = 24.96\ lb\ /\ 17.69\ ft^3 = 1.41\ lb/ft^3$$

The rest of the data for weight of cake and c data for each trial can be found in Appendix III.

The pressure drop for each trial was determined by subtracting the atmospheric pressure from the desired pressure and then converting to pounds per square foot. A sample calculation of this for Trial 4 is as follows:

$$pressure\ drop = desired\ pressure - atmospheric\ pressure$$
$$\Delta P = 60\ psi - 14.7\ psi = 45.3\ psi\ (144\ in^2/ft^2) = 6.52 * 10^3 lb/ft^2$$

Next, the viscosity of the filtrate needed to be calculated, and the filtrate temperature was 73F. From this, the viscosity at 73F could be interpolated from viscosities of 70F and 80F, found in a Properties Table of Liquid Water.[2]

$$\frac{(\mu - .982)}{(.862 - .982)} = \frac{73-70}{80-70}$$
$$\mu = 0.946\ cP$$
$$\mu = 0.946\ cP * (6.72 * 10^{-4}\ (lb/ft-s)/\ cP) = 0.000636\ lb_f/ft-s$$

Then, knowing all the other variables except for alpha, alpha can be determined:

$$K_c = \frac{\mu c \alpha}{A^2 \Delta p g_c}$$
$$0.857\ s/ft^6 * 2 = \frac{(0.000636\ lb_f/ft-s)(1.4109\ lb/ft^3)\alpha}{(0.461\ ft^4)(6523.8\ lb/ft^2)(32.174\ ft-lb/lb_f-s^2)}$$
$$\alpha = 1.85 * 10^8\ ft/lb$$

R_m can also be determined:

$$\frac{1}{q_0} = \frac{\mu R_m}{A \Delta P g_c}$$
$$30.545\ s/ft^3 = \frac{(0.000636\ lb_f/ft-s)R_m}{(0.679\ ft^2)(6523.8\ lb/ft^2)(32.174\ ft-lb/lb_f-s^2)}$$
$$R_m = 6.85 * 10^9 ft^{-1}$$

Table 1: Summary of Trial Results

Trial	Desired Pressure Feed (psi)	Slope $K_c/2$	Intercept $\frac{1}{q_0}$	R_m	α
2	75.79	0.505	38.925	1.16E+10	2.60E+08
3	40	1.2	49.801	6.24E+09	1.01E+08
4	60	0.857	30.545	6.85E+09	1.85E+08
5	80	0.861	23.12	7.47E+09	2.72E+08
6	90	1.18	17.279	6.44E+09	6.67E+08
7	50	0.892	36.182	6.32E+09	2.24E+08
8	50	0.679	37.724	6.59E+09	1.86E+08

(Trial 1 data was omitted, which will be explained in discussion section.)

A few outliers were present in the data since the R_m value in trial 2 was a larger order than the other R_m values and α in trial 7 was larger than the other α values.

Plotting log of alpha against log of the pressure drop from all the trials, the following graph was generated and a linear regression was determined.

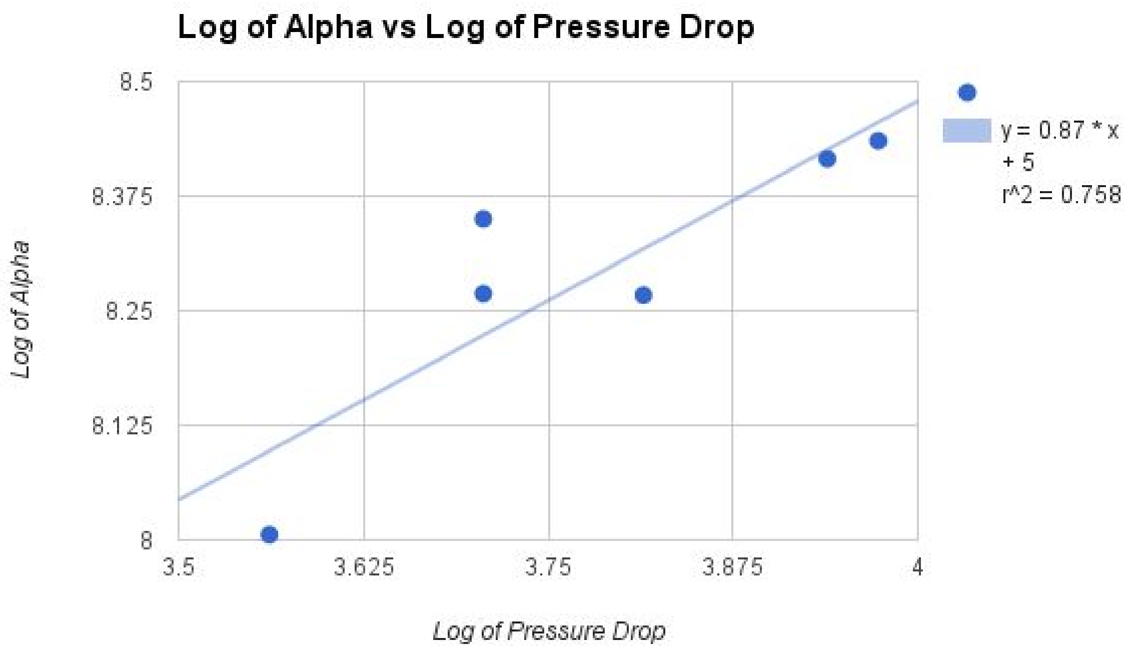

Figure 5: Log of Alpha vs Log of Pressure Drop

The slope of the trendline indicates the compressibility coefficient, s, which was approximately 0.9.

DISCUSSION

It should be noted that the data obtained from the first trial were ignored since the data were very scattered; this could be because Trial 1 was the first run and the data recorded did not accurately represent the trial, see Appendix I and II for data. Plots of time per unit volume against volume obtained for subsequent trials (II to VIII) showed a generally positive linear relation with high R^2 values and a range R^2 between 0.649-0.944. This indicates a strong linear correlation between t/V and volume. At higher volumes, the plots all appear fairly linear than at lower volumes where deviations from the linear nature are seen. This could be a result of the changing resistance and cake buildup happening at low volumes being passed through the filter happening in a nonlinear manner while at higher volumes the cake buildup occurs at a slower rate due to the amount already collected, allowing for a linear relationship to be seen. Deviations from linearity may occur since the beginning of filtering does not have a linear correlation, and this may result in an overall lower R^2 value for some of the experimental trials.

From the plots of time per unit volume against volume (Appendix II), the slopes and intercepts of the plots were used in calculations to find the filter medium resistance, R_m, and the specific cake resistance, α, respectively. A summary of these results are seen in Table 1 in the results section. From the data and plots of cake resistance against pressure (Appendix IV) it can be seen that cake resistance increases linearly with pressure with a strong correlation coefficient. A plot of filter medium resistance against pressure (Appendix IV) also showed a strong linear correlation with an outlier at Trial VI at 90 psi. This was the highest pressure used during the experiment and more fluctuations were seen in the pressure reading when set to 90 psi.

From the calculations in the above section, the compressibility coefficient s for the marble slurry was found to be 0.87. The typical values of s range from 0.2 to 0.8, while a true incompressible cake should yield have an s value of 0. The compressibility coefficient is at the higher end of the expected range, and this may be due to errors within the lab. The results indicate that the cake is not incompressible ($s \neq 0$), which is to be expected from literature value of the compressibility factor of marble slurry[1] which falls within the range of compressibility and also from the material properties of marble dust.

The numerous sources of errors in this lab might explain the deviation of the calculated compressibility coefficient from the typical range of the compressibility coefficient for $CaCO_3$. One source of error was the presence of water in the sampled and weighted filter cake. After filtration and air blow down of the filter cake in some trials, a significant amount of water collected around the bottom of the tray and the samples taken may not have been an accurate representation of the filter cake moisture content. Also during data collection of the volume of slurry in the tank, the stirring action of the mixer caused a degree of uncertainty in the recorded data by causing the liquid level to wobble during measurements. Also, the opaque tanks made it difficult to read the liquid level during data collection and could have been a source of errors. In measuring the total weight of cake collected, a balance scale was used which isn't the most accurate way of determining the weight of the filter cake collected. Finally, during experimentation, the pressures were not constant at our desired pressures, but rather they were fluctuating by ± 5 psia, and this could lead to some inaccuracies with the data collected.

RECOMMENDATIONS

For future work, a recommendation would be to try to reduce the water level fluctuation, since the stirring sometimes caused the level to fluctuate and it was hard to record an accurate reading of the level. Decreasing the mixer speed had still resulted some fluctuation in the level in the tank. The exact height was also sometimes hard to determine due to the coloring of the tank so a clear tank may result in more accurate results. Another recommendation would be to see if there is a way to make the desired pressure fluctuate less, as the pressure would not be able to stay at a certain set point rather it would fluctuate back and forth that set point. A procedural issue that occurred was during blowdown. It was hard to determine when the blow down was complete, and the blowdown is not supposed to be for too long or the cake will dry out. The cake had dried out once in this experiment's trials, but there were times that liquid was still in the apparatus and not completely flushed out. Another recommendation is to ensure that the trays are properly aligned to prevent leakage as there was leakage even though the trays were thought to be aligned. Lastly, an equipment modification may be larger tank sizes so more volume will be able to pass through the filter, and the pump may then stop by itself. These trials were manually stopped due to the marble dust slurry reaching a low level in the tank.

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4.

APPENDIX I

Data from all the Trials

Table 2: Trial 1 Data @ 50 psi

Time(sec)	Height (cm)	Slurry displaced (cm)	Height (ft)	Volume Displaced(ft^3)	t/V (s/ft^3)
0	97	0	0	-	-
80	90	7	0.23	1.57	51.04
180	83	14	0.46	3.13	57.42
240	78	19	0.62	4.25	56.41
300	73	24	0.79	5.37	55.82
360	67	30	0.98	6.72	53.59
422	62	35	1.15	7.84	53.84
477	58	39	1.28	8.73	54.62
539	52	45	1.48	10.08	53.49
576	48	49	1.61	10.97	52.50
623	46	51	1.67	11.42	54.55
671	42	55	1.80	12.32	54.48
720	37	60	1.97	13.44	53.59
774	32	65	2.13	14.56	53.18
805	30	67	2.20	15.00	53.66
844	28	69	2.26	15.45	54.62
876	27	70	2.30	15.67	55.89

Table 3: Trial 2 Data @ 75 psi

Time (sec)	**Slurry displaced (cm)**	**Height (cm)**	**Height (ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
17	0.00	69.00	0.00	0.00	
40	4.00	65.00	0.13	0.90	44.66
60	6.00	63.00	0.20	1.34	44.66
95	10.00	59.00	0.33	2.24	42.42
120	13.00	56.00	0.43	2.91	41.22
160	18.00	51.00	0.59	4.03	39.70
180	20.00	49.00	0.66	4.48	40.19
210	24.00	45.00	0.79	5.37	39.08
230	26.00	43.00	0.85	5.82	39.50
250	28.00	41.00	0.92	6.27	39.87
270	29.00	40.00	0.95	6.49	41.58
300	33.00	36.00	1.08	7.39	40.60
330	36.00	33.00	1.18	8.06	40.94
360	38.00	31.00	1.25	8.51	42.31
380	40.00	29.00	1.31	8.96	42.42
400	43.00	26.00	1.41	9.63	41.54
420	44.00	25.00	1.44	9.85	42.63
450	47.00	22.00	1.54	10.52	42.76
480	49.00	20.00	1.61	10.97	43.75
510	51.00	18.00	1.67	11.42	44.66
645	58.00	7.00	1.90	12.99	49.66
696	66.00	15.00	2.17	14.78	47.09
774	73.00	22.00	2.40	16.35	47.35
800	75.00	24.00	2.46	16.79	47.63
840	78.00	27.00	2.56	17.47	48.09
870	81.00	30.00	2.66	18.14	47.97

900	83.00	32.00	2.72	18.59	48.42
930	86.00	35.00	2.82	19.26	48.29
990	90.00	39.00	2.95	20.15	49.12
1050	93.00	42.00	3.05	20.83	50.42
1110	98.00	47.00	3.22	21.94	50.58
1170	103.00	52.00	3.38	23.06	50.73
1230	107.00	56.00	3.51	23.96	51.34
1290	112.00	61.00	3.67	25.08	51.44
1350	115.00	64.00	3.77	25.75	52.42
1410	120.00	69.00	3.94	26.87	52.47
1470	123.00	72.00	4.04	27.54	53.37
1590	132.00	81.00	4.33	29.56	53.79
1650	135.00	84.00	4.43	30.23	54.58
1680	138.00	87.00	4.53	30.90	54.37

Table 4: Trial 3 Data @ 40 psi

Time (sec)	**Height (cm)**	**Slurry displaced (cm)**	**Height (ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	78.00				
60	73.00	5.00	0.16	1.12	53.59
120	67.50	10.50	0.34	2.35	51.04
180	62.00	16.00	0.52	3.58	50.24
240	58.50	19.50	0.64	4.37	54.96
300	54.50	23.50	0.77	5.26	57.01
360	50.50	27.50	0.90	6.16	58.46
420	46.00	32.00	1.05	7.17	58.61
480	42.00	36.00	1.18	8.06	59.54
540	39.00	39.00	1.28	8.73	61.83
660	31.00	47.00	1.54	10.52	62.71

720	28.00	50.00	1.64	11.20	64.31
780	22.00	56.00	1.84	12.54	62.20
840	20.00	58.00	1.90	12.99	64.68
900	18.00	60.00	1.97	13.44	66.99
960	14.00	64.00	2.10	14.33	66.99

Table 5: Trial 4 Data @ 60 psi

Time (sec)	**Height (cm)**	**Slurry displaced (cm)**	**Height (ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	97.00				
60	88.00	9.00	0.30	2.02	29.77
90	84.00	13.00	0.43	2.91	30.92
120	82.00	15.00	0.49	3.36	35.73
150	78.00	19.00	0.62	4.25	35.26
180	75.00	22.00	0.72	4.93	36.54
210	71.00	26.00	0.85	5.82	36.07
240	67.50	29.50	0.97	6.61	36.33
270	64.00	33.00	1.08	7.39	36.54
300	60.00	37.00	1.21	8.29	36.21
330	58.00	39.00	1.28	8.73	37.79
360	56.00	41.00	1.35	9.18	39.21
390	53.00	44.00	1.44	9.85	39.58
420	49.50	47.50	1.56	10.64	39.49
450	46.50	50.50	1.66	11.31	39.79
480	45.00	52.00	1.71	11.64	41.22

510	42.00	55.00	1.80	12.32	41.41
540	39.00	58.00	1.90	12.99	41.58
570	37.00	60.00	1.97	13.44	42.42
600	34.00	63.00	2.07	14.11	42.53
630	31.50	65.50	2.15	14.67	42.95
660	29.00	68.00	2.23	15.23	43.34
690	26.50	70.50	2.31	15.79	43.71
720	24.50	72.50	2.38	16.23	44.35
750	22.00	75.00	2.46	16.79	44.66
780	20.00	77.00	2.53	17.24	45.24
810	18.00	79.00	2.59	17.69	45.79

Table 6: Trial 5 Data @ 80 psi

Time (sec)	**Height (cm)**	**Height Displaced(ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	95.00	0.00		
30	89.00	0.20	1.34	22.33
60	84.00	0.36	2.46	24.36
90	79.00	0.52	3.58	25.12
120	74.00	0.69	4.70	25.52
150	72.00	0.75	5.15	29.12
180	68.00	0.89	6.05	29.77
210	64.00	1.02	6.94	30.25
240	61.00	1.12	7.61	31.52
270	56.00	1.28	8.73	30.92

300	53.00	1.38	9.40	31.90
330	48.00	1.54	10.52	31.36
360	46.00	1.61	10.97	32.81
390	43.00	1.71	11.64	33.49
420	41.00	1.77	12.09	34.73
450	37.00	1.90	12.99	34.65
480	34.50	1.98	13.55	35.43
510	31.00	2.10	14.33	35.59
540	28.00	2.20	15.00	35.99
570	25.00	2.30	15.67	36.36
600	21.00	2.43	16.57	36.21
630	19.00	2.49	17.02	37.02
645	17.00	2.56	17.47	36.93

Table 7: Trial 6 Data @ 90 psi

Time (sec)	**Height (cm)**	**Height Displaced(ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	84.00	0.00		
9	79.00	0.16	1.12	8.04
35	75.00	0.30	2.02	17.37
60	71.00	0.43	2.91	20.61
84	69.00	0.49	3.36	25.01
105	65.00	0.62	4.25	24.68
120	62.00	0.72	4.93	24.36
140	60.00	0.79	5.37	26.05
160	58.00	0.85	5.82	27.48
180	54.00	0.98	6.72	26.79
200	52.00	1.05	7.17	27.91
220	49.50	1.13	7.73	28.48
240	47.00	1.21	8.29	28.97
260	44.00	1.31	8.96	29.03
300	38.00	1.51	10.30	29.12
320	35.00	1.61	10.97	29.16
340	33.00	1.67	11.42	29.77
360	30.00	1.77	12.09	29.77
380	27.00	1.87	12.76	29.77
400	25.00	1.94	13.21	30.28

Table 8: Trial 7 Data @ 50 psi

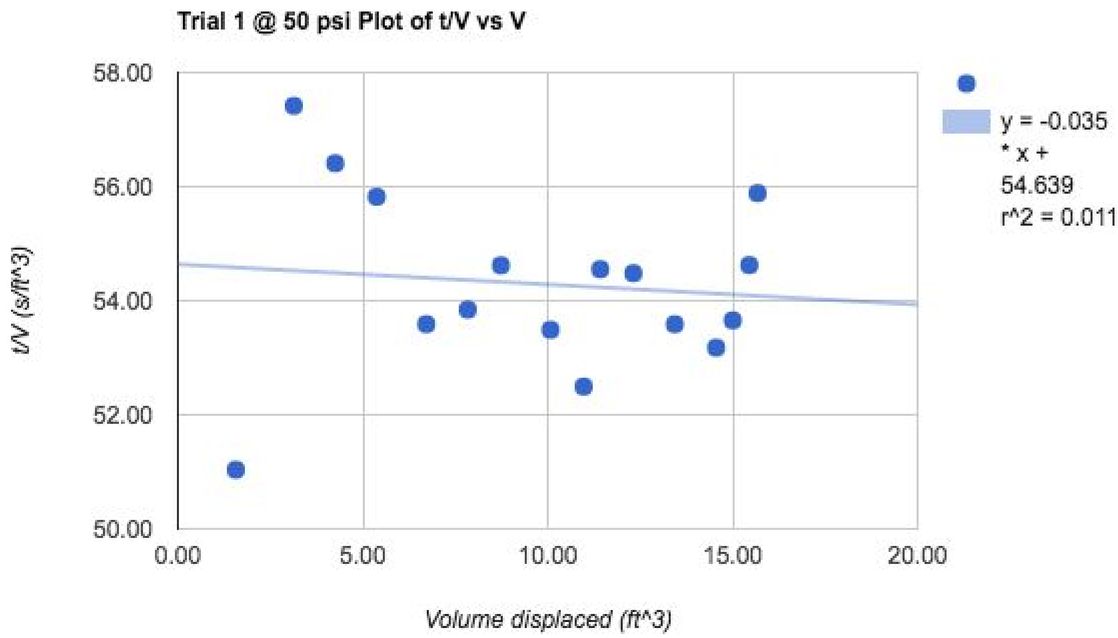
Time (sec)	**Height (cm)**	**Height Displaced(ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	97.00	0.00		
60	89.00	0.26	1.79	33.49
90	86.00	0.36	2.46	36.54
120	83.00	0.46	3.13	38.28
150	80.00	0.56	3.81	39.40
180	77.00	0.66	4.48	40.19
210	75.00	0.72	4.93	42.63
240	73.00	0.79	5.37	44.66
300	64.00	1.08	7.39	40.60
330	64.00	1.08	7.39	44.66
360	61.00	1.18	8.06	44.66
390	59.00	1.25	8.51	45.83
420	56.00	1.35	9.18	45.75
450	53.00	1.44	9.85	45.67
480	50.00	1.54	10.52	45.61
510	47.00	1.64	11.20	45.55
540	46.00	1.67	11.42	47.28
570	43.00	1.77	12.09	47.14
600	41.00	1.84	12.54	47.85
630	38.00	1.94	13.21	47.69
660	35.00	2.03	13.88	47.54
690	33.00	2.10	14.33	48.15
720	30.50	2.18	14.89	48.35
750	29.00	2.23	15.23	49.25
780	27.00	2.30	15.67	49.76
810	24.50	2.38	16.23	49.89

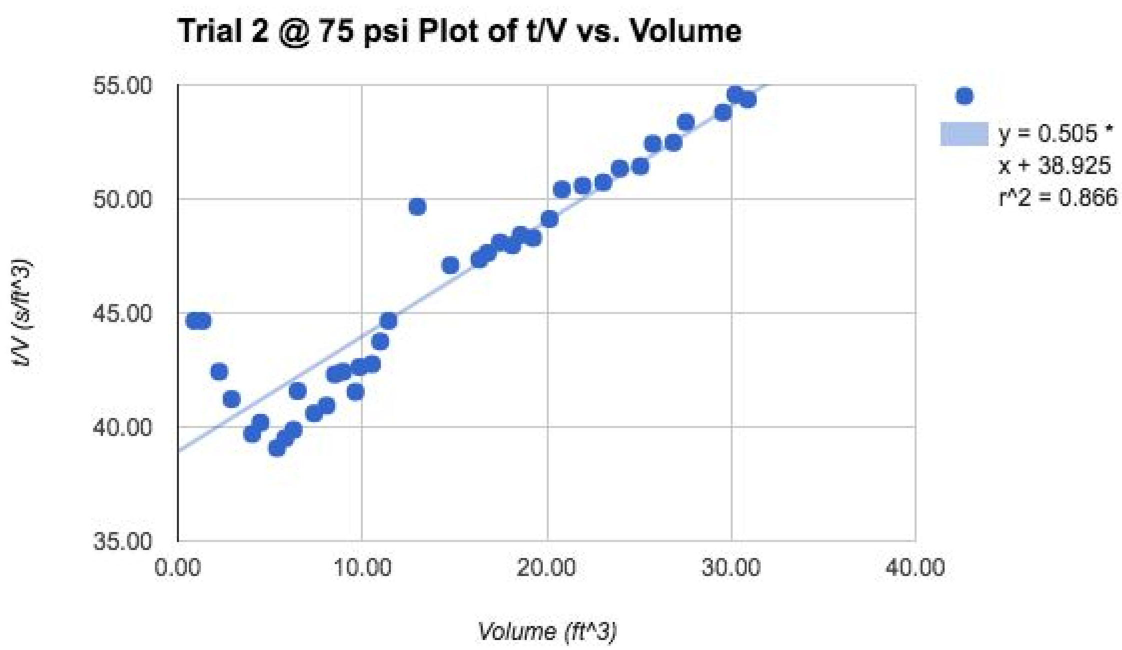
Table 9: Trial 8 Data @ 50 psi

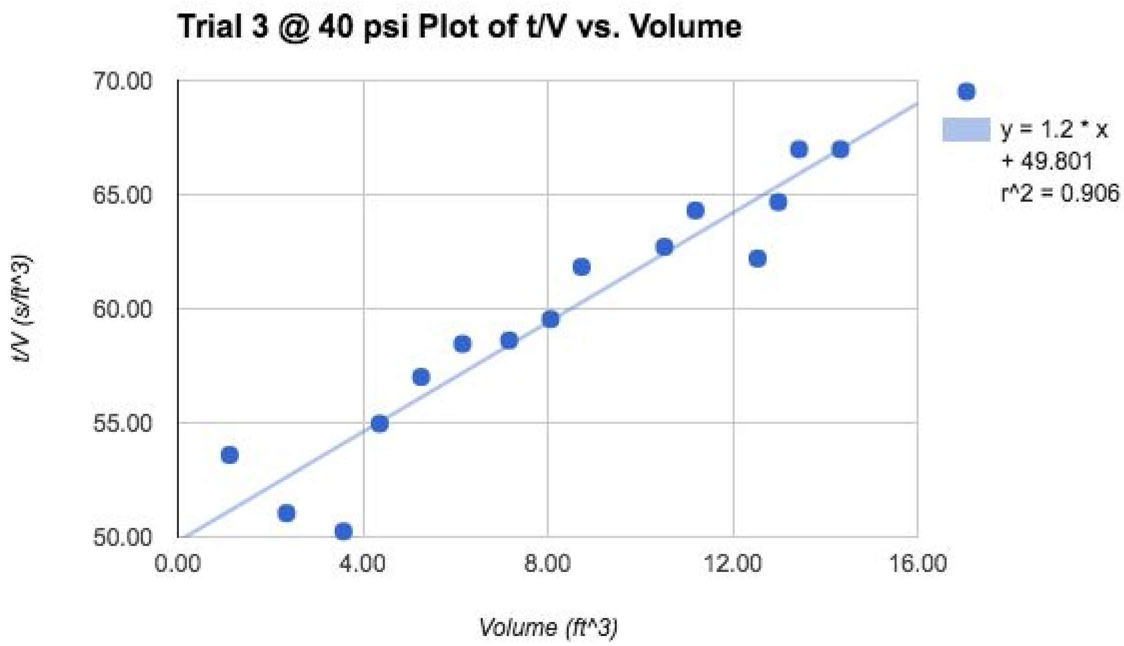
Time (sec)	**Height (cm)**	**Height Displaced(ft)**	**Volume Displaced(ft^3)**	**t/V (s/ft^3)**
0	98.00	0.00		
30	94.00	0.13	0.90	33.49
60	91.00	0.23	1.57	38.28
90	89.00	0.30	2.02	44.66
120	85.00	0.43	2.91	41.22
150	81.00	0.56	3.81	39.40
180	78.00	0.66	4.48	40.19
210	75.50	0.74	5.04	41.68
240	72.00	0.85	5.82	41.22
270	69.00	0.95	6.49	41.58
300	66.00	1.05	7.17	41.87
330	63.00	1.15	7.84	42.11
360	61.00	1.21	8.29	43.45
390	59.00	1.28	8.73	44.66
420	56.00	1.38	9.40	44.66
450	53.00	1.48	10.08	44.66
480	50.00	1.57	10.75	44.66
510	48.00	1.64	11.20	45.55
540	45.00	1.74	11.87	45.50
570	43.00	1.80	12.32	46.28
600	41.00	1.87	12.76	47.01
630	39.00	1.94	13.21	47.69
660	36.00	2.03	13.88	47.54
690	33.00	2.13	14.56	47.41
720	32.00	2.17	14.78	48.72
750	28.00	2.30	15.67	47.85
780	24.00	2.43	16.57	47.07

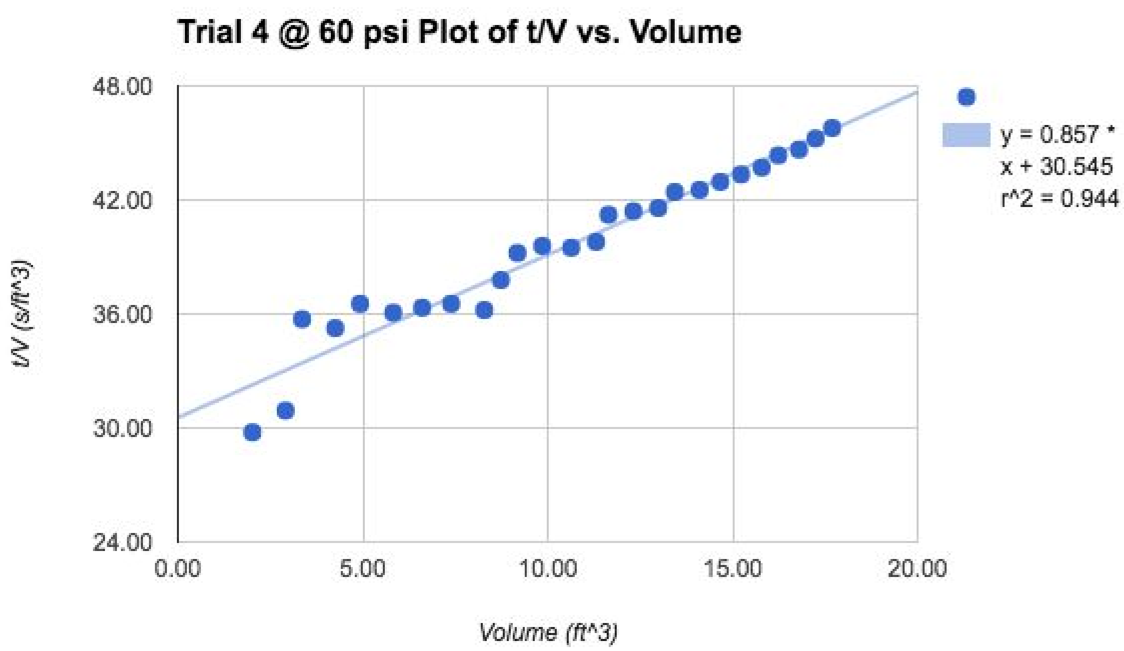
APPENDIX II

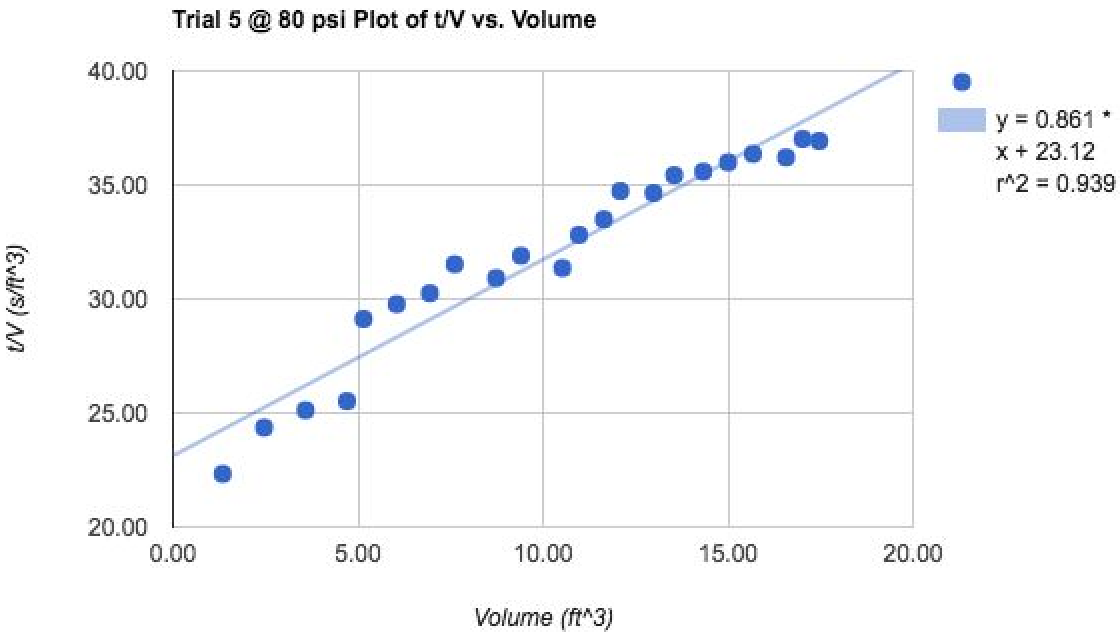
Plots of Trials

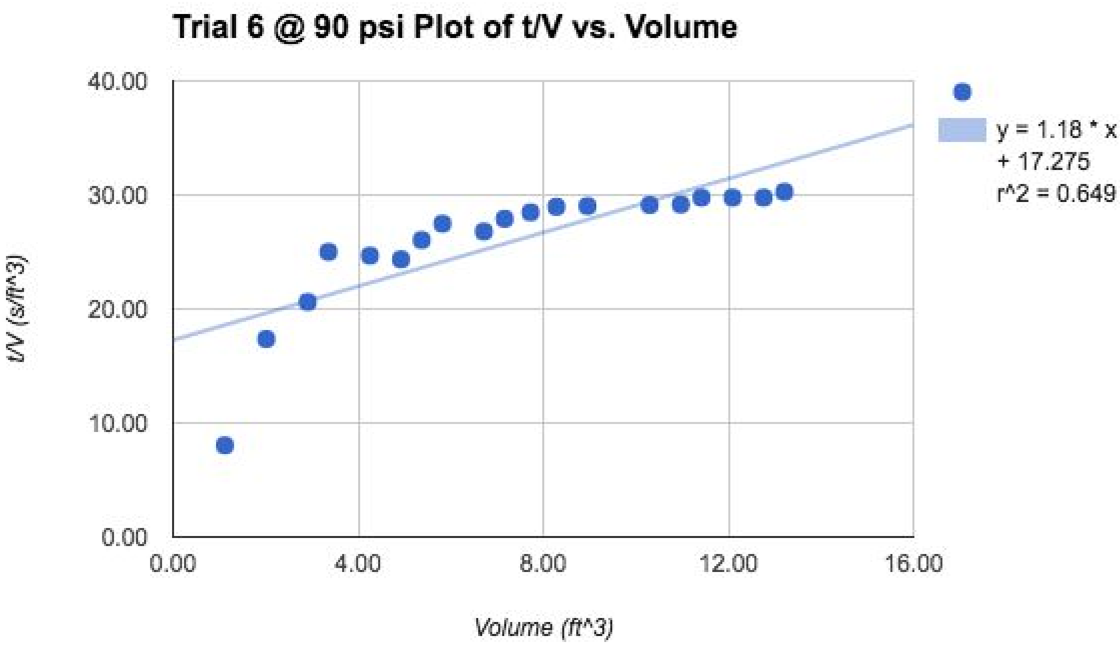


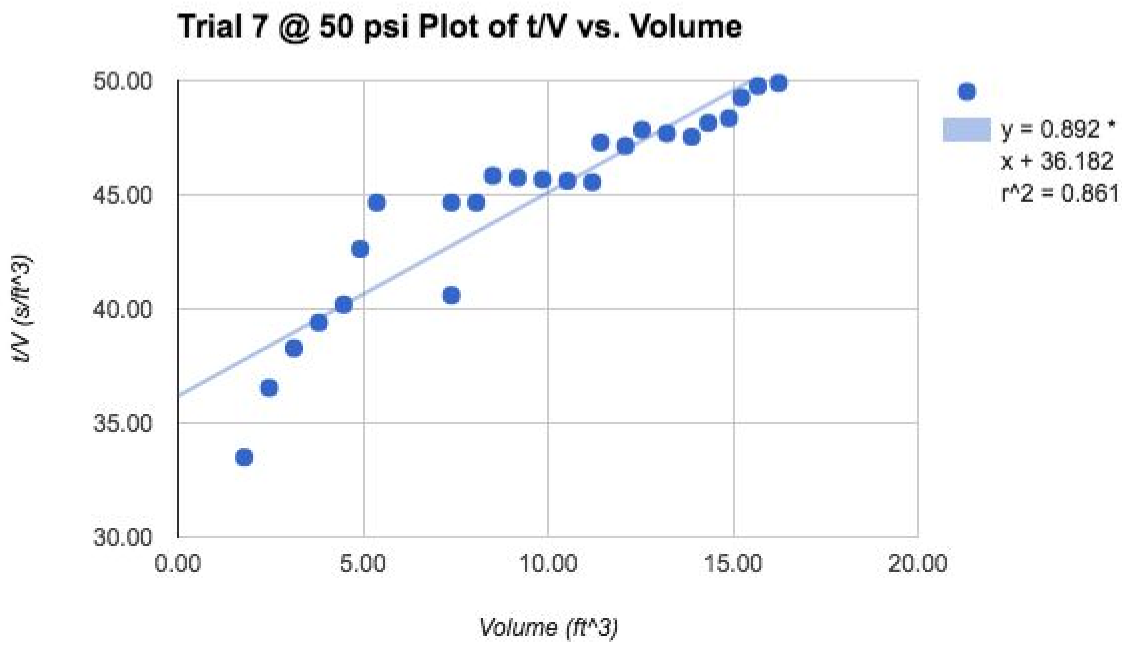


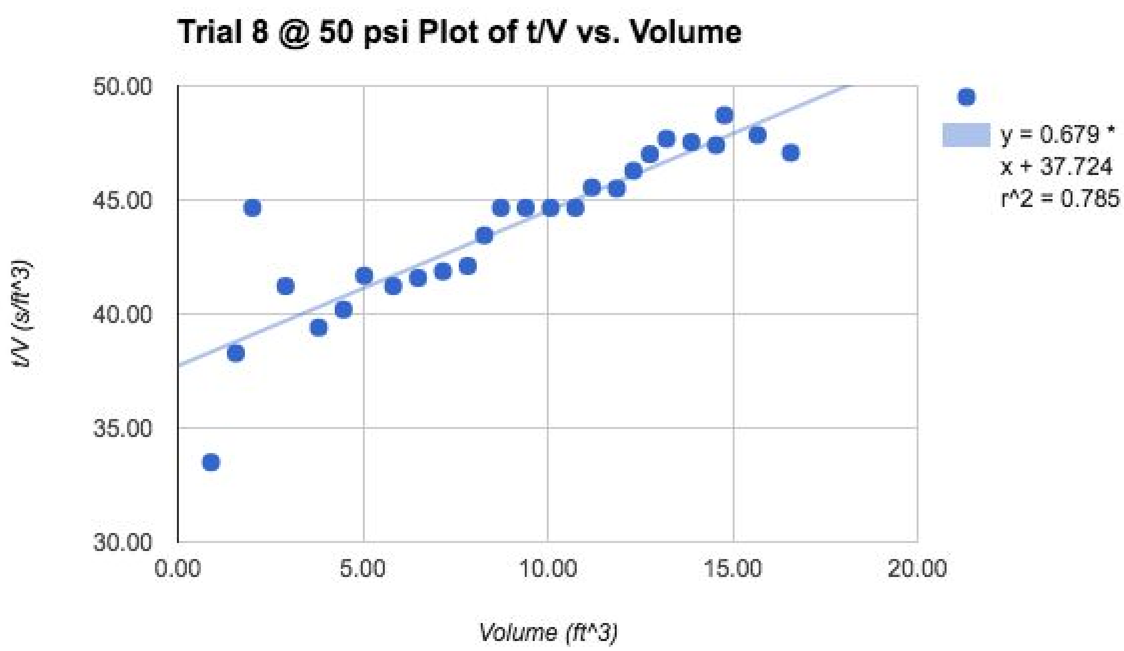

Trial 3 @ 40 psi Plot of t/V vs. Volume
70.00
65.00
60.00
55.00
50.00
t/V (s/ft^3)
0.00
4.00
8.00
12.00
16.00
Volume (ft^3)
y = 1.2 * x
+ 49.801
r^2 = 0.906


Trial 4 @ 60 psi Plot of t/V vs. Volume
48.00
42.00
36.00
30.00
24.00
t/V (s/ft^3)
0.00
5.00
10.00
15.00
20.00
Volume (ft^3)
y = 0.857 *
x + 30.545
r^2 = 0.944


Trial 5 @ 80 psi Plot of t/V vs. Volume
40.00
35.00
30.00
25.00
20.00
0.00
5.00
10.00
15.00
20.00
t/V (s/ft^3)
Volume (ft^3)
y = 0.861 * x + 23.12
r^2 = 0.939


Trial 6 @ 90 psi Plot of t/V vs. Volume
40.00
30.00
20.00
10.00
0.00
0.00
4.00
8.00
12.00
16.00
t/V (s/ft^3)
Volume (ft^3)
y = 1.18 * x + 17.275
r^2 = 0.649


Trial 7 @ 50 psi Plot of t/V vs. Volume
50.00
45.00
40.00
35.00
30.00
t/V (s/ft^3)
0.00
5.00
10.00
15.00
20.00
Volume (ft^3)
y = 0.892 * x + 36.182
r^2 = 0.861


Trial 8 @ 50 psi Plot of t/V vs. Volume
50.00
45.00
40.00
35.00
30.00
t/V (s/ft^3)
0.00
5.00
10.00
15.00
20.00
Volume (ft^3)
y = 0.679 * x + 37.724
r^2 = 0.785

APPENDIX III

Data of Weights of Cake and Calculated Weights

Table 10 :

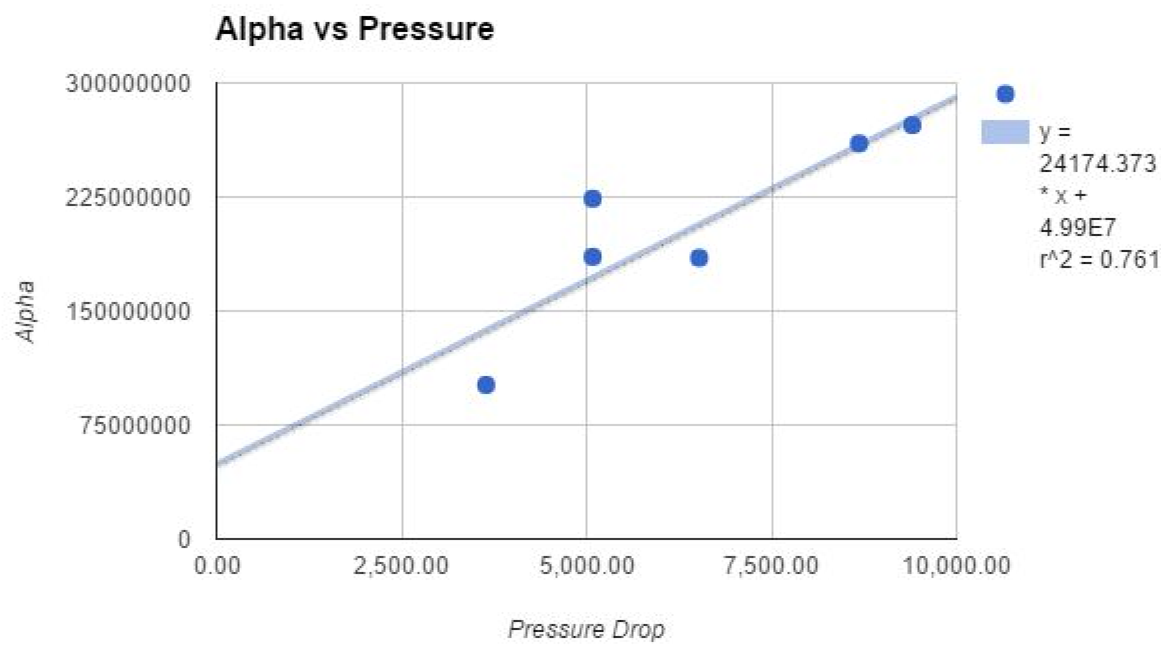
	weight of wet cake + tray (lb)	weight of wet cake	weight of cake	c (lb/ft^3)
Trial 1	42.5	25	19.26	1.23
Trial 2	48	30.5	24.31	0.79
Trial 3	54.25	36.75	28.86	2.01
Trial 4	49.5	32	24.96	1.41
Trial 5	46.5	29	24.24	1.39
Trial 6	37.5	20	15.63	0.90
Trial 7	39	21.5	16.51	0.95
Trial 8	37.25	19.75	15.16	0.87

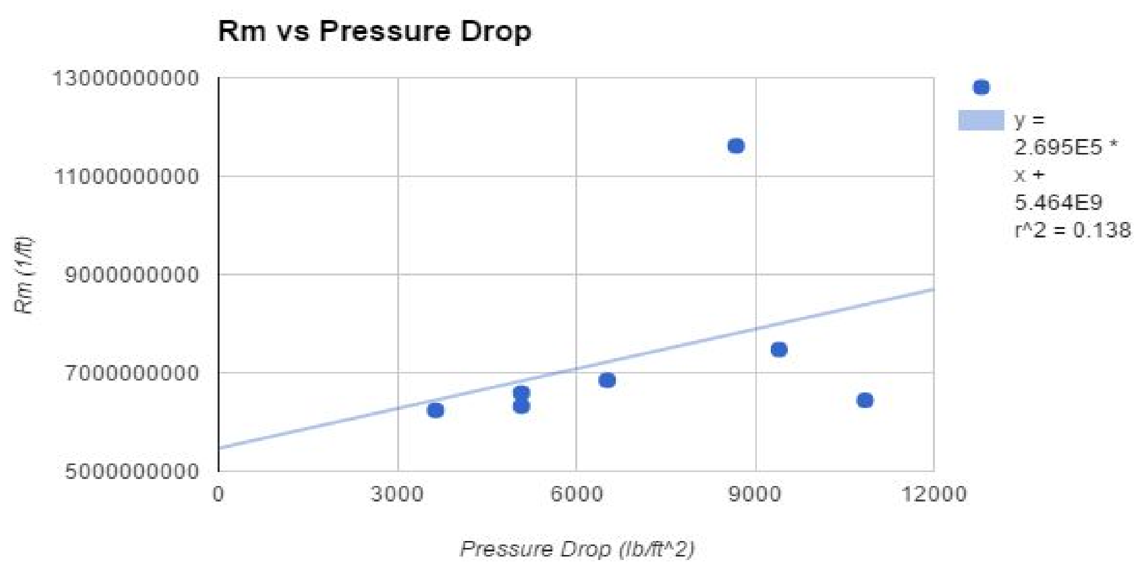
Table 11: Data of Sampled Cake Weight and Moisture Content

	Sample	tray weight (g)	tray+wet weight	after oven, 24hrs	% cake	% moisture	avg % cake
trial 1	1	5.4	80.5	63.8	0.778	0.222	0.770
	2	5.4	74	57.9	0.765	0.235	
	3	5.5	83.2	65.2	0.768	0.232	
trial 2	4	5.6	32.7	27.5	0.808	0.192	0.797
	5	5.4	46.5	38.7	0.810	0.190	
	6	5.6	49.6	39.6	0.773	0.227	
trial 3	4	5.5	116.5	92.6	0.785	0.215	0.785
	5	5.4	82.9	66.3	0.786	0.214	
	6	5.5	117.3	93.3	0.785	0.215	
trial 4	1	5.4	125.3	98.6	0.777	0.223	0.780
	2	5.5	134.9	105.4	0.772	0.228	
	3	5.5	102.4	82.1	0.791	0.209	
trial 5	7	5.5	74.8	64.4	0.850	0.150	0.836

	8	5.5	70.6	59.6	0.831	0.169	
	9	5.4	64.8	54.5	0.827	0.173	
trial 6	7	5.5	58.8	47.2	0.782	0.218	0.782
	8	5.5	80.6	64.1	0.780	0.220	
	9	5.5	78.6	62.7	0.782	0.218	
trial 7	2	5.6	87.9	68.6	0.765	0.235	0.768
	6	5.5	140.1	109.5	0.773	0.227	
	4	5.5	133.6	103.6	0.766	0.234	
trial 8	5	5.3	93.4	72	0.757	0.243	0.767
	3	5.5	127	99.2	0.771	0.229	
	1	5.6	89.7	70.7	0.774	0.226	

APPENDIX IV


Alpha vs Pressure
300000000
225000000
150000000
75000000
0
Alpha
0.00
2,500.00
5,000.00
7,500.00
10,000.00
Pressure Drop
y = 24174.373 * x + 4.99E7
r^2 = 0.761


Rm vs Pressure Drop
13000000000
11000000000
9000000000
7000000000
5000000000
Rm (1/ft)
0
3000
6000
9000
12000
Pressure Drop (lb/ft^2)
y = 2.695E5 * x + 5.464E9
r^2 = 0.138