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Press Dewatering of Sludge with Applications of an Electric Field

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By

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ABSTRACT

In the paper industry today, there is a rising concern over the question of what to do with the paper mill sludge. Although in the past most of the sludge was sent to a landfill, this disposal method is becoming less and less acceptable due to increasing environmental concerns, decreasing landfill space and increasing costs.

Since sludge contains a large fraction of water, one of the alternatives is to increase the dewaterability of the sludge through the use of electrokinetic forces. Increased dewatering of the sludge would allow for more economical alternatives to sludge disposal, such as incineration, as well as decrease the sludge handling, transportation, and disposal costs by reducing both volume and weight. The main objective of this thesis was to determine if the application of an electric current through a sludge press would increase the amount of dewatering in the sludge.

A simulated press that allowed for the sludge to be pressed in-between two charged screens and water to be collected from both the top and bottom of the press was designed and constructed. During experimentation, drainage amounts and final sludge consistency was collected under varying voltage applications and compared to a control run with no voltage.

From the results, it could be concluded that the application of an electric field did indeed help increase the dewaterability of the sludge. The results also show that ion migration does take place in the sludge with positively charged particles carrying water molecules towards the negatively charged screen. Further studies in applying this concept at higher pressing consistencies as well as other applications is recommended.

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INTRODUCTION

One of the major issues facing the paper industry today is how to reduce the cost of sludge disposal. With landfill space decreasing and environmental regulations increasing, there is a growing concern over what to do with the sludge. In North America alone, there are one hundred pounds of sludge produced per ton of paper production (1). This equates to approximately 4.6 million tons of sludge being produced in just one year. Of this, 70% goes to the landfill, 21% gets incinerated, 8% gets land applied and 1% gets recycled or reused (2).

In sludge, water accounts for a large fraction of the material make-up. By increasing the amount of water being removed from the sludge, several benefits will arise. These benefits include the following: 1) reducing the leachate production at landfills, 2) increasing the energy value of the sludge when incinerated, and 3) decreasing the hauling and disposal costs by reducing the volume and weight of the sludge (3). Currently, various mechanical devices are used to increase the consistency of the sludge anywhere from 10% to 50% solids.

There were three main objectives to this thesis. The first was to design a simulated sludge press that could pass an electric current through the sludge and also remove the water from both the top and bottom of the device. Second was to test the effects that different voltage (current) levels had on the dewaterability of the sludge. The final objective was to determine the effects of ion migration on dewaterability.

BACKGROUND

Electrokinetics involves the movement of charged particles or water molecules in an applied d.c. electric field. In electrokinetics, there are two main forces taking place. The first, electro-osmosis, refers to the movement of a conducting liquid through a membrane. The second, electrophoresis, is the opposite of electro-osmosis and refers to the movement of charged particles through an electric field. Electrokinetic dewatering works by applying an electrical potential across a material causing the positive ions to migrate towards the negative electrode. Along the way, the positively charged ions "pick up" water molecules and carry them towards the negatively charged plate. When they reach the cathode, the water molecules are released.

"The origins of electrokinetics are embedded in double-layer theory and the distribution of charge at surfaces." (4) The double layer theory is explained by having one layer of charges held closely together and immobile while having a second layer free to move with the attraction or repulsion of an applied electric field (5). An electrical potential is then created at the slip plane between the two layers and is known as the zeta potential. It was noted earlier that in the electro-osmotic force, water is moved through a membrane. For this to happen, a pressure gradient must have been developed so that flow could occur (4). The equation that explains this differential pressure can be found in equation #1 **(Appendix 1)** (4). It may also be inferred that the electrophoretic movement is proportional to the field strength and to the zeta potential and can be calculated by equation #2 **(Appendix 1)** (4).

While applications of electrokinetics have been used in both the clay and mining industries for some time now in helping them to separate suspensions of solids and liquids, the paper industry has done little in there use and application of electrokinetics for dewatering of sludge. There have been electrokinetic cells designed that will allow for dewatering and thickening of various materials. One such device is used in the dewatering of free flowing sewage and consists of a vertical electrode with a moving filter belt (6). The sewage was found to increase in consistency from 2.63% to 24.2% solids when passed through this device (6).

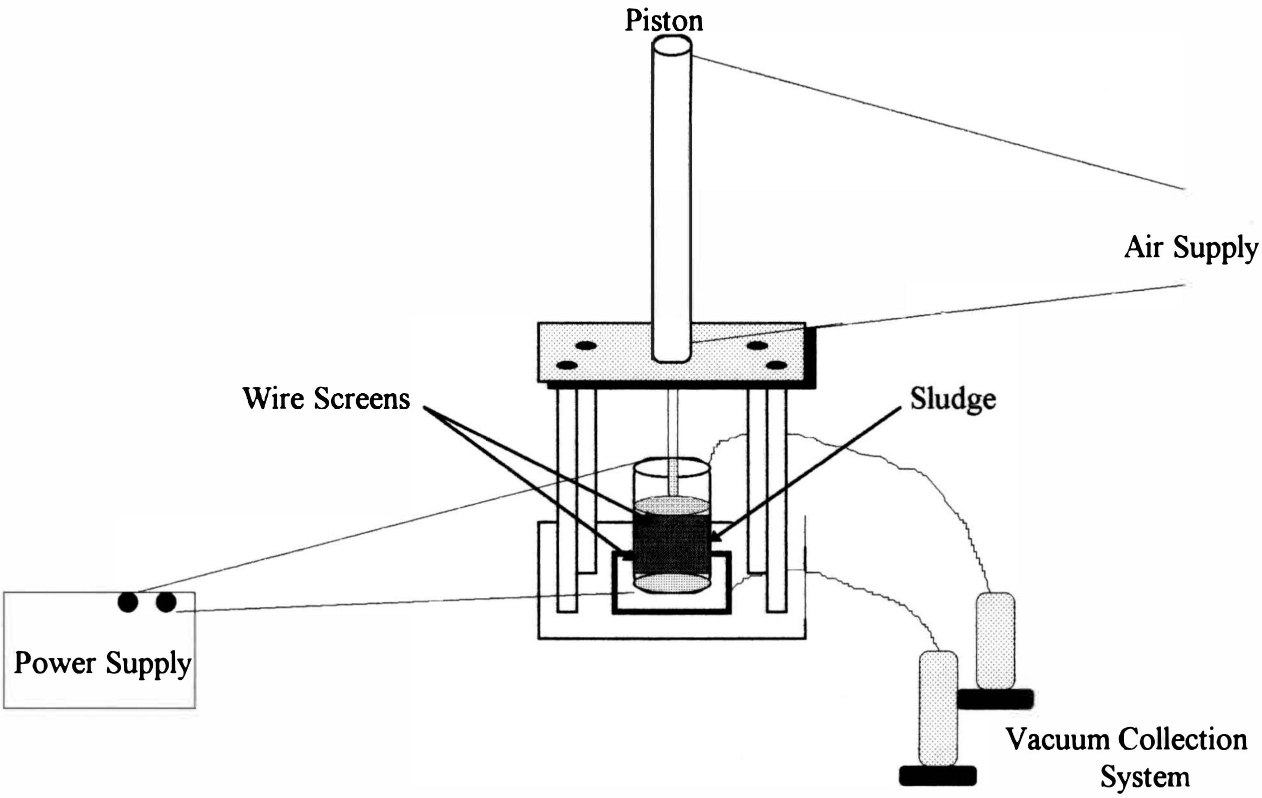
There has also been a field study involving the application of electrokinetics to two sludge landfills (7). In this study, electrodes were placed in the landfills with the cathodes having the ability to pass and collect water in them. After forty days, the solids level at one landfill increased from 9% to 27% and the solids level at the other landfill increased from 6% to 25%.

Another experiment that relates more closely to my thesis was done by a past WMU student. She studied the effects of electrokinetics on the dewatering rate of sludge under gravity conditions (4). In that study, sludge was placed between two electrically charged screens and allowed to drain. The results showed that the application of the electric current did increase the dewatering rate of the sludge under gravity conditions.

PROCEDURE

The construction of the pressing device consisted of an acrylic tube, several acrylic discs glued together and molded to fit into the tube, an air powered piston, four screens (two fine mesh and two large mesh), and a stand **(Figure 1)**.

Figure 1. EXPERIMENTAL DESIGN SETUP



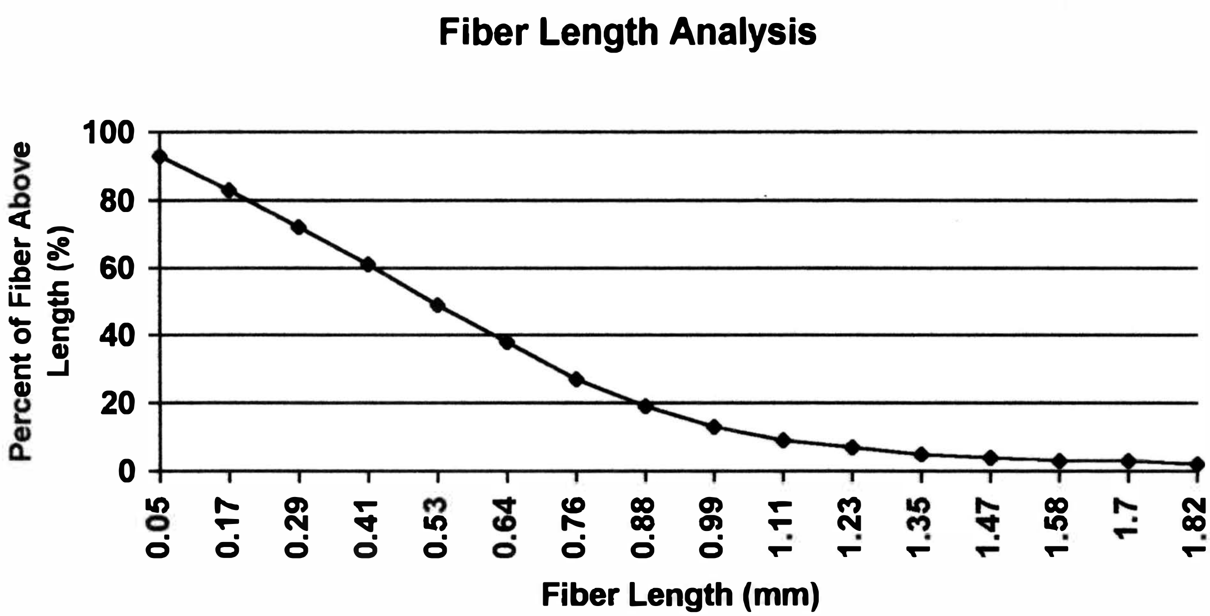
At the bottom end of the acrylic tube, an immobile disc was placed. The disc was designed to allow for the collection of the water draining out and was hooked up to a vacuum that would help remove and collect the water. The bottom disc also had a screw drilled through it to allow for a charged connection between the power supply and the screen. The large mesh screen was placed on top of the bottom disc with the fine mesh screen above it. This allowed for both the connection to the power supply and the filtering and draining of the water to take place out of the bottom. The top disc was attached to the piston and could freely move up and down the tube. This disc as well had a hole drilled in it and a connection to a vacuum to allow for collection of water out of the top. It too had a screw drilled in it to allow for the connection between the power supply and the screens.

The experimental design consisted of nine runs. The first run was done as a control run and had no voltage applied. Runs two through six consisted of varying voltage levels of 1, 5, 10, 15, and 20 volts with the cathode connected to the bottom of the tube. Runs seven through nine had the cathode attached to the top and ran under voltage levels of 5, 10, and 15 volts.

The sludge used was a simulated sludge with a 50/50 mixture of hardwood/softwood fibers and a 20% ash content (10% TiO_2, 90% hydrosparse 30 clay). The sludge mixture was refined in the Valley Beater for two hours under thirty pounds of weight attached to the arm. A Kajaani fiber length analysis can be seen in **Figure 2**.

For each run, approximately 100 ml of the simulated sludge was dumped into the acrylic tube with the screen on the bottom. The top screens were then placed on top of

Figure 2. Kajaani Fiber Length



the sludge and the device was placed under the top disc and press. The piston would then be activated and would start lowering the disc into the tube. As this was going on, the vacuums were turned on and the power supply activated at the desired voltage level. As the discs pressed the sludge together, water would be collected out of the top and bottom of the tube into separate collection containers. The press was run for two minutes under 18 psi of pressure. During this time, the current was checked periodically. When the two minutes were up, the press was deactivated and raised, the vacuum turned off and the power supply turned off. Measurements of the amount of water removed from each end were taken along with the final pad consistency of the sludge.

RESULTS

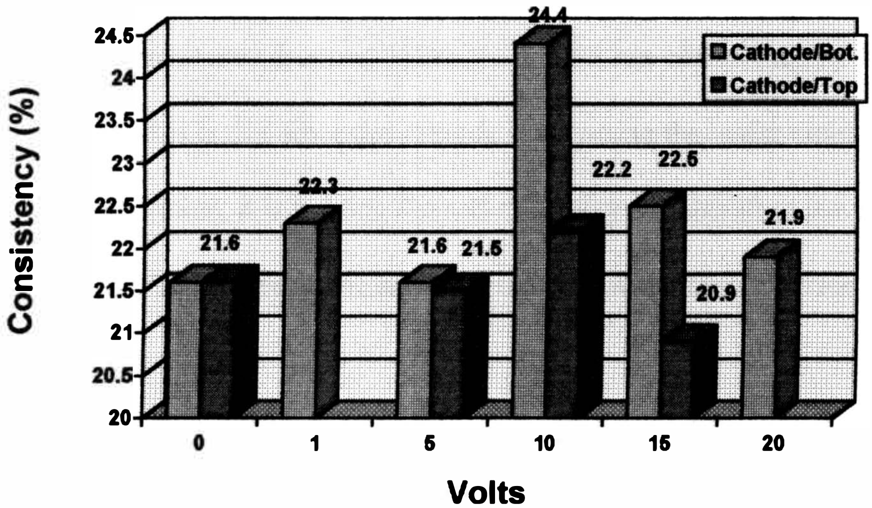
Consult **Appendix 2** for the data values and results of this experiment.

DISCUSSION

The most difficult and time consuming aspect of this thesis was the designing and building of the pressing device. A design was needed that would both allow for an electric current connection and a vacuum drainage connection at both the top and bottom of the device. Several designs were constructed on paper until an appropriate one was thought up. Once the final design was constructed on paper, acquiring the necessary materials and then finding the right equipment to craft the device became another problem. It required traveling around to several of the departments around campus as well as purchasing several other small hand tools for the construction. After the device was built, several dry runs were taken and minor adjustments were made. For the most part, the pressing device worked fairly well for the conditions it was placed under. One minor problem that was faced was that water drained out of the bottom of the tube before it could be sucked up by the vacuum. This may have resulted in some small losses in water but nothing significant. Time restraints also became a problem since the power supply could only be loaned out for one week.

The results shown in **Figure 3** show that the amount of water drained from the sludge increased when voltage was applied to the sludge with the cathode at the bottom. This would support the fact that electro-osmosis and electrophoresis is taking place when a current is applied. When compared to the control run with 0 volts, all but one of the other runs with the cathode at the bottom had a higher final pad consistency than the consistency at 0 volts. At one volt, the final pad consistency jumped up by .7 percent

Figure 3. Voltage Vs. Consistency



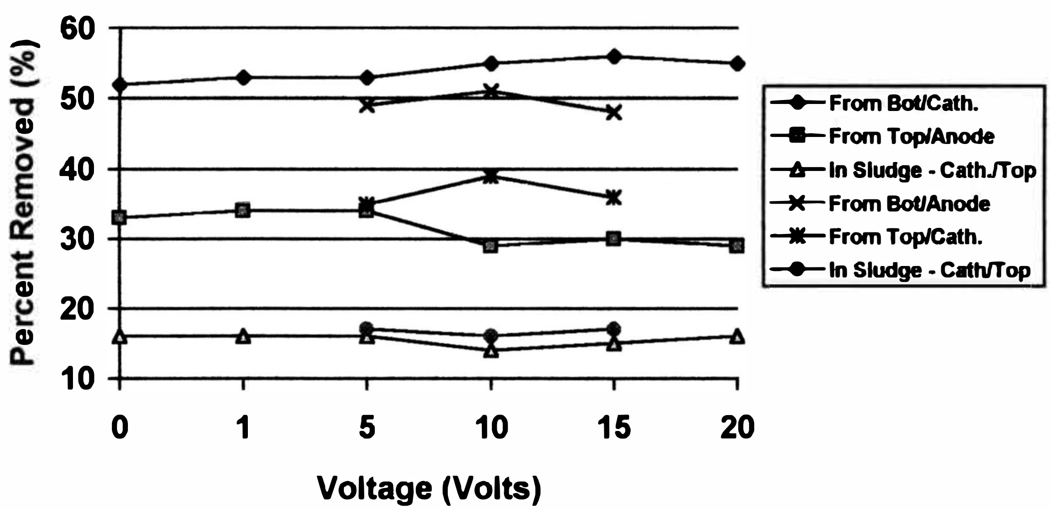
while at five volts, the final pad consistency dropped back down to 21.6% which is even with the control run. The only explanation that can explain this is that there is some electrical phenomenon taking place at five volts but the expectation would be for the consistency of the pad to be between 22.3 % and 24.4%. The amount of water removed peaked out at 10 volts at 24.4% pad consistency. This consistency is nearly 3% higher than the control run which is a considerable difference. At 15 and 20 volts, the pad consistency dropped back down again but still remained higher than the control run. This information suggests that electrokinetics are at work and that the cathode electrode is attracting the water molecules so it can be removed from the sludge.

When the cathode was switched to the top of the press, totally different results occurred. At five volts, the pad consistency dropped, only by .1%, but it still dropped. At

10 volts, the pad consistency was above the control run consistency but the consistency was still considerably lower than at 10 volts with the cathode at the bottom. Then at 15 volts the pad consistency dropped below the control run consistency by .7%. One explanation for this is that since the cathode is attracting the water molecules upwards through ion migration, it is fighting the pull of gravity and therefore leaving some of the water molecules suspended in the sludge without allowing them to drain out either the top or the bottom.

This ion migration theory can also be seen in **Figure 4**.

Figure 4. Percent of Water Removed



From this graph, it can be seen that there is a definite difference in drainage amounts when the cathode is at the bottom as compared to when it is at the top. When the cathode was at the bottom, more water was removed from the bottom then when the cathode was at the top. This is also the case when looking at the drainage amounts out of the top of the device. When the cathode is at the top, more water is removed out of the top then when the cathode is at the bottom. Likewise, when the cathode is at the top, more water remains in the sludge then when the cathode is at the bottom. All of this information supports the idea that ion migration takes place and moves towards the cathode. It would also explain why the pad consistencies were higher when the cathode was at the top because the cathode was pulling the water molecules against the force of gravity and they were getting suspended in the sludge pad.

Another interesting observation that took place was that as the pressing time increased, the current decreased. This can be explained by the physics equation which states that voltage is equal to the product of electrical current and resistance. In this experiment, the water was the conductor and the fibers provided the resistance. Thus since the voltage remained constant, as the water was removed, the resistance of the fibers increased causing the current to decrease.

CONCLUSIONS

The results of this experiment showed that applying an electric current through a simulated sludge under pressing conditions did increase the amount of dewatering in the sludge. The amount of water removed was the highest when the cathode was placed at the bottom of the device under a voltage of 10 volts. When the cathode was placed at the top, the migration of the water towards the cathode had to fight the pull of gravity and thus did not get as favorable results. In some cases it even decreased the amount of water removed when compared to a control run with 0 volts. The ion migration theory could be seen when looking at the amount of water removed off of each side. When the cathode was attached to the top, more water was drained off the top than when the anode was attached there. Along the same lines, when the cathode was attached to the bottom, more water was removed than when the anode was attached there.

RECOMMENDATIONS

As these results indicate and past studies have shown, the application of an electric field to sludge does increase the amount of water removed from the sludge. Thus I would recommend that further electrokinetic studies be done on sludge that simulates the higher consistencies found in the paper industry today (around 30% - 50%). I would also recommend electrokinetic studies on furnish pulps to see if it has the same effects it does on sludge. If so, there may be practical applications of applying this knowledge to the paper machine itself in helping to increase dewaterability on the machine.

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APPENDIX

Equation #1

The pressure developed due to an applied voltage through a capillary resulting in electro-osmotic flow is calculated as follows:

$$\Delta P = \frac{2\zeta\varepsilon F\iota}{\pi r^2}$$

ζ = zeta potential ε = dielectric constant of bulk phase F = field strength
ι = capillary length r = capillary radius

Equation #2

The electrophoretic velocity:

$$v = \frac{\zeta\varepsilon F}{4\pi\eta}$$

η = viscosity of bulk phase

APPENDIX #2

Table #1

Voltage (Volts)	Test #	Current (ma)	Calc. Beg. Wt. of Sample (gms)	Cathode/Anode	Drainage Bottom (ml)	Drainage Top (ml)	Wt. After Pressing (gms)	Wt. After Drying (gms)	Consistency After Press (%)	Std. Dev. of Cons.
0	1	0	116	Bottom/Top	56	37	23.01	4.97	21.6	
	2	0	122	Bottom/Top	60	40	24.82	5.23	21.1	
	3	0	122	Bottom/Top	64	37	23.77	5.25	22.1	
Average									**21.6**	**0.414**
1	1	4 to 10	126	Bottom/Top	68	38	24.19	5.40	22.3	
	2	4 to 10	128	Bottom/Top	66	43	24.36	5.49	22.5	
	3	4 to 10	134	Bottom/Top	62	46	26.08	5.78	22.2	
Average									**22.3**	**0.153**
5	1	50 - 80	109	Bottom/Top	59	37	21.23	4.70	22.1	
	2	50 - 80	140	Bottom/Top	70	44	28.03	6.03	21.5	
	3	50 - 80	143	Bottom/Top	68	45	29.04	6.14	21.1	
Average									**21.6**	**0.411**
10	1	100 - 200	98	Bottom/Top	51	32	17.69	4.20	23.7	
	2	100 - 200	144	Bottom/Top	76	36	23.94	6.19	25.9	
	3	100 - 200	125	Bottom/Top	67	33	22.81	5.38	23.6	
Average									**24.4**	**1.035**
15	1	200 - 350	117	Bottom/Top	63	32	22.59	5.05	22.4	
	2	200 - 350	137	Bottom/Top	75	37	26.03	5.88	22.6	
	3	200 - 350	109	Bottom/Top	58	35	20.64	4.68	22.7	
Average									**22.5**	**0.135**
20	1	300 - 400	123	Bottom/Top	63	36	23.75	5.27	22.2	
	2	300 - 400	127	Bottom/Top	66	37	24.80	5.47	22.1	
	3	300 - 400	126	Bottom/Top	70	30	25.07	5.41	21.6	
Average									**21.9**	**0.262**

**This data was collected at the end of a 2 minute time period under 18 psi of pressure.*

Table #1 (cont.)

Voltage (Volts)	Test #	Current (ma)	Calc. Beg. Wt. of Sample (gms)	Cathode/Anode	Drainage Bottom (ml)	Drainage Top (ml)	Wt. After Pressing (gms)	Wt. After Drying (gms)	Consistency After Press (%)	Std. Dev. of Cons.
5	1	40 - 70	116	Top/Bottom	53	39	23.35	5.00	21.4	
	2	40 - 70	129	Top/Bottom	56	42	25.86	5.55	21.5	
	3	40 - 70	132	Top/Bottom	61	45	26.33	5.66	21.5	
Average									**21.5**	**0.034**
10	1	100 - 200	103	Top/Bottom	58	38	20.01	4.42	22.1	
	2	100 - 200	135	Top/Bottom	60	54	25.88	5.80	22.4	
	3	100 - 200	128	Top/Bottom	60	46	24.73	5.50	22.2	
Average									**22.2**	**0.132**
15	1	200 - 350	110	Top/Bottom	52	35	22.64	4.74	20.9	
	2	200 - 350	126	Top/Bottom	56	46	25.32	5.40	21.3	
	3	200 - 350	128	Top/Bottom	59	47	27.10	5.51	20.3	
Average									**20.9**	**0.409**

**This data was collected at the end of a two minute time period under 18 psi of pressure.*

Table #2 Percent of Water Removed

Voltage (Volts)	Test #	Cathode/Anode	From Bottom (%)	From Top (%)	In Cake (%)
0	1	Bottom/Top	51	33	16
	2	Bottom/Top	51	34	17
	3	Bottom/Top	55	32	16
Average			52	33	16
1	1	Bottom/Top	56	31	16
	2	Bottom/Top	54	35	15
	3	Bottom/Top	48	36	16
Average			53	34	16
5	1	Bottom/Top	56	35	16
	2	Bottom/Top	52	33	16
	3	Bottom/Top	50	34	17
Average			53	34	16
10	1	Bottom/Top	54	34	14
	2	Bottom/Top	55	26	13
	3	Bottom/Top	56	28	15
Average			55	29	14
15	1	Bottom/Top	56	28	16
	2	Bottom/Top	57	28	15
	3	Bottom/Top	56	34	15
Average			56	30	15
20	1	Bottom/Top	53	31	16
	2	Bottom/Top	54	30	16
	3	Bottom/Top	58	25	17
Average			55	29	16
5	1	Top/Bottom	48	35	17
	2	Top/Bottom	48	36	16
	3	Top/Bottom	50	35	17
Average			49	35	17
10	1	Top/Bottom	58	38	16
	2	Top/Bottom	47	42	16
	3	Top/Bottom	49	37	16
Average			51	39	16
15	1	Top/Bottom	49	33	17
	2	Top/Bottom	46	38	17
	3	Top/Bottom	48	38	17
Average			48	36	17