Comparison of Vacuum Pipe Performance in a Tank Vac System

T. Thandal & M. Walmsley

School of Engineering, University of Waikato, Hamilton
taran-97@hotmail.com, walmsley@waikato.ac.nz

Abstract

Rain water harvesting is a common practice all over the world and especially important in New Zealand. A typical rooftop rain water harvesting system comprises three basic subsystems; a catchment system (roof), a delivery system (filters and gutters), and a storage system (rain water tank) (Chao-Hsien Liaw 2004). One major issue with rain harvesting is the hygienic state of rain water tanks. As the rain falls and enters the tank, it can often pick up dirt and other organic matter from the roof and gutters creating sludge. The tank vac is a system which automatically cleans out the base of a tank during times of heavy rain fall. It works by creating a siphon to suck out the sludge at the base of the tank through 'vacuum pipes'. The purpose of this research is to find the optimum set up to achieve maximum cleaning potential. Paper pulp was used as a substitute for actual tank sludge for convenience and to obtain more consistent results. It was found that the horizontal vacuum pipe had the best performance.

1. Introduction

Rain water harvesting is a common practice all over the world and especially important in New Zealand. A typical rooftop rain water harvesting system comprises three basic subsystems; a catchment system (roof), a delivery system (filters and gutters), and a storage system (Chao-Hsien Liaw 2004). At the moment around 10 percent of New Zealand households obtain their domestic water usage by rain water harvesting. This is often due to the city water supply not being available to rural areas

One major issue with rain harvesting is the hygienic state of rain water tanks. As the rain falls and enters the tank, it can often pick up dirt and other organic matter from the roof and gutters. This organic matter enters the tank and sinks to the base creating a layer of sludge (Abbot 2007). This sludge is potentially an issue as it creates a nutritious environment for bacteria to grow. Not only is the bacteria harmful to human health but also depletes the oxygen level in the water. Water quality is determined by the level of oxygen in it, with low oxygen levels the water can begin to taste bad and have a fowl colour. Another potential issue is the sludge gets dawn into the filter and it reduces the life span creating expensive maintenance costs.

Tank Vac is an automatic tank cleaning system which works without any external energy requirements, once installed it operates automatically. The system (Fig. 1) is made up of:

- Vacuum pipe
- Down pipe
- And a restrictor (siphon generator)

In times of heavy rain fall the water full's up the tank and eventually begins to trickle into and down the down pipe. As rain continues to fill the tank, 'head' builds up and once there is enough water exiting through the down pipe the siphon is generated. The siphon then creates a negative pressure (vacuum) in the pipes which then dramatically increases the overflow rate. As a result, the sludge from the base of the tank is sucked out through small inlet holes. The siphon is then killed when the water level reduces enough to expose an air bleed valve. This then thought to clean the thank leaving behind high quality, oxygen enriched water (Agnew 2004).

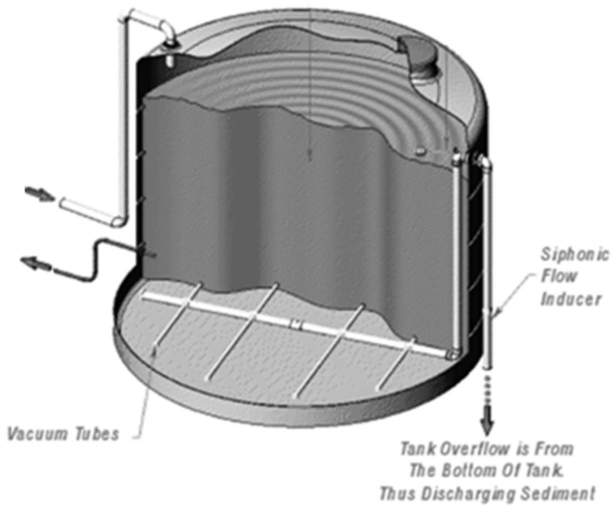

Figure 1, visual break down of a Tank Vac system

One issue surrounding the performance of the system is the arrangement of the vacuum pipes at the base of the tank. Originally the Tank Vac system was designed with a 'branched system' of vacuum pipes. This design was shortly replaced by a single pipe stretched across the base to reduce installation costs. It was assumed that the branch system provided little or no benefits in

terms of removing the sludge from the base of the tank however no formal research was done to prove this. This then leads on to the research question; what is the optimal arrangement for vacuum pipes in a Tank Vac system in terms of improving water quality?

3. Methodology and Materials

The literature review highlighted many critical points which contributed to the construction of this experiment. It was indicated that the amount of sludge built up on the base of a rain water tank is an excellent indicator to the quality of the water. Therefore in order to decide on the best design of the tank vac system, an experiment should be performed on which design can remove the most amount of sludge. However sludge is difficult to obtain as it would have to be scraped off a base of a rainwater tank or physically made. This could be a very time consuming process and is therefore an impractical way to test the designs. Instead paper pulp was used as it is cheap and easily obtained.

It is important the flow properties are similar to sludge however it does not need to be the exact same. This experiment will not be testing the performance of the tank vac system, only comparing the designs. As the paper pulp will be consistent for all the experiments, fair and accurate comparison data can be obtained. It is however important that the paper pulp settles at the base of the tank and is light enough to flow out when the tank vac system is operating. An experimental trial was conducted, based on visual observations the paper pulp performed as expected and was deemed suitable for this experiment.

The tank used was 480L, generally domestic rain water tanks average a capacity of 1800L. The tank has a 0.8:1 width to length ratio giving it a tall, thin shape. The internal pipe diameter used for the scaled tank vac system was 32mm giving it a 1:6 scale ratio to the full scale product.

3.1 Apparatus

The tested designs are variations of the tank vac system. These variations include designs that have been implemented previously, currently and designs that have been recently proposed. Five different set ups in total will be tested in this study. Each of the set ups combining variations that can be described under two different categories; **how the water is drawn out** and **variations in the vacuum pipe set up**.

The water can be drawn out using two different methods; naturally overflowing and syphoning. Current competitors on the market have a system that has the water naturally over flowing. This is where the overflow water is drained from the base as oppose to the top. Syphoning the water involves having a restrictor located somewhere in the down pipe. As the flow from the tank becomes sufficient, it is thought that the sudden reduction in diameter due to the restrictor creates a syphon in the down pipe. Gravity then draws out the water in the tank with a powerful suck. Attempts to create a syphon without the resistor were attempted on the experimental rig but proved to be ineffective. The water ended up trickling out just as it would for a naturally overflowing system.

The next category of variations to the tank vac system is how the vacuum pipes are set up. There are three different designs (Fig. 2); they are as follows:

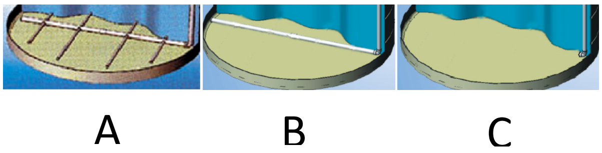

Figure 2. Three vacuum pipe setups to be tested

3.1.1. Base Design

This design is currently used by competitors in conjunction with a naturally overflowing setup. This design basically has no vacuum pipes; the overflow pipe just extends and sits at the base of the tank (Figure 2c). It can be said the inlet diameter equal to the internal pipe diameter. This is the cheapest vacuum pipe set up and is now under consideration as a proposed future design due to its simplicity.

3.1.2. Horizontal Pipe

This design is currently used in the tank vac model in conjunction with a siphon overflowing system. This design extends the overflow pipe stretching it across the floor of the tank (Figure 2b). This extended pipe has 22 holes evenly distributed along the side facing the base of the tank to allow water to enter in. The opposite end of the pipe is blocked off thus giving the total inlet area two times the internal diameter. This extended pipe adds cost to the installation fee and is proposed to be removed hence the base design proposal.

3.1.3. Tree Pipe

This design was previously used in the tank vac model in conjunction with a siphon overflowing system. It is a further extension to the horizontal pipe set up as it as it adds more vacuum pipes to cover a larger surface area of the base (Figure 2a). Two extra pipes are added and attached by the centre to the horizontal pipe perpendicularly. The first branch is attached a third of the way down the horizontal pipe where the second is attached two thirds down. This provides an extra 14 holes to contribute to the inlet area. This design was originally removed to save installation costs as it was thought to be of no benefit in comparison to the horizontal design, this will now be tested.

The five setups to be tested are broken into combining different vacuum pipes with a naturally overflowing system and a siphoning system, they are as follows:

Natural Overflow
- Base Design (A)
- Horizontal Pipe (B)

Siphon Overflow
- Base Design (C)
- Horizontal Pipe (D)

- Tree Pipe (E)

Each setup is allocated a letter for future referencing.

3.2. Experimental

The following section discusses the procedures taken to test the above 5 setups and the methods used to ensure testing was fair. The procedures differ for the natural and syphoning overflow however the preparation is the same for both. Four flushes were done for each test to compare how the system preformed after multiple flushes.

Preparation

- The water tank is first emptied and rinsed out with water.
- The tank was filled with water to a height of 920mm which is marked on the tank.
- 1.4 kg of damp paper pulp was added to a 10 L container of water and stirred well to separate the fibres.
- The pulp solution was then poured into the tank evenly in a swirling motion.
- The tank was then stirred thoroughly using a large pipe while the paper pulp was still sinking to the ground. The stirring action must be back and forth to ensure the pulp settles evenly on the base. If a swirling motion is used, the paper pulp will tend to drift into the middle with none sitting around the edges.
- The setup to be tested was then installed while the paper pulp was settling.
- 15 minutes of settling time was given, this ensured the paper pulp was completely settled on the base.
- A sieve is place at the exit of the overflow pipe to catch any exiting paper pulp.

For siphon flow testing:

- The siphon was manually started by covering up the outside exit on the down pipe and by sucking the water up though the top bleed hose. This first causes the water to trickle out and eventually enough flow is generated to begin the siphon.
- As soon as the siphon begins, the timer is started and the siphon is killed after one minute two seconds (after an outflow of 60L). This is done by removing the screw wedged in the air bleed hose ensuring a consistent volume is achieved each flush.
- The collected paper pulp was then scraped off into a container labelled flush one.
- In order to get the second flush the tank need to be topped off again to 920mm.
- Care must be taken to fill the tank and not disturb the paper pulp at the base. This was done by using an overhead trickle pipe (described in the next section).
- Once the tank was filled up to the correct level the above four steps were repeated until four flushes were achieved.

For natural flow testing:

- The tank was filled up to a 915mm height, just before the water begins to trickle out the pipe.
- The flow is then set to 15L/min and the water is allowed to tickle out the pipe. The sieve is once again placed under the over flow pipe to catch the paper pulp. The inflow of water is stopped after 4 minutes (equalling 60L of fluid)
- The collected solids were scraped off into a container labelled flush one.
- The above steps were repeated until four flushes were obtained.

For both cases, the samples were dried overnight at 60^{o}C, weighed and recorded.

3.3. Fair Testing

Initially trial test were done on the system to see if consistent results could be achieved. These trials were highly inconsistent with repeated results outlying each other by up to 300%. The inconsistencies were narrowed down to the following reasons:

- Inconsistent flush volumes caused by random head height required to start the siphon.
- Sieve mesh size allowing some pulp fibres to escape
- Inflow disturbing the pulp paper layer on the base of the tank. Even a slight shift of this base layer cause large changes in the results.
- Uneven distribution of sediment on the tank floor.

In order to overcome these issues the following steps were taken:

The previous method, starting the siphon involved filling the tank up until enough head was built to create the siphon. This caused the siphon to be created at random heights and therefore was difficult to obtain a consistent flush volume. This problem was overcome by manually starting the siphon. The system of pipes was not primed as it was installed ensuring the water would not begin to trickle out as the tank was filling. Instead the air was sucked out of the pipe forcing the water to flow from the base of the tank and out the down pipe. The siphon would begin provided enough head height was present which was true as the tank was filled to 915mm each flush. The flow rate of the flush was obtained by timing how long a 25L bucket took to fill under the siphon. Each of the three designs produced different flow rates so each had to be tested. The time to exhaust 60L was then calculated using basic mathematics. For each test the timer was started when the siphon began and was physically stopped by removing the air bleed hose plug.

Two procedures were put in place to ensure the paper pulp did not escape through the mesh. This was by purchasing a tight mesh sieve and by ensuring the paper pulp was not blended for too long. The pulp was mixed up just until the fibres could separate and stopped. This allows a higher chance of the mesh to catch them while still having the flow properties it is

expected to have. This was tested in a sample beaker recovering 95% of the original content of paper pulp.

One of the greatest issues was how the paper pulp sat at the base of the tank. If this was only slightly disturbed the results could drastically change. As the tank is filling via the hose, the flow of the water can upset the sediment at the base shifting where it sits. It was found a flow rate of 4 L/m would not disturb the sediment however this would require a large amount of time to fill the tank. Instead an overhead trickle pipe was made up from some left over pipe. Five holes were drilled into a pipe 900mm long with one end blocked off using tape. This pipe was rested above the tank (in the middle) and a hose was placed into the free end. The water then trickled down evenly out of the five holes at a rate which visually displayed no upset of the sediment base.

It was found that using 700g of damp paper pulp per test created inadequate floor coverage when the debris settled. In order to ensure the distribution of the sediment layer was as consistent as possible, the damp paper pulp content was doubled to 1.4kgs. This then provided enough fibres to adequately cover the base which will lead to more consistent results.

4. Results and Discussion

With the added methods of fair testing, the results obtained from the experiment were much more consistent especially for the first flush. It was found that this initial flush removed the largest amount of debris in comparison to the later flushes. Roughly 70% of the debris removed in the first flush exited in the first 30 seconds for tests using the restrictor. This initial burst was observed to quickly remove the localised debris from around the inlets with the rest of the paper pulp exiting slowly after. It was expected that the debris would redistribute continuously as the pulp is removed, this however was not the case. This phenomenon greatly affected the results as the amount of debris obtained from the 2nd 3rd and 4th flush was only a small fraction of the first flush. This made it more difficult to gain a consistent reading for these latter flushes. In order to gain accurate results, the average was taken for around three separate tests for each design.

The total amount of debris removed can be defined as the sum of the pulp collected from all four flushes. The most effective design for removing debris from the water tank was setup D, Restrictor + Horizontal pipe (Figure 3). The raw data values obtained for this set up were consistently greater than each of the other designs thus providing a platform to confidently say this design had the best overall performance.

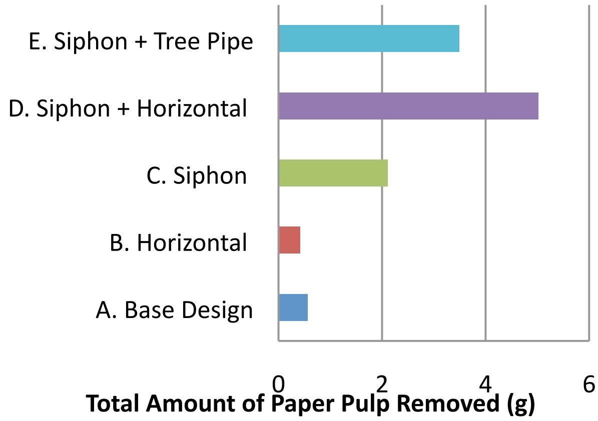

Figure 3. Total debris removed for each set up

The three setups using the siphon over flow system (C, D & E) clearly performed better than the natural overflow systems (A & B). This is due to the restrictor increasing the flow rate by creating a vacuum inside the pipe. This has been shown to improve the rate of removal by up to 10 times if the results for B and D are compared.

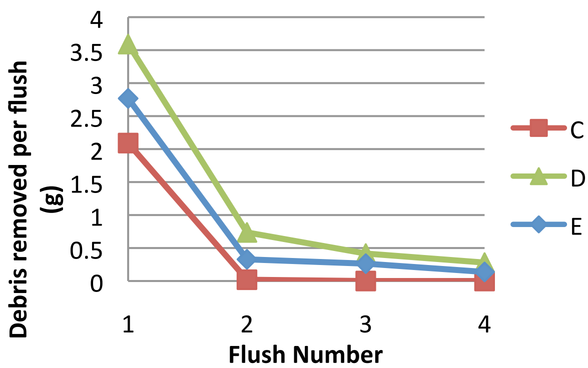

Figure 4. Debris removed per flush for setups using the restrictor

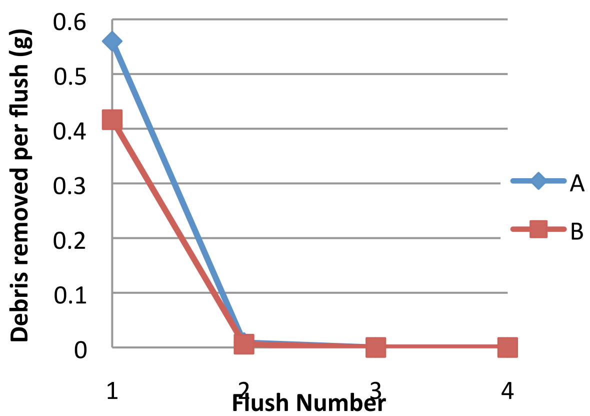

Figure 5. Debris removed per flush for natural overflow systems

For the **natural flow systems** (A & B), only the first flush exhausted had any significant amount of paper pulp. The majority of the pulp obtained from the first flush was extracted within the first 30 seconds. After this initial period, very little or zero pulp was extracted from the remainder of the first flush or any of the other flushes (Figure 5). The rate of removal for the later flushes in setup E & D were small but still had a comparative value (Figure 4), the natural overflow designs had next to zero. For the natural overflow system, it is expected that as the paper pulp has just been mixed and the pipe installed, the pulp fibres settle to the base and cover up the holes in the vacuum pipe. As the flush occurs only the initial fibres blocking these holes are exhausted to make way for the flow of water. The overhead trickle pipe does an excellent job of not disturbing the fibres settled at the base meaning the debris does not get a chance to redistribute. Instead the water flows right above the settled fibres leaving them untouched and therefore they remain at the base of the tank.

Similar trends can be seen in setup C using only the siphon (Figure 4), initially a quantifiable amount of pulp is recorded for flush one and zero for the later flushes. The siphon caused all the debris surrounding the inlet to be collected up in the first flush (Figure 4). The later flushes then had no debris left to collect and the siphon was just left exhausting water from the base. This however does highlight an important limitation to this experiment. Even though this scaled tank vac system is not physically cleaning the tank, it is still exhausting the 'oxygen deprived' water from the base of the tank. This experiment obviously does not account for this. Another issue seen with this setup was a 'blow back effect'. A large amount of water or air travelled back down the pipe after the siphon was killed. This was then observed to push the paper pulp further away from the inlet providing less chance for it to be collected in the later flushes.

It was originally hypothesised that the tree design would perform better overall in comparison to the horizontal pipe due to the larger floor coverage area. It can be seen that this was not the case as the horizontal pipe removed 1.5g more pulp on average (Figure 3). It is expected this is due to the extended floor coverage building up more friction causing some inlet holes to be unused. Covering a larger surface area can be advantageous when the siphon is powerful enough to overcome this increased friction. For this experiment however it proved to be counterproductive, a balance needs to be achieved.

The consistent results of this experiment were highly dependent on how still the sediments remained at the base of the tank and thus a great deal of effort was given to ensure this. It was noticed that the pulp exhausted by a flush would greatly increase the more the sediment was disturbed. For one particular trial, the hose was pointed at the bottom of the base, set to 12 L/min and left there for 8 seconds. This was repeated over four flushes and the results showed a drastic increase in performance (Figure 6). This increased the cleaning efficacy of the tank vac system by 400%. Only one trial was done however so further investigation would be required however this still shows a large potential for improvement.

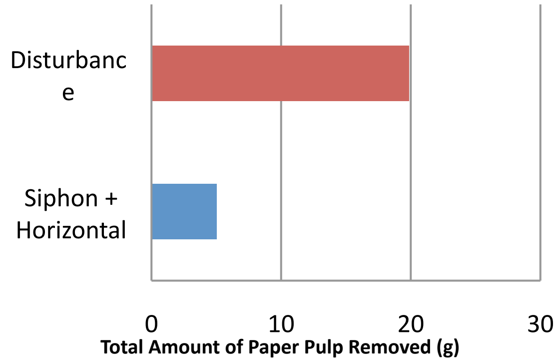

Figure 6. Total debris removed for 'disturbance' theory

5. Conclusion

The added improvements to the system described in the fair testing section were proven to be effective and relatively consistent results were obtained for the first flush. The later flushes were however still inconsistent and required repeat tests to be done to ensure accurate results were obtained.

It was found that the most effective set up was the current tank vac design (setup D), the restrictor + horizontal pipe. This showed that it removed the most amount of debris per flush and in total.

The siphon over flow system increased the exit flow by creating suction in the vacuum pipes drawing in local fibres. Without the siphon the flow rate was natural which produced poor results. The siphon over flow system was shown to perform up to 10 times better in comparison to the natural overflow system.

The vast majority of pulp fibres exited in the first 30 seconds of the first flush with only a small fraction exiting in the later flushes. This was due to the pulp fibres settling on the inlet holes and being collected to make way for the flow rate of water.

It was hypothesized that the tree pipe set up would have a better performance in comparison to the horizontal pipe set up due to more floor coverage. This was not the case as the extended floor coverage created more friction leaving some holes unused.

The results were highly sensitive to movement of the pulp fibres at the base of the tank. It was found that if the pulp fibres are disturbed before the flush occurs, the results can improve up to 400%.

6. Recommendations

It is recommended that tank vacs current design should not be changed as it had the best performance. To

improve the system, a method of applying this idea of 'disturbance' could be to introduce a mechanism that unsettles the sludge each time the system flushes.

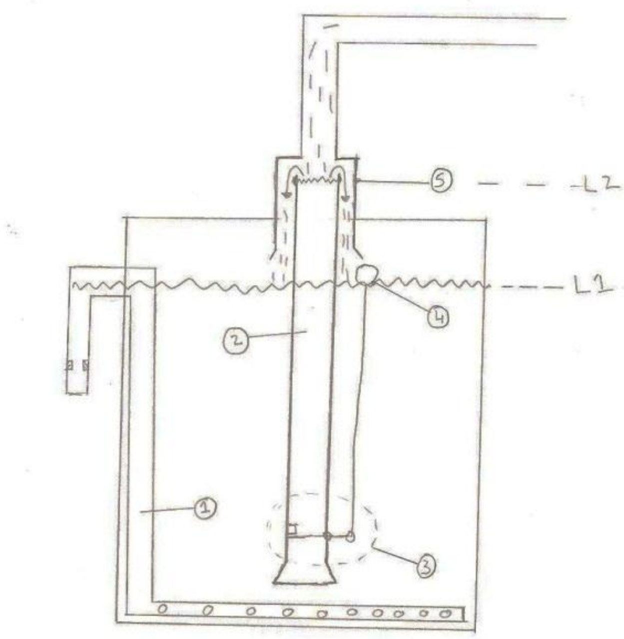

Figure 7. Proposed design to improve Tank Vac system

Figure 7 displays a typical rain water tank (6) with the tank vac system installed (1). The outer pipe (5) is where the rain would enter from the guttering system of a house. This proposed design revolves around the inner pipe (2) and the magnetic valve system (3 & 4). As the rain water enters the tank, it would first full up the inner pipe (2). The shut off valve (3) at this point is closed allowing the water to fill to right to the top. As the rain continues to enter, the water then overflows out to the rest of the tank. Once the level of the tank is sufficient enough to cause an overflow, the buoy (4) will pull on the string attaching it to the magnetic valve (3) and open it. This will cause the water in the inner pipe (L2) to flow out into the base of the tank until it reaches the level at L1. **This flow will disturb the sludge and then begin to siphon the water out**. Provided an optimum system is developed, the sludge should be cleared out ensuring a clean tank each time. The drop in water level will cause the magnetic valve to close and the cycle can begin again.

By implementing this system, the manufacturing cost would be higher however the efficiency could be increased by 400%. More research would be required in order to deem this idea a feasible option or not.

7. Acknowledgements

The author would like to tank Dr Michael Walmsley for supervising this experiment.

8. References

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9. Appendix: Raw Date

Tree + Res

	Test			
Flush	1	2	3	Average
1	2.823	2.351	3.13	2.768
2	0.568	0.183	0.234	0.328333
3	0.278	0.275	0.237	0.263333
4	0.221	0.098	0.094	0.137667
Total	3.89	2.907	3.695	3.497333

Res

	Test			
Flush	1	2	3	Average
1	**2.215**	2.338	1.72	2.091
2	0.028	0.031	0	0.019667
3	0	0	0	0
4	0	0	0	0
Total	2.243	2.369	1.72	2.110667

Hor + Res

	Test		
Flush	1	2	Average
1	3.267	3.917	3.592
2	0.592	0.881	0.7365
3	0.447	0.386	0.4165
4	0.315	0.244	0.2795
Total	4.621	5.428	5.0245

Base Design

	Test		
Flush	1	2	Average
1	0.526	0.594	0.56
2	0	0.018	0.009
3	0	0	0
4	0	0	0
Total	0.526	0.612	0.569

Horizontal

	Test		
Flush	1	2	Average
1	0.321	0.512	0.4165
2	0	0.012	0.006
3	0	0	0
4	0	0	0
Total	0.321	0.524	0.4225

Extra Test

Flush	
1	6.62
2	7.304
3	2.695
4	3.254
	19.873