INVESTIGATING THE PULSER PUMP

BY

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PROVISO

Any who wish to use this work may, provided it is referenced where appropriate. Distributing a final research dissertation is not the norm, but this is a courtesy which has been extended to Mr. Brian White for his interest and assistance.

This work was created for a final year project and the ‘Supervisor’, i.e. Mr. Brian Skinner was permitted to see a section of this work once before the final submission (5 months before). Please bear this in mind when using this work and exercise discretion as some areas would have benefit from being adjusted and clarified. In particular this relates to, but is not limited by; confusion over the physical meaning of the variables in Dachos’ paper and the actual driving head used during the experiments carried out within this paper.

Abstract

The Pulser Pump has the innate advantage of being a non-mechanical pumping device, it is unlikely to break down and after initial setup it is self-sustaining. Despite this, there is significant reluctance to adopt this technology in the scientific community. One reason for this is the lack of knowledge of how it operates. By designing and constructing a suitable laboratory model based on theory and practice, two experiments were designed and performed in order to answer a series of research questions and thus develop the knowledge base of the Pulser Pump. These experiments found that inflow, pumping height and the number of riser pipes to be critical variables. It was also discovered that there is potential for the Pulser Pump but that it suffered in practicality. It concluded that in order to fully realize this potential further research must be done.

Certificate of Authorship

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> Each and every quotation, diagram or other piece of exposition which is copied from or based upon the work of others has its source clearly acknowledged in the text at the place where it appears.
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> All practical work has been carried out by me with no more assistance from members of the department than has been specified.
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> All additional assistance which I have received is indicated below and referenced in the report.”

Name: MICHAEL TURNER

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Acknowledgements

Firstly, I would like to thank my supervisor, Mr. Brian Skinner for his continued support and guidance throughout the duration of this dissertation, without whom this would have been significantly more difficult. I am truly indebted and thankful for his assistance in all aspects of the research undertaken.

Secondly, Mr. Brian White; with no obligation to help me he used his personal time and went to admirable lengths to provide assistance where it was required, especially regarding the theory of a working laboratory model. Furthermore, and perhaps most importantly, without Mr. Whites' continued effort to bring the Pulser Pump to the attention of the scientific community this project would never have been conceived.

Lastly, my gratitude extends to all members of the Loughborough University laboratory staff, and in particular Mr. Mick Barker whom provided significant assistance with regard to the specific design aspects and the construction of the laboratory model where my experience was very limited.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

PP	Pulser Pump	SC	Separation Chamber	PH	Pumping Height
HT	Header Tank	RP	Riser Pipe		

1 Introduction

The Pulser Pump (PP) is a non-mechanical method of pumping air and water to an elevation above the source water. It does not rely on conventional means such as pumps that are powered by motors or by-hand. The air entrained by the inflowing water is compressed and upon depressurisation it lifts the water in a small diameter pipe. Once the system is up and running it can provide a constant supply of free water and it requires minimal components for construction and has no moving parts. Directly, the intention of using the PP would be to pump water but indirectly the air used in pumping the water is output in a cool and dry state, similar to that of air-conditioning. There are inherent advantages to utilising the PP and its' applications are diverse. Beside what is stated above it has been used to:

- Aerate water (Removes Sulphur, Nitrogen and Phosphorous compounds) which provides a better environment for marine life.
- Decompose animal slurry faster, also removing the threat of hydrogen sulphide gas build-up by pumping air into the waste.

Unfortunately, thus far there has been a reluctance to adopt the PP, its' low output volume and seemingly controversial nature probably haven't helped. Decades and centuries ago, before the introduction of motorised power the PP would have fit perfectly within day-to-day life. However, there is an arguably common belief that in a world of industry and motorised power that inventions and small-scale projects like the PP are a step-back and have no-place in our world. They have become shadowed by a continual urge to push-forward with technology.

"Wisdom demands a new orientation of science and technology toward the organic, the gentle, the elegant and beautiful."

— *E.F. Schumacher, Small Is Beautiful: Economics as if People Mattered (2011)*

The very low-level of adoption of the pump is partly due to the minimal amount of published material available. There are clear gaps in knowledge, and it seems that nothing has been formally published about the pump. This report shall be the first formal laboratory investigation which is specific to the PP, detailing it's working principles, critical variables affecting its' performance and determining if there is still a place for technology like this in our world. The PP is wholly under-utilised and the content herein shall bring knowledge of the PP to a wider audience, providing a foundation that can be built upon.

1.1 BACKGROUND

Knowledge of the Pulser Pump is scarce, and its' origins are hazy; there exists limited information relating to the actual pump and this is evident as it's invention was believed to be the first of its' kind by Brian White in 1987. However, it is now accepted that Charles H. Taylor in 1896 was the original inventor, albeit indirectly. He utilized the principles involved in the pumps operation to pump dry and cool air into mining facilities, defining it as a 'Hydraulic Air Compressor' (HAC), the most successful adoption of the HAC was the Ragged Chutes Compressed Air Plant in Canada, designed, engineered and built by Taylor himself (H 2009). The principles behind both the HAC and the PP are exactly the same, hence the origin of invention lies with Taylor; the difference between the HAC and PP are the intended outputs. The HAC used the water to cool, and pump the air into mines, and the water used in this process was disregarded and considered a by-product of generating the clean air. The PP used compressed air to pump the water and despite the objective of the HAC to pump air, it did emulate the PP and pump water indirectly. In the Ragged Chutes Plant when the pressure became too high the air would force the water level below that of a submerged release pipe and blow the water out, resulting in a geyser plume. (H 2009).

1.2 SCOPE AND OBJECTIVES

1.2.1 Scope

The scope of the report is fairly broad. It aims to develop and build upon existing knowledge of the PP by investigating critical operational variables which define the performance of the pump. In accomplishing this, attempts to improve its' output and assess its' suitability/applicability in developed and developing countries can be made. Furthermore, a foundation has been set with clear direction for suggested future work. There are limitations to the report which have been detailed in Chapter 5: Discussions and Conclusions.

1.2.2 Objectives

1. Review the current progress of investigations on the PP and identify the areas for testing.
2. Provide a working laboratory model where the areas for testing as identified in Objective 1 can be executed.
3. Assess the results and provide a brief evaluation to the potential suitability/applicability of the PP in developed and developing countries.

1.3 POTENTIAL IMPACT OF RESEARCH

The research undertaken in this report is unlikely to provide anything ground-breaking to the scientific community, rather it will serve as the most comprehensive report of the PP to date which illustrates many of the variables which affect the PP. The greatest impact of this research is the possibility of another researcher taking this fundamental and broad approach of the PP to new heights by investigating other areas as recommended in Chapter 5: Discussions and Conclusions. The PP has clear potential to be tapped and it deserves the attention of other investigations; a hope of this report.

1.4 AN OVERVIEW OF THE DISSERTATION

1.4.1 Chapter 1: Introduction

This chapter introduces the Pulser Pump (PP) as the research to be undertaken, including its' origin and background, the current state-of-the-art, the intentions of the report and the means by which these intentions will be fulfilled.

1.4.2 Chapter 2: Literature Review

This chapter calls upon all discovered literature which has been deemed relevant and useful to understanding the working operation of the PP and variables which affect it. The content within this section acts both as a starting point of designing the research questions and experiments, and as a reference point for the analysis of the results.

1.4.3 Chapter 3: Methodology

The methodology chapter details all the steps taken during this report, from acquiring research sources to designing and building the experiments, and finally to the analysis methods utilised in assessing the results. Justifications of all decisions made are also provided here.

1.4.4 Chapter 4: Analysis and Synthesis of Results

Those results captured in line with the methodology will be analysed here using a series of graphical plots and specific statistical functions. This chapter seeks to explain the relationships between the variables involved in the operation of the PP, and the degree to which each is critical. This is the data and justifications which the conclusions are based upon.

1.4.5 Chapter 5: Discussions and Conclusions

This chapter relates the findings of the analysis back to the original objectives of this report which are stated in Section 1.2 and determine whether or not they were achieved. Limitations to both the report and the experimentation will also be discussed along with clear direction and recommendations for future research on the PP.

1.4.6 Chapter 6: References

This chapter lists all of the references used during the writing of this report. As the amount of information about the PP is minimal this chapter isn't particularly large and so much of the work herein has been developed first-hand.

1.4.7 Chapter 7: Appendices

All supporting information which helps to supplement all chapters is included within this section.

1.5 TIME MANAGEMENT STRATEGY

A GANTT chart was created to plan out the time-frames for each element of this report. This chart was updated as often as possible throughout the course of this research project; the final chart can be seen in Appendix C – Time Management. Time was a major issue with this project, a significant portion of this was taken up during the 'Methodology' section, much longer than originally intended, which concerned everything regarding the laboratory design, setup and data capture. Essentially, everything was created from scratch.

2 Literature Review

The following section aims to collate existing knowledge of the Pusler Pump (PP), and the principles of its’ operation in order that appropriate investigations are carried out to fill some gaps in knowledge.

To date there is a lack of formal and published information on the PP. The only information found specific to the actual PP are videos from Brian White (2011b), descriptions, drawings (White, B 2003c) and an informal laboratory report of a miniaturised PP that the author themself (Dacho, 2012) have noted its basicity.

Secondary, and supplementary information gained included descriptions of Vortex Flow, Air-Entrainment and Two-Phase Flow in order to fully describe each operational phase with working principles. By obtaining this information a formal and comprehensive laboratory report of the PP was produced, providing an ‘official’ foundation for further research to begin.

A third area in which literature was sought was that which relates to the minimum required water-consumption for human use in different parts of the world. The third objective, “Assess results and provide a brief evaluation to its’ potential suitability/applicability for situations in developed and developing countries” and the acquisition of this information contributed to achieving the third research objective.

Although it is not the norm, at this point it must be re-iterated that prior to this report there existed a modicum amount of information and results upon the PP. Part of this review of literature is to ascertain how the PP works by collating and analysing the bits and pieces of information available. There is only one document (Dacho, 2012) showing similarities to that of a laboratory report on the PP; despite the report being uploaded to a website named ‘Appropedia’, which carries the same controversies as ‘Wikipedia’, according to Brian White through email conversations the content originates from a laboratory report produced by students in the Civil Engineering department of Queens University in Toronto. The original report was requested multiple times, but unfortunately it was never acquired and so discretion must be exercised.

2.1 General Operating Principles

Hoffman (2002) states that the PP is essentially a combination of two devices, a 'Trompe' for entraining the air and an 'Air-Lift Pump' for lifting the air; a trompe (Figure 1) is a device most commonly used during the Iron Age where it provided a steady stream of air for use in mines and furnaces. In the trompe, water falls down a standpipe, and air is drawn into the water through orifices in the pipe. In the PP, this entrainment process is via a vortex, and White (2003c) describes it as "the same basic principle that sucks air down the sink or bath plughole when you pull the plug". The energy of falling water pressurises the air within the water and when the water enters a larger space, called the Separation Chamber (SC) the widening of the route causes the velocity of the water to slow, the air is released from the water and rises to the top of the chamber. For a Trompe used during the early centuries the air was then tapped off to provide a stream of air for use in mines and furnaces, such as a Catalan Forge (Hunt 1977, Taylor 1951).

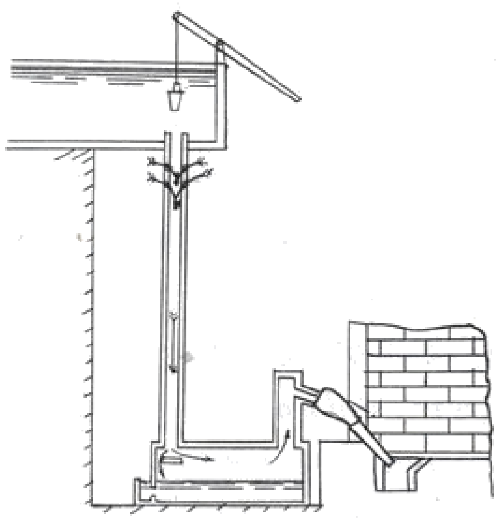

Figure 1: The Trompe (Taylor, 1951)

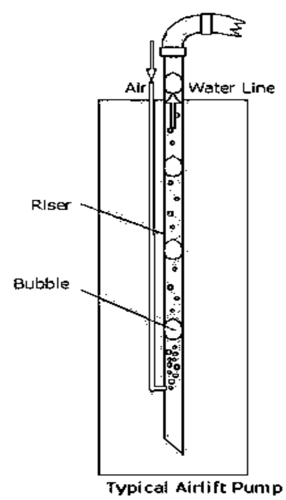

Figure 2: The Air-Lift Pump (Bogdan, 2006)

The second-stage of the PP emulates the operation of an 'Air-Lift Pump' as can be seen above in Figure 2. An Air-Lift Pump is a means of artificially lifting a liquid, and the air-lifting operation depends on the injection of air into the bottom of a pipe that is partially submerged in liquid (Khalil et al. 1999). The buoyancy of the air injected causes it to rise and lift water with it. The PP is simply a combination these two processes, it uses the Trompe as a means of organically entraining air into the water, and the air is tapped off to drive the water up the Riser Pipe (RP). Figure 3, seen below is a sketch of the combined working principles.

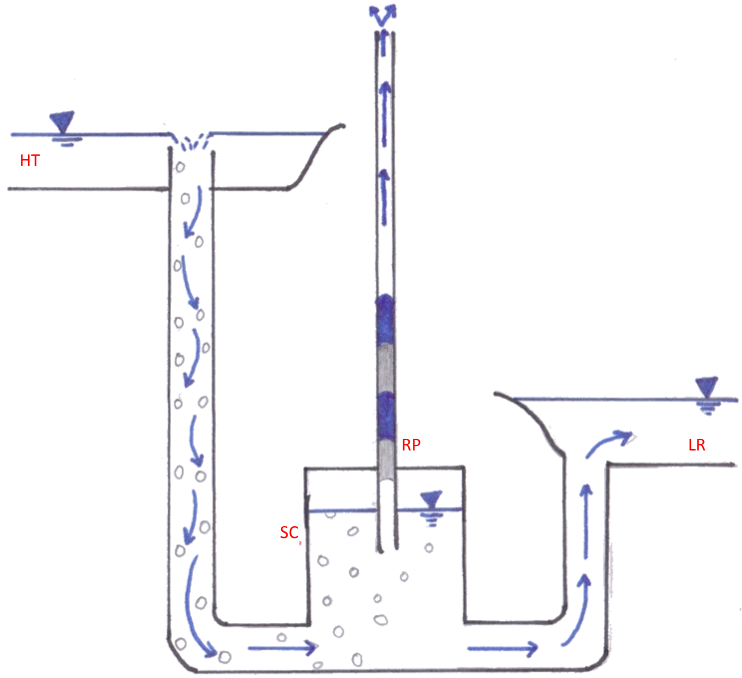

Figure 3: Pulser Pump Operating Principles

As can be seen from the figure above there exists a 'Trompe' section and an 'Air-Lift' section. The standpipe that is partially submerged below the water level in the Header Tank (HT) acts like a plughole, (White B, 2003c). When the water falls it 'sucks' air along with it as shown by the air bubbles; the volume and velocity of the falling water then acts to compress the air. As the water enters the Separation Chamber (SC) the expansion of the route causes the velocity of the water to slow, and allows the compressed air to rise to the top of the SC. The water carries on flowing to the Lower Reservoir (LR). The RP that extends below the water level on the SC is 'loaded' with a slug of water. As the process continues there is a build-up of air pressure in the SC; as this increases it correspondingly forces the water level in the SC to lower. When the water level reaches the bottom of the RP, some of the compressed air shoots into the RP and carries a slug of water up the pipe. There is a sudden depressurisation of the SC as the water level rises due to a lower volume of compressed air. A cyclic process of pressurisation and depressurisation develops, hence the naming identifier 'Pulser'.

In an e-mail conversation with Brian White (2012a), he advised that for the PP to work the SC had to be pressurised, hence the need for a LR to provide opposite water pressure head.

2.2 SPECIFIC OPERATING PRINCIPLES

As stated in the introduction of the literature review there exists what appears to be an informal laboratory report (Dacho 2012) carried out by a student of Queens University in Toronto. Throughout their report and from observation of their own experiment they introduce certain specific elements of how the PP operates and take a focus on flow regimes. Unfortunately, the report is inconsistent with the amount of detail it goes into and fails to consider other elements to the PP operation. In order to create an appropriate experimental situation it is necessary to consider all elements of the PP operations despite some of these elements only being hinted at in previous documents.

2.2.1 Vortex Flow and Air-Entrainment

The report by Dacho (2012) notes that the water is in a state of turbulent flow but she fails to elaborate or give evidence for this statement. However, Douglas, et al. (2005) describe turbulent flow as stochastic and characterized by continuous small fluctuations in the magnitude and direction of the velocity of the fluid particles, accompanied by corresponding small fluctuations in pressure. In order to determine if flow is laminar (water moves in parallel unison) or turbulent the Reynolds Number (Re) is used. A Reynolds number below 2000 describes laminar flow, and above 2000 is turbulent.

A component of turbulent flow is the formation of vortices, and Douglas, et al. (2005), note that water flowing through a central hole in a container is an example of a free vortex. This is not dissimilar to the experimental setup defined in Chapter 3: Methodology of this report. Conservation of angular momentum is a function of velocity, mass and distance and so the wider the radius of the vortex the slower it spins. Conversely, the smaller the vortex radius the faster it spins (Noguchi et al. 2003). At the point of water release, say like a plug in a sink, there are suction forces generated by the water falling down the pipe; causing a change in velocity. With reference to Noguchi, et al. (2003) the differential velocity between fluid particles at the centre, compared with those at the outside causes a spinning motion and thus generates a vortex. The suctions forces that are present also suck air into the ‘drain’ and the volume, and velocity of the water keeps the air from escaping. See Figure 4 which illustrates the generation and effect of water falling through a hole.

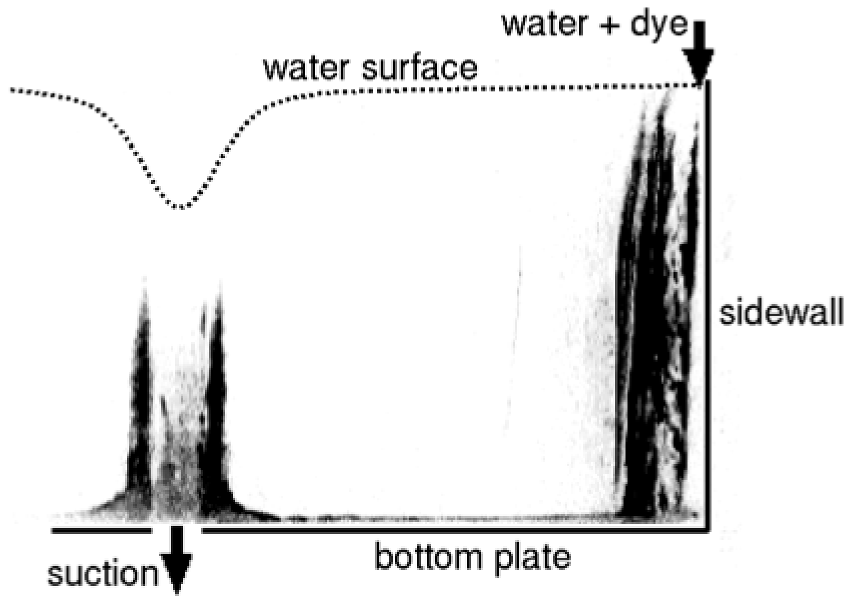

Figure 4: Vortex and Suction (Noguchi et al., 2003)

2.2.2 Multi-Phase Flow

The report by Dacho (2012) contains their attempt of the scientific model of the theory of the PP. Only considering the pumping phase of the PP, they neglect elements described above such as Vortices and Air-Entrainment. Their explanations are basic, but provide enough information (through observation) to allow for another portion of literature to be searched, that of Two-Phase Flow which relating back to this dissertation emulates the second part of the PP, which is essentially an Air-Lift Pump. In actual fact the term 'Two-Phase Flow' is part of a more general term 'Multi-Phase Flow' which considers two or more mediums flowing together. Bar-Meir (2011) provides Figure 5, showing the potential combinations for multi-phase flow, it can be clearly seen that it's not simply just solid-liquid or liquid-gas, it can also be solid-solid, or even liquid-liquid-solid-gas. Importantly, Bar-Meir (2011) also notes that the air around us is often considered a single-phase as a homogenous assumption, but "air is made of well mixed gases", and there are some cases in which "air-flow must be considered multi-phase".

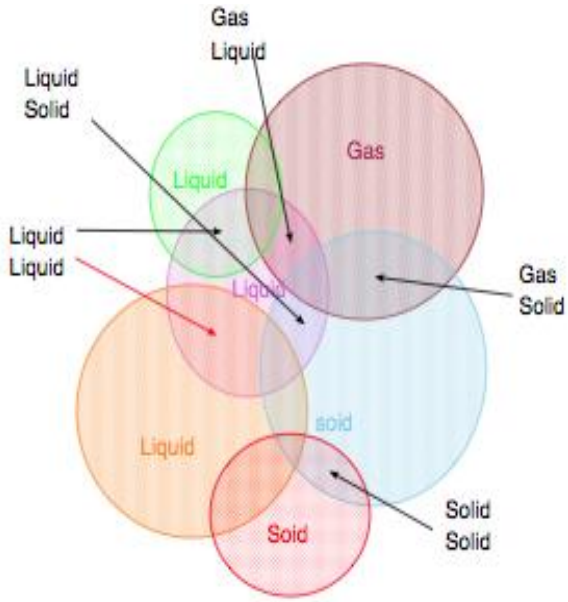

Figure 5: Multi-Phase Flow Combinations (Bar-Meir, 2011)

The report on the PP by Dacho (2012) notes that there are "at least seven different regimes of two-phase flow", again the author fails to elaborate but claims that their PP exhibited "several" during the course of experimentation. In contrast, Bar-Meir (2011) presents potential for five different regimes (Figure 5) and describes the formation of the slug flow in the Riser Pipe (RP) of the Pulser Pump (PP) and how its' formation differs depending on the verticality or slope of the RP. Dachos' (2012) description of slug flow is bland and illustrates the process by a horizontal image, although this helps the reader to appreciate what slug flow is there is a difference between vertical slug flow.

Conversely to horizontal flow, Bar-Meir (2011) explains that when flowing against gravity the fluid must occupy the entire cross-section of the pipe. An important principle is also detailed, that for flow against gravity the lighter medium (assuming two-phase flow liquid-gas) acts as a buoyancy force, while the effect of gravity acts to weigh down the heavier medium. The heavier medium is "more dominated by gravity (body forces)", while the lighter medium is "more dominated by the pressure driving forces". (Bar-Meir 2011)

To further this, the pressure forces causing the air to rise through the water form as small bubbles, labelled 'bubble flow', the increase of air leads to the collision and subsequent accumulation of these bubbles. When a large bubble is formed it is described as a 'slug'. At this point Dacho (2012) makes no mention of the other flow regimes, indicating that only bubble and then slug flow occur during the air-lift phase of the PP. However, if the air content keeps increasing a 'super slug' is formed, named 'Churn Flow', continual increase yields 'Annular Flow', which is essentially a column of rising air that dispels liquid to the outer part of the tube (Bar-Meir 2011).

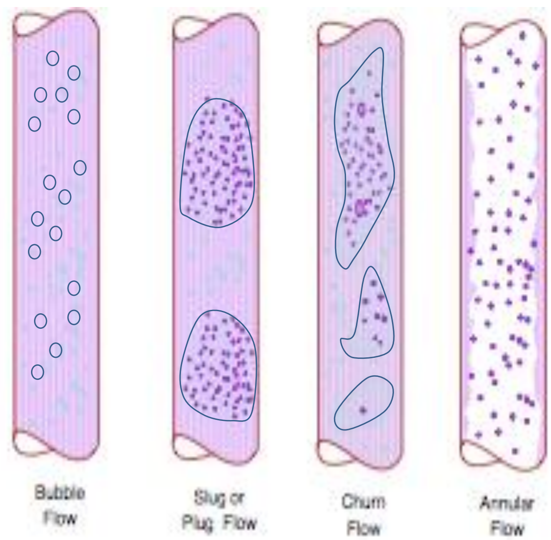

Figure 6: Vertical Flow Regimes (Bar-Meir, 2011)

From the above image (Figure 6), it can be seen that minimal flow of liquid shall occur if the flow regime enters the 'Annular' flow stage and so it seems logical to keep the flow among 'Slug' or 'Churn" flow. Certainly, experiments conducted by Kouremenos and Staicos (1985 cited in White, SJ. 2001) appear to agree concluding that the most efficient flow regime was in-fact slug flow. White (SJ., 2001) also elaborates on this claim noting that following experiments there exist optimum operating conditions for maximum efficiency of an airlift pump at specific diameters of RP(s). The findings indicate that the optimal solution is very close to the transition from slug flow to churn flow.

Interestingly, to supplement this claim and provide further guidance to the experiments described in Chapter 3: Methodology section of this report, Nickin (1963 cited in White, SJ. 2001) speculated that increased efficiency might be obtained by using small-diameter tubes below a diameter of 20mm, in doing this the surface tension which promotes slug flow will be more dominant. Email correspondence (White, B. 2012a) suggested an idea to bundle a number of 6mm (0.25") internal diameter tubes together as an option to test, according to the above sources this will promote an increase in surface tension and likely ensure the flow is slug or churn. This may also explain why Dacho (2012) only mentions slug flow, their RP diameter was approximately 19mm (0.75"), just below the 20mm margin suggested by Nickin (1963).

Dacho (2012) claims “For flow in the slug regime, the diameter of the tube allowed depends on the speed of the flow and its’ viscosity”, however no reference is provided to support this claim and their experiments do not test the diameter of the RP(s). White (SJ. 2001) conducted experiments on a powered air-lift pump (recall this pumps air directly into a submerged Riser Pipe (RP)) and observed variables that were affecting the flow-regime. At “low airflow rates bubbly flow was observed, but it did not pump the liquid up the tube at all. Upon slowly increasing the airflow rate, bullet shaped bubbles which occupy almost the entire diameter began to form” (White, SJ, 2001). Importantly, White (SJ. 2001) observes that if the airflow rate continues to be increased then the flow regime will transition to churn and then annular flow, which resulted in intermittent, and unstable water discharge from the top of the tube. At this point it is appropriate to introduce the results provided by Dacho (2012); one claim in particular stands out “It is expected that as the hydraulic head (of the Header Tank (HT)) increases, the flow rate (of the Riser Pipe (RP)) will also increase. This effect was demonstrated by the pump and results are shown below”. The results have been dissected in greater detail and are presented on the forthcoming pages but this claim is the opposite of the observations experienced by (White SJ. 2001), and Dachos’ (2012) results completely disprove her own claim. The results (Dacho 2012) show that by increasing the hydraulic head, the flow rate decreases. When one relates this to flow regimes this suggests that increasing the hydraulic head increases the airflow rate, and the consequence of this shall be the introduction of churn and annular flow, thus yielding a lower flow rate, as illustrated by their results. It appears that her interpretation of her own results (Dacho, 2012) is incorrect in this case.

2.3 REVIEW OF PUBLISHED RESULTS ON THE PERFORMANCE OF THE PULSER PUMP

The document, “Pulser Pump”, by Dacho (2012) based on a report for Queens University in Toronto builds upon work by others, including that of Brian White. This is the only document discovered in the literature review with any semblance of results that are specific to the PP, and they are mediocre at best. The report states, “It is expected that as the hydraulic head increases, the flow rate will also increase”, but it fails to elaborate on the claim and does not return to that statement after the results were found. The results themselves have been presented in such a way to make drawing any conclusions difficult. See Figure 7 below, taken from said report. The lack of analysis has ensured the results are inaccessible to the reader, and from the point of view of this report it is necessary to explain their results to broaden the picture of what is expected in the experiments forthcoming. See Figure 8 for an interpretation of Dachos’ (2012) variables.

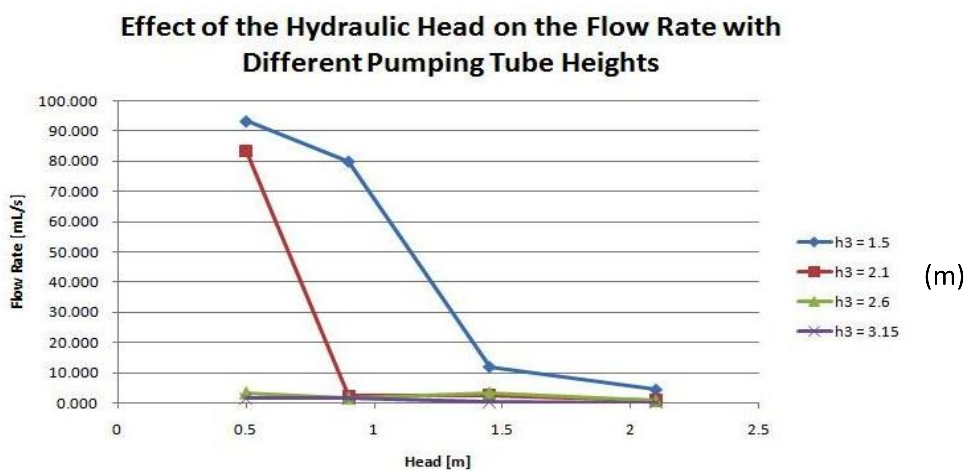

Figure 7: Hydraulic Head vs. Flow Rate through the RPs' (Dacho, 2012)

Firstly, each line represents the flow rate out of individual Riser Pipes’ (RP) set at different pumping heights, i.e. the blue line illustrates a fixed RP height of 1.5m. Secondly, the axes are Hydraulic Head vs. Flow Rate (through the RP), located on the variable x-axis and the measured y-axis respectively. Taking into account the blue line it shows that as the hydraulic head increases, the flow rate decreases and zeros off at approximately 2.1m. Comparatively, when considering the red line with a RP height of 2.1m, the same happens but no flow is reached at approximately 1m of head. For RP heights of 2.6m (green line) and 3.15m (purple line) there is insufficient head to pump almost any amount of water. The results are insufficient in number, and it could be argued that the graph has been plotted incorrectly; in any case the results shown here disprove their hypothesis that as the hydraulic head increases so does the flow rate.

Despite this mix-up the hypothesis they chose is certainly logical, an increase in hydraulic head increases the water pressure, and consequently the compression experienced by the air (since water is incompressible), leading to an increase in airflow rate and thus liquid flow rate out of the Separation Chamber (SC) and into the RPs'. As explained earlier research from White (SJ. 2001) suggests an 'upper-limit' to the airflow rate as a continual increase will introduce churn and annular flow in the RPs'. However, it is interesting, and perhaps surprising that if this is what happened, then Dachos' (2012) report should have contained information and observations of not just slug flow, but churn and annular flow. In any case, this is an area that will benefit from being clarified. It further reinforces the idea that sources that are not peer-reviewed should be approached with discretion.

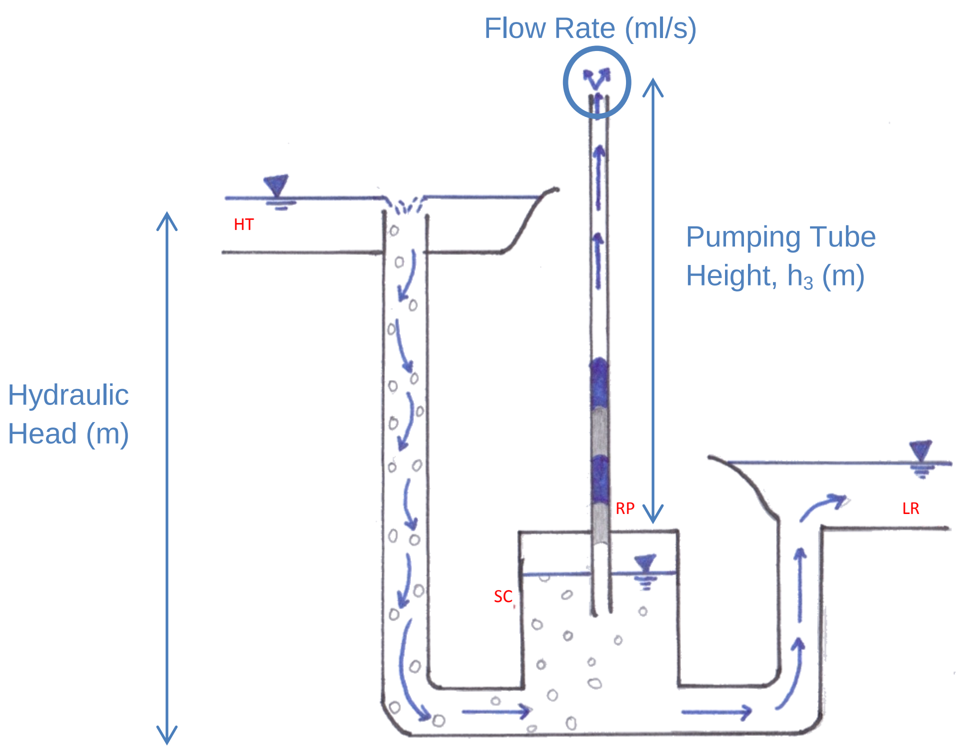

Figure 8: Interpretation of Dachos' (2012) Variables

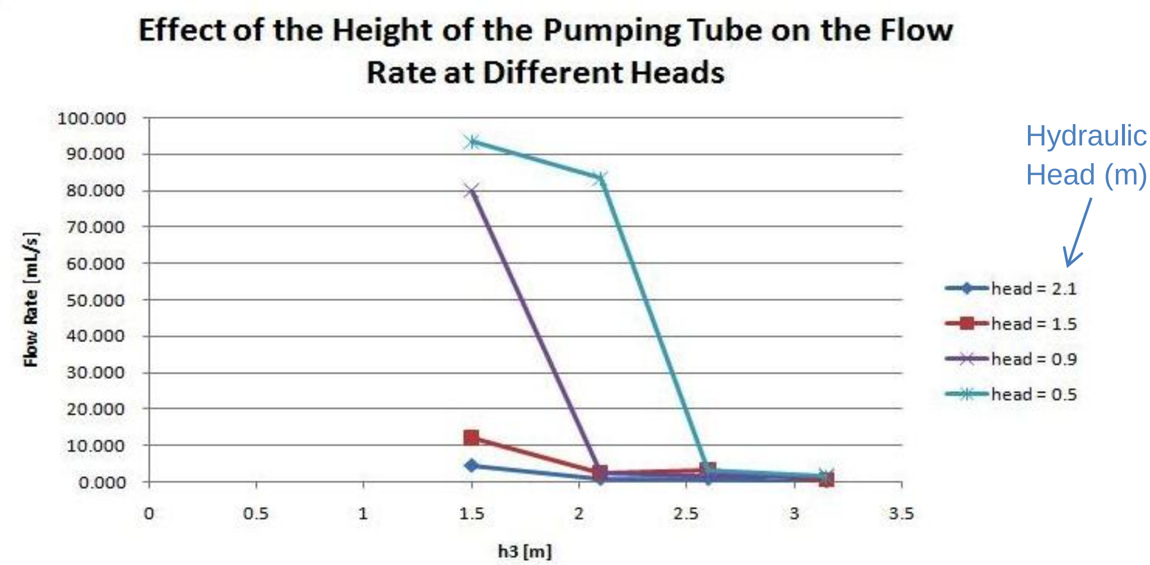

Figure 9: Effect of the Height of the Pumping Tube on the Flow Rate at Different Heads (Dacho, 2012)

The comment associated with this graph is “As the height of the pumping tube increases, more energy is required for the pulses to reach the top of the tube”. The ‘pulses’ referred to are actually slugs of air and water that shall be investigated in the coming pages. The results appear to be in-line with her comment but again the findings are not developed. Subsequent to these graphs Dacho (2012) combines both sets of results into a 3D graph, see Figure 10 below, and notes that the plot shows how the “flow-rate depends on both hydraulic head and the height of the pumping tube”.

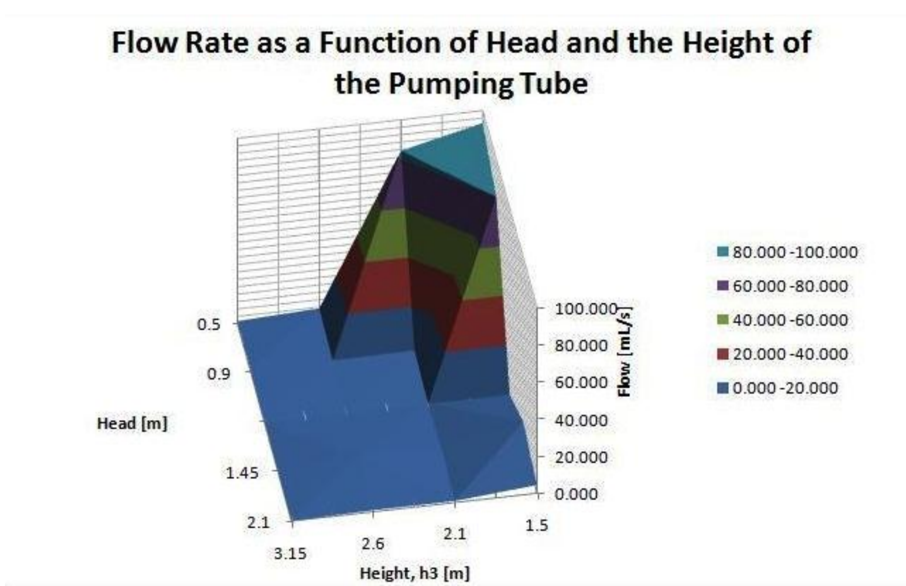

Figure 10: Hydraulic Head vs. Riser Pipe Height vs. Flow Rate (Dacho, 2012)

The flow-rate does depend on both the hydraulic head and the height of the pumping tube, which can be seen without the need for a 3D graph. However, the pumping heads are all very low, limiting the potential applications for the pump. The only advantage to using this graph is visualizing the optimal solution, namely high head and low pumping height, and defining a region where flow-rates based on hydraulic head and pumping head can be approximated. If one required an approximate solution it would be more appropriate to obtain the equations of the two 2D graphs and work them independently.

Dacho (2012) notes that problems were encountered concerning the reproducibility of results, describing them as "questionable". Leading on from their conclusions they provide recommendations for future work. Importantly, they note that the experimental model would greatly benefit from a peer review and specifically state that the experimental model should be "tested using a more rigid testing scheme, with many more tests at each height and head"

2.4 USES OF THE PULSER PUMP

According to Howard and Bartram (2003), the minimum water quantity for basic health is 20 l/c/d, of which about 7.5 litres is required for consumption. This figure is recalled upon in Chapter 4: Analysis and Synthesis of Results and compared with the water quantity found during experimentation.

2.5 SUMMARY

The state-of-the-art is as follows; there is minimal literature available which is specific to the PP, and the information that does exist is wholly under-developed regarding its' performance and applicability. It becomes appropriate to suggest that the performance of the pump can be increased, or at least tested in numerous ways to provide a more thorough understanding to its' operation, at which point potential uses can begin to be investigated. The following chapter will detail all aspects of the route taken for investigation and justify all decisions made.

3 Methodology

After reviewing a series of appropriate literature this section aims to describe and illustrate all the workings undertaken to build upon the currently very limited literature and justify those choices made that have led to the results provided in Chapter 4: Analysis and Synthesis of Results.

3.1 PHILOSOPHY

Recalling Chapter 1: 'Introduction' the Pulser Pump (PP) has the innate advantage of being powered by nothing but compressed air. There has been no formal publication of research and its' existence and potential are wholly unknown in the scientific community. A formal investigation into this area shall at the very least provide a foundation so further work can be done and the potential of the PP tapped. In order to provide this foundation the controlling variables must be found. As such the research questions were aligned to expose those variables by creating and developing appropriate laboratory experiments that would lead to the accomplishment of those objectives defined in Section 1.2:

1. Review the current progress of investigations on the PP and identify the areas for testing.
2. Provide a working laboratory model where the areas for testing as identified in Objective 1 can be executed.
3. Assess the results and provide a brief evaluation to the potential suitability/applicability of the PP in developed and developing countries.

The research questions were developed based on a review of literature that constituted liaison via e-mail with Brian White, a review of an informal PP publication by a student of Queens University in Toronto and further areas of interest deemed appropriate from the said research. The culmination of the literature and subsequent understanding led to the development of Research Questions and corresponding hypotheses as given in Section 3.3

3.2 APPROACH

At the beginning of this project little information was known about the PP, and the lack of information as has been mentioned previously did not bode well for the understanding of it. One crucial piece of the puzzle was Brian White; recalling Section 1.1 it was believed that he was the original inventor, but despite this not being true his independent discovery of the PP has only played to the advantage of this report. Mr. White had conducted various tests upon the PP (20 years prior) and provided explanations as to the operation of the pump; essential where formal publications did not exist. Thankfully, it was possible to make contact with him initially through his personal website and then email correspondence thereafter which proved most valuable. He was in all terms the primary research source, hugely helpful, reliable and provided direction where more information could be gained. Unlike many other projects it was irrational to begin to develop the laboratory experiment without the input from Mr. White. As such contact was sought at the very beginning of the project before any laboratory decisions were made.

3.3 STRATEGY, DATA COLLECTION AND DATA ANALYSIS

Research questions were designed to be broad in order to have the capacity to incorporate a degree of flexibility for variables of the PP operation. Consider if the research questions were too specific then the experiments, results and conclusions would be too focused on a singular function and unable to consider other effects; wholly inappropriate for an experiment where so little research has been undertaken. The research questions were as follows:

1. By increasing the water inflow, does this correspond with an increase in outflow through the Riser Pipes (RP)?

Hypothesis: Increasing the inflow shall cause a corresponding increase in outflow through the RP, up to a limit upon which further increase shall yield a decrease in outflow.

Justification: By increasing the inflow, the volume and degree of air-compression (due to increased velocity) will provide the ability to pump more water. However, too much air, as discovered in Chapter 2: 'Literature Review' will prevent the formation of the slug flow regime and replace this with churn, followed by annular flow, both of which lift considerably less water than slug flow.

2. By increase the pumping head, does this correspond to a decrease in outflow through the RPs?

Hypothesis: Increasing the pumping height (PH) will cause a significant drop in the outflow.

Justification: By increasing the PH this will increase the energy required of the pressurised air to overcome forces such as the friction of the internal wall of the RP.

3. By increasing the number of RPs does this correspond with an increase in outflow?

Hypothesis: Increasing the number of RPs will increase the outflow, provided there is sufficient inflow to satisfy the RPs.

Justification: By increasing the number of RPs' to carry water then the total volume carried will probably also increase; the extent to which is unknown but it would be expected to be a proportionate increase.

With the 1st phase laboratory setup with a singular RP, research questions 1 and 2 could be investigated simultaneously in a single experiment, labeled 'Experiment 1'. The 2nd phase laboratory setup 'Experiment 2', investigated Research question 3; some of these results were applicable in aiding the investigation of research questions 1 and 2, so much of the data could be inter-linked with each other.

3.3.1 General Laboratory Design

The basic laboratory model for data collection was setup based on information gained throughout the literature review. Significant pre-lab setup was required; this included acquiring a suitable position in the laboratory, acquiring a tower scaffold, modifying this where necessary and then the task of sourcing materials and building the equipment into a working model. This constituted a significant portion of time; Figure 11 shows the initial lab setup sent to Mr. White via e-mail for comments. This first iteration was very early in the design stage, more of a concept for the purposes of the risk assessment but it didn't vastly alter when compared with the final setup.

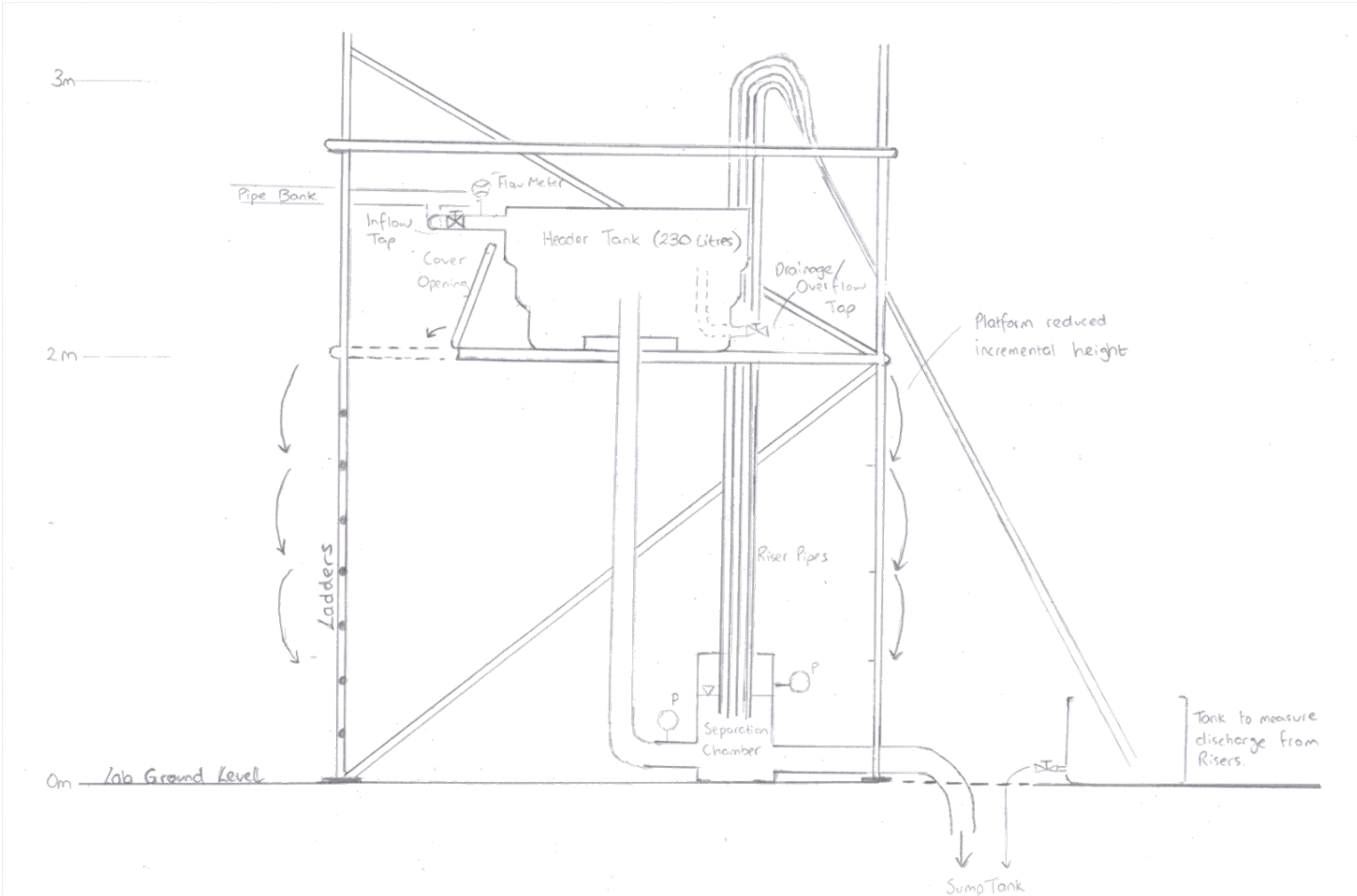

Figure 11: Initial Lab Setup Sketch

Upon receiving the lab setup, Mr. White suggested that the Separation Chamber, (SC) must be pressurised in order for the pump to operate. To achieve this there was a need to generate opposite water head, the result of which is Figure 12. The SC was positioned below the ground the level of the lab, and the outflow pipe leading from this chamber was vertical. Therefore as water flowed through the system the vertical outflow pipe would generate water head and pressurise and contain the air in the SC. This is best illustrated on Figure 12 which Mr. White confirmed should work and provided ballpark pipe dimensions to use.

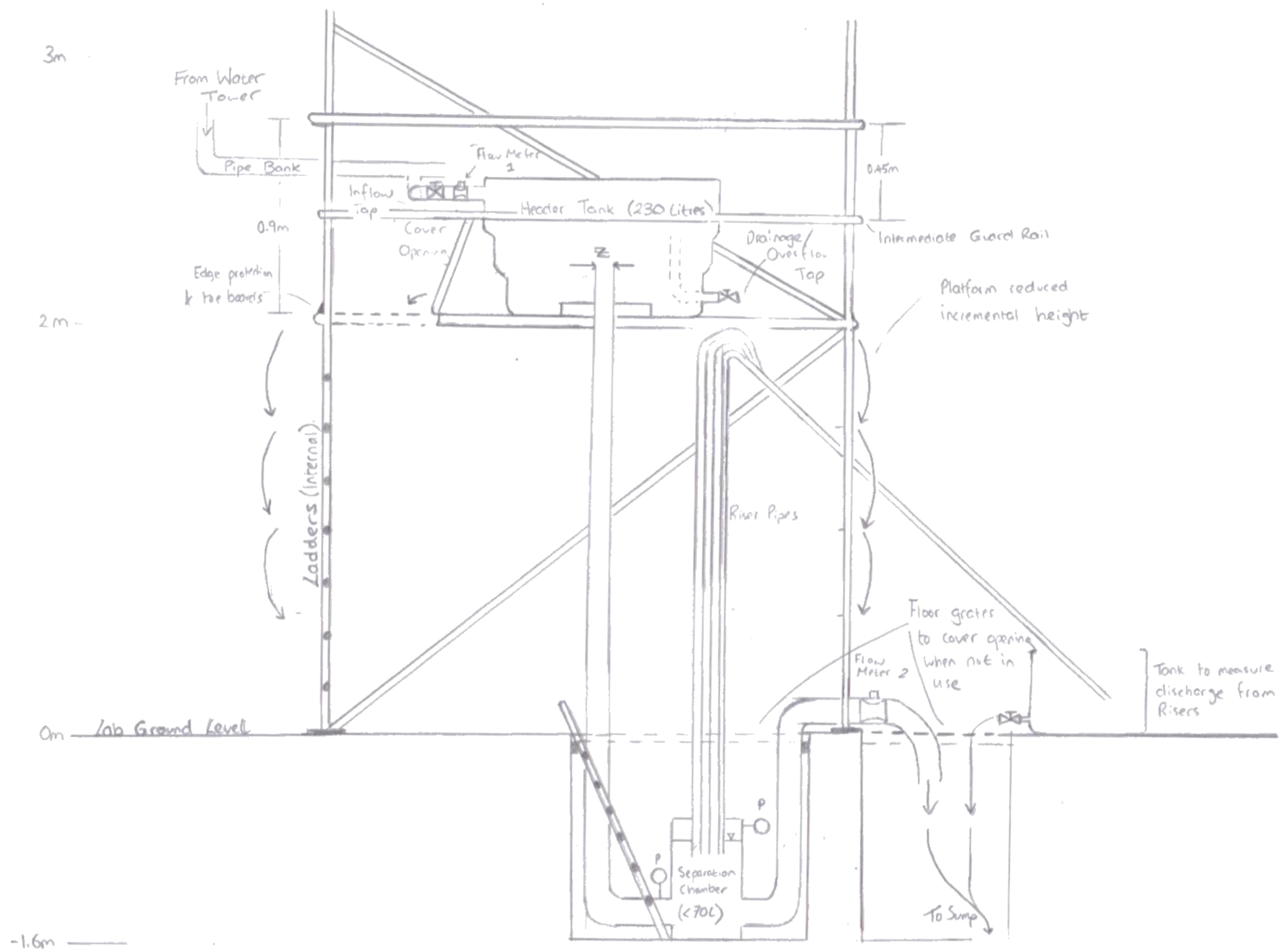

Figure 12: Adjusted Lab Setup Sketch

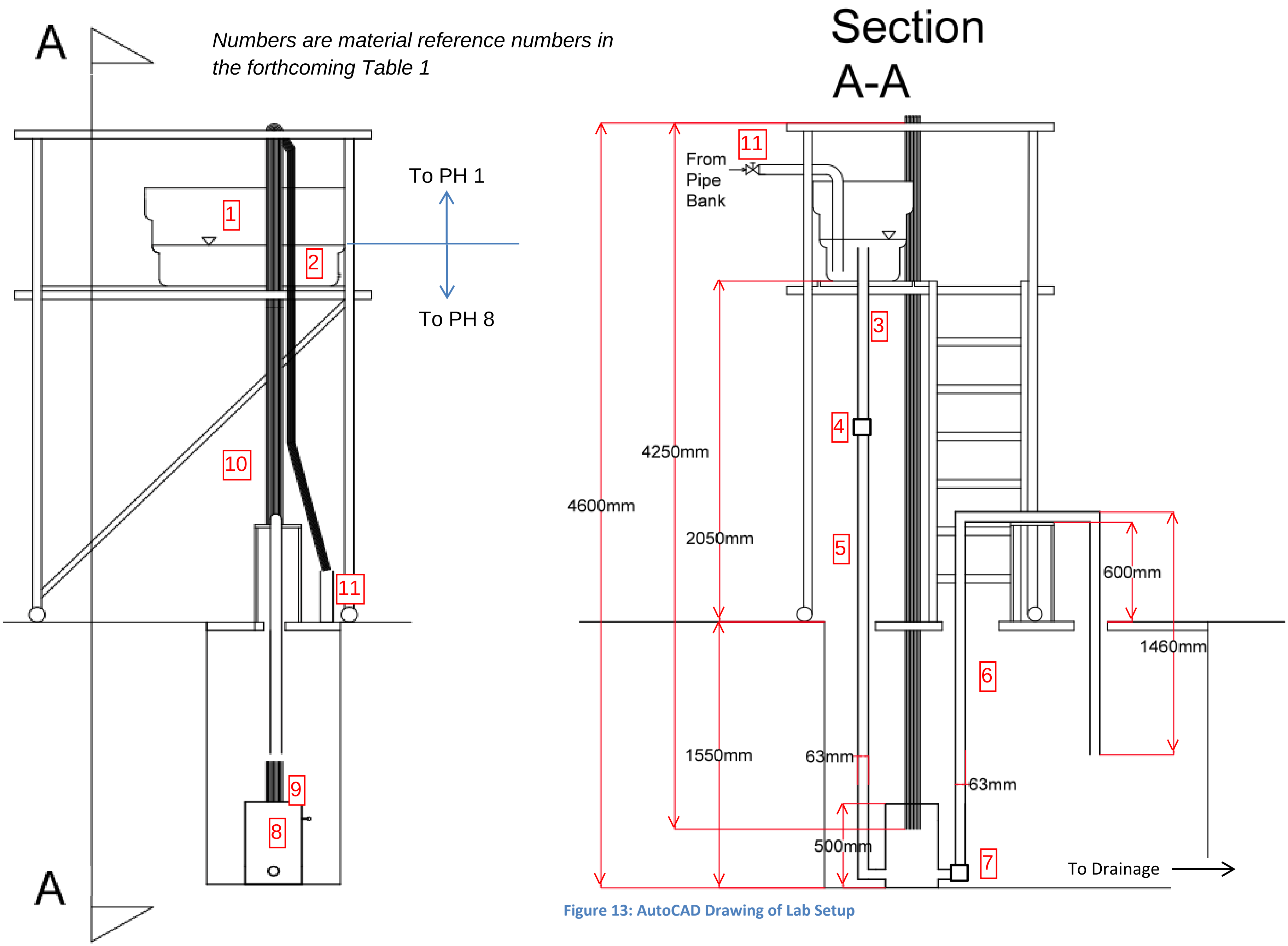

Figure 13: AutoCAD Drawing of Lab Setup

Figure 13 shows the final lab detail drawing that was completed. The only dimensions shown are the ones that were known, and so for all intents and purposes this was suitable starting point upon which the materials and equipment could be sourced and experiments built. There is some variation to the real setup as this was done before all materials were collected, the main differences and associated problems encountered were:

Use of Flow Meters: Only one flow-meter had the potential to be suitably used and this was on the inflow. It wasn't possible to position flow meters on the outflow from the second plastic pipe (6) and the RP (10) due to configuration incompatibility and lack of appropriate equipment.

Pressure Gauges: These were intended to be used on the SC (8) to record and illustrate the pressurisation/depressurisation sequence within the chamber and directly linked to a data logger. Unfortunately, the below ground level lab area became extremely wet during testing and there were health and safety concerns with the water coming into contact with sensitive electrical equipment. Furthermore, suitable bespoke fittings would have been necessary to ensure complete air and water tightness over the pressure sensors, carrying a risk to the rest of the experimentation if the precautions failed. Due to this, ideally it would have been done after all testing had been completed but the reasons detailed coupled with time-constraints caused this advantageous aspect to be neglected.

Scaffolding Type: Initially, the hope was to adjust the height of the Header Tank (HT) to see how this affected the outflow through the RPs'; the height adjustment was to be done by discrete steps in the scaffolding as is shown in Figure 12. However, the scaffolding used was configured differently to what was expected and the only possible intermediate height adjustments were large as it required another section of scaffolding to be installed. This posed numerous difficulties namely the amount of effort that would be required in adjusting the pipe-work, the fact that it would have only been possible to set it at one other height, the health and safety concerns over this extra height and the extreme difficulty with erecting the extra section of scaffolding in the cramped laboratory. The implausibility of this scenario in this particular laboratory setup led to the neglection of this testing variable.

Table 1: Material Reference Table

Item Reference	Name
1	Header Tank
2	Flange Fitting
3	Perspex Pipe
4	Rubber Sleeve
5	Plastic Pipe 1
6	Plastic Pipe 2
7	Elbow Joints
8	Separation Chamber (SC)
9	Bulkhead Fittings
10	Riser Pipes (RP)
11	Measuring Cylinder
12	Flow Meter

3.3.2 Theory of Operation

The concept here is that the water flows into the Header Tank (HT, 1), from the pipe bank water supply. The water will fill the HT, fall through the Perspex/Plastic downpipe (3 & 5) and enter the Separation Chamber (SC, 8). The water and air will separate to some degree; with the water rising up the second plastic pipe (6) generating water head (which pressurises the SC) and discharge into the adjacent, below ground level drainage ditch. The air will rise through the Riser Pipes (RPs, 10) through the roof of the SC and carry an amount of water above the head of the HT. The RP will be variable in pumping height and will drape back down to be collected in the measuring cylinder (11), similar to that shown in Figure 13.

3.3.3 Material List

Material Reference #: 1

Item Name: Header Tank (HT)

Data:

Capacity = 230 litres

<u>Description</u>

The tank used had to be capable of containing sufficient water to feed the PP. Again, due to lack of any rational information concerning how fast the system would run, and the types of inflow rates to use it was decided that choosing the sensibly large tank was the better option. Figure 14 opposite shows the chosen HT and the attached flange

Figure 14: Header Tank (HT) with Flange-Fitting Attached.

Material Reference #: 2

Item Name: Flange Fitting

Data:

63mm OD Steel Compression Joint

<u>Description</u>

A flange fitting was chosen as suitable, waterproof method of connecting the Perspex Pipe to the HT, it also allowed for the potential of adjustment to the height that the Perspex Pipe extends into the HT.

Figure 15 opposite shows the flange fitting connected to the underside of the HT, with the hole made in the scaffolding platform to accommodate the fitting and the threaded connections which act to compress the Perspex pipe.

Figure 15: Flange-Fitting Connection

Figure 16 shows the view from inside the HT, we see how the flange fitting is bolted onto the base of the HT and the Perspex pipe rising through. The entry length of the Perspex pipe could have been adjusted by reducing the compression on the Perspex pipe and sliding it up to the new desired length. Although this was not done, the provision for adjustment was there with this fitting, and this will be desirable for future works as explained in the Recommendations section in Chapter 5: Discussions and Conclusions. A nominal 200mm was chosen as the entry length.

Figure 16: View from Inside HT

Material Reference #: 3, 4 & 5

Item Name: Perspex Pipe, Plastic Pipe & Jubilee Clip

Data:

Perspex/Plastic Pipe = 63mm OD

Description

The major advantage to using this material (Perspex) was that it allowed for observation of the process of air-entrainment as the water fell. It was essential to build a foundation of as much information as possible about this relatively unknown pump and by observing the processes involved to as much extent as possible aided in accomplishing this. There was only a limited supply of correct diameter Perspex pipe, and so the remainder of the downpipe length belonged to a standard plastic pipe. The pipes were connected using a rubber sleeve and two jubilee clips to prevent leakage.

Figure 17: 64mm OD Plastic Pipe Used

Figure 18: Perspex-Plastic Pipe Connection, Rubber Sleeve & Jubilee Clips

Material Reference #: 7

Item Name: Elbow Joints

Description

The most expensive part to the lab setup; industrial standard joints were the only certain way of preventing leakage. Consider water flowing down the Perspex/Plastic downpipe (3 & 5), approximately 4.2m of gravity flow turning sharply by 90° into the SC caused concern for the horizontal pipe entering the SC to snap; couple this with significant water pressure and the need for a very strong, water-tight connection is clear.

These fittings provided what was necessary. Gripping onto a large length of pipe helped to alleviate stresses in the pipe and concentrate them at the joint. A chain-wrench was used to tighten the threaded collars and this prevented leakage. Figure 19 and Figure 20 show the working and expanded form of the joint, respectively.

Data:

Philmac® 90º Elbow Joints, 63mm Outside Diameter, Compression Fitting

Figure 19: Working Form of the Elbow Joint

Figure 20: Expanded Form of the Elbow Joint

Material Reference #: 8 | Data:

Item Name: Separation Chamber (SC) | AutoCAD Drawing: Appendix A – Methodology

Description

The PP works on the concept of pressurised air, if the air escapes then the pressure drops and the potential for the system to pump is damaged. The chamber had to be air-tight at all costs, this may not seem particularly difficult when considering conventional air-tight containers but this was a bespoke element to this lab. The detailed drawing of the SC can be seen in Appendix A – Methodology.

The rationale behind the choice was fairly crude; the Perspex-Plastic pipe exiting the HT (Item References 3 & 5) had an outside diameter of 63mm, and so by matching the pipes connecting to the SC to this it was hoped this would ensure a flow consistency and prevent any unforeseen and serious issues. It seemed a sensible starting point and during experimentation no problems were encountered and so in retrospect it may not have been as important as first thought. However, there was some strange behavior which has been discussed in Chapter 4: Analysis and Synthesis of Results.

The SC was salvaged from a used piece of thick plastic similar to that shown in Figure 22 overleaf. The original use of this piece was unknown, but it was hand-sawn at either end to become a manageable size to work with. The top and bottom interfaces were smoothed and a piece of thin plastic was solvent-cemented to the base of the SC; further solvent cemented joints include the two pipes exiting the SC. Solvent-Cement essentially fuses and bonds the two pieces of plastic together, similar to that of a traditional weld and as such provides a strong, water-resistant bond. Despite this, relating back to the description of the elbow joints there was concern over the exit pipes snapping upon the flow of water, this was because the weld could only bond the thickness of the SC wall, approx. 15mm.

For the top, a circular piece of Perspex was bolted down into the plastic wall of the SC; the interface was sealed using silicone. The silicone seal was applied as a semi-liquid, and so matched the imperfections of the interface incredibly well (as opposed to a traditional rubber-ring seal) it was then dried and left to cure. The holding-down bolts provided the compression and this proved to be effective at containing both water and air. Considering Figure 22 as the input, Figure 21 shows the output of the changes described here. The choice of Perspex for the top was a fortunate luxury; it was never intended for it to be fashioned of that material, but with the option there, this carried the potential benefit of observing what was actually happening within the SC.

Figure 22: Similar Original SC Before Modification

Figure 21: Modified Air and Water-Tight SC

The precautions taken here to ensure water and air-tightness of the SC were sufficient; which with reference to Dacho (2012) was the main setback encountered during their experimentation.

Material Reference #: 9

Data:

Item Name: Bulkhead Fittings

Brass, 6mm Diameter

Description

The bulkhead fittings were a special element, and the most difficult part to get right. A fitting had to be found that could withstand significant pressure, was long enough to fit through the Perspex lid, and had the ability to connect tubing together at each end. Thankfully, and after much searching a company from Germany had the perfect fitting that proved to be incredibly valuable; if these fittings didn't contain the pressure then the experiment could not have been completed.

Figure 23: Typical View of Bulkhead Fitting

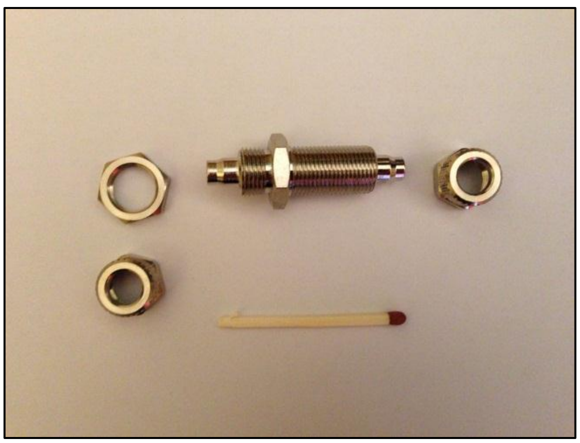

Figure 24: Expanded View of Bulkhead Fitting

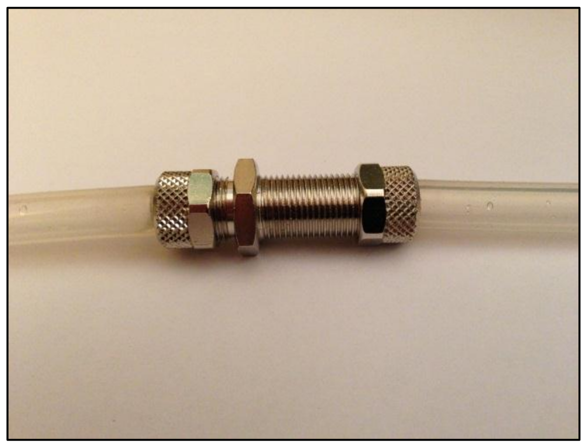

Figure 25: Bulkhead Fitting with RP Attached

A typical view of the bulkhead fitting is shown in Figure 23, and the corresponding expanded view is seen in Figure 24 along with a match to represent the scale of the fitting. These fittings had a hollow inside to allow the water to pass through, a Riser Pipe (RP) is pushed onto the nipples at either end of the fitting and the nuts provide the compression to keep the RPs' in place and prevent leakage. Figure 25 shows how the RPs' are attached, it is important to clarify that these are two separate pipes, and the bulkhead fitting mediates the connection through the Perspex top. Each fitting had one nut attached to the threads, and a spare to compress onto the surface to which it was attaching too, namely either side of the Perspex top; rubber washers and PTFE tape were used to aid in preventing leakage.

Material Reference #: 10

Item Name: Riser Pipes (RPs)

Data:

Fisher Scientific Flexible Tubing, 6mm Internal Diameter, 10m lengths.

Description

These were made of clear plastic flexible tubing as shown in Figure 28. The clarity of the tubing had the innate advantage of allowing for the observation of the different flow regimes that the system went through. The flexibility of the RPs proved to be essential for crimping when multiple RPs were sequentially 'activated', (i.e. 1 RP active, then 2 RPs' active etc.) and the actual positioning of these pipes among the scaffolding. When extra length was required plastic joints were used to connect two pieces of the flexible tubing together, these were acquired from the same supplier, Fisher Scientific; an example of this is shown in Figure 26.

Figure 28: Riser Pipe (RP) Flexible Tubing

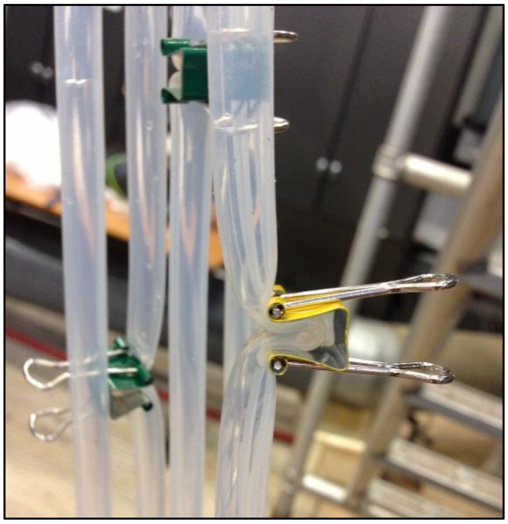

Figure 27: Crimping RPs'

During Experiment 2 when it was essential to observe how activating multiple RPs' from 1-5 affected the outflow it was necessary to find a way of ensuring the other RPs' were deactivated. This was done by crimping the pipe, and securing with it with a simple clip, an example of this is illustrated in Figure 27. This proved to be an effective solution to stemming the air and water flow. White (2012,b) suggested the use of this small diameter pipe, claiming it would 'match' with a 63/75mm inflow pipe. Relating back to Chapter 2: Literature Review Nickin (1963 cited in (White 2001) also noted that a RP below 20mm will improve efficiency due to surface tension promoting slug flow.

Figure 26: RP-RP Plastic Connector

In Section 3.3.7 ‘Experiment 2’ of this Chapter, there are a few issues that were explored concerning the difficulty with getting the pump to operate when increasing the number of active RPs’. One such issue was whether or not the grouping method of the RPs’ within the Separation Chamber (SC) had an effect on the pumps operation. During the process of eliminating the cause for why only one riser was active, it was believed that perhaps the initial approach of bundling the tubing together, as shown in Figure 29 may inhibit the natural behavior of the water and air mixture. By grouping the tubing together, there was the notion that this might be directing the water and air mixture through one RP. An alternative solution to allow the RPs’ to fall vertically was seen as a fairer, unbiased approach that is illustrated in Figure 30. All the lengths of tubing were cut to the same length (approx. 100mm). As it turned out, and which will be explored later this wasn’t the cause of the pump not operating as intended.

Figure 29: Bundled RP Configuration

Figure 30: Free RP Configuration

Material Reference #: 11 & 12

Item Name: Measuring Cylinder & Flow Meter

Description

The measuring cylinder Figure 32 was simply used for measuring the amount of water discharging out of the RPs. The flow meter, Figure 31 was essential in determining the amount of inflow into the system and returning to that flow on forthcoming tests to a relatively high degree of accuracy.

Data:

Measuring Cylinder: Azlon 2000ml Capacity, 20mm Graduations

Flow Meter: Parker EASIFLOW EF7731114220, 150l/min, 5l/min Graduations

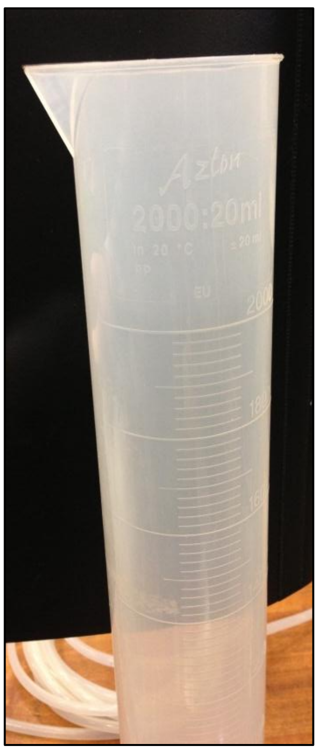

Figure 32: Measuring Cylinder Used

Figure 31: Flow Meter Used

3.3.4 Laboratory Setup Images

Numbers are material reference numbers from Table 1

Figure 34: Overall Lab Setup

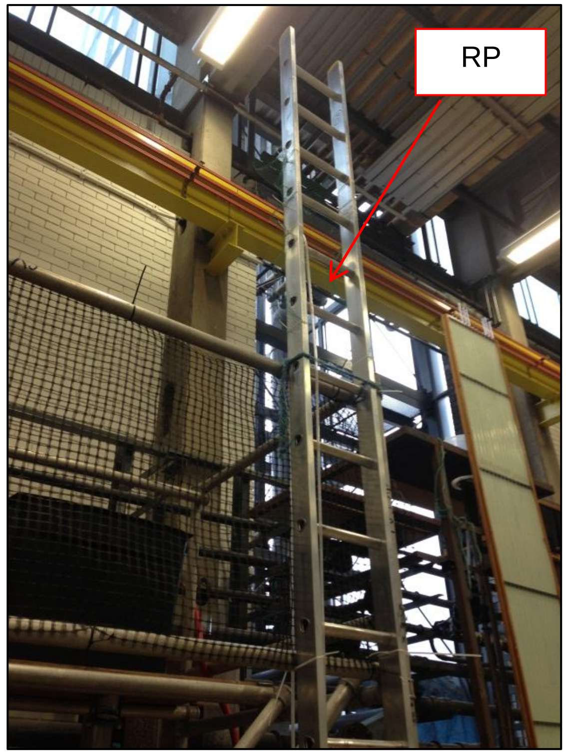

Figure 35: Ladder Used to Suspend RPs'

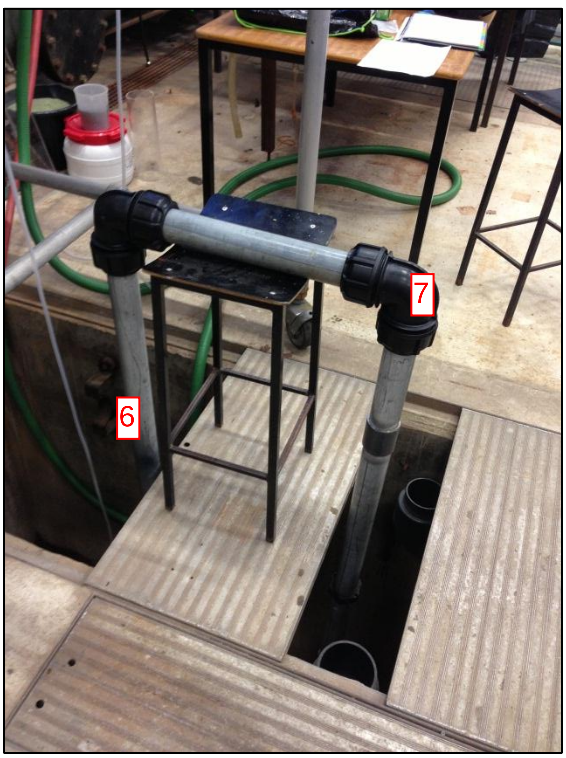

Figure 36: Main Outflow Pipe. Pressurises SC

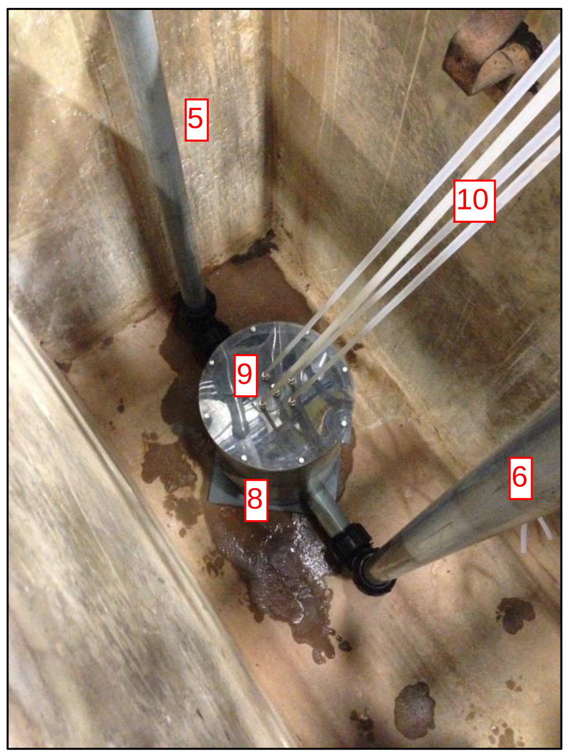

Figure 33: SC with 5 RPs'

3.3.5 Prototype Test

Once connection of all the elements listed in Table 1 was completed the system was ready for its' first run. Considering the amount of elements, and how crucial many of them were to the successful operation the priority at this stage was to see if the pump actually worked before any tests were run. As such no testing variables were in place, no flow meter, no pre-defined Pumping Height (PH) was set and no method of water collection. Initially, only a single RP was chosen to test due to the concerns over the airtight capability of the Separation Chamber (SC); ofcourse it would be far easier to remedy issues with one RP than have five experiencing the same issue.

Initially, it was desired to run the system slowly for three reasons, the first being to test the strength of the joints/connections in terms of structural and water-tight capability without overloading it with a significantly high energy flow. Second, it was unclear as to the amount of inflow the PP would need to run, and finally it was considerable effort to tap into the pipe bank manifold. This being said, a readily available simple garden hosepipe was chosen. It was noticed that unless the inflow was increased sequentially, as opposing to decreasing sequentially (i.e. from 30l/min to 35l/min, rather than 35l/min to 30l/min) the system would take a significant amount of time to respond. By increasing the inflow it didn't stop; this led to more efficient testing. The outcome of the prototype test, problems encountered and supporting explanations are provided in Chapter 4: Analysis and Synthesis of Results.

3.3.6 Experiment 1

3.3.6.1 Purpose

This experiment was designed to answer Research Questions 1 and 2, being:

1. By increasing the water inflow, does this correspond with an increase in outflow through the Riser Pipe (RP)?
2. By increase the pumping head, does this correspond to a decrease in outflow through the RPs?

3.3.6.2 Design

Throughout this section the term ‘Pumping Height’ (PH) will be used frequently, this is defined as the height the water is pumped above the original water level. With regard to Figure 35, the ladder was attached to the scaffolding and each step was used as a pumping height level whereby the RP was suspended upon each step. This ensured that it was easy to adjust the pumping height to discrete intervals. A mesh was also applied to the ladder for intermediate pumping heights. Recalling Dachos’ (2012) results in Section 2.3 it can be seen in Figure 7 that the ability of their setup to pump lies within a small threshold from 0.5m-1.5m. In other words within that difference in pumping height (1m) the pump operates at both maximum and minimum flow. This suggests that the pumping height variable is highly sensitive but they have only recorded three results to define this region. With regard to the design of ‘Experiment 1’ the pumping height spanned from 0.2m to 1.5m, giving a difference of 1.3m; this region has been illustrated by six pumping heights, double that of Dachos’ (2012).

3.3.6.3 Data Collection Procedure

The RP was positioned at the desired pumping height (PH) and allowed to loop down to the point of collection, which was the below-ground drainage ditch. Using the flow meter the valve was turned the required amount to start at 30l/min. As the water filtered into the system and began to flow through the main outflow pipe (Table 1, Ref: 6) the RP began to pump. Ensuring a consistent pumping flow the discharge was measured using the measuring cylinder (Table 1, Ref: 11) for 60 seconds. Measurement started at 0:05s and ended at 1:05s so as to minimize erroneous data while moving the measuring cylinder into place. Five measurements were taken at each PH to attempt to reduce the amount of variability in results, a factor that Dacho (2012) also noted. The inflow was always changed by increasing, not by decreasing; this reasoning was explained in Section 3.3.5 ‘Prototype Test’. The system was shut off while altering PHs’.

3.3.6.4 Problems Encountered

Only a single issue was encountered that couldn't be resolved here; initially the inflow was set to 25l/min but this proved to be insufficient to get the pumping working. Instead, testing had to begin at 30l/min.

3.3.7 Experiment 2

3.3.7.1 Purpose

This experiment was designed to answer Research Question 3, being:

3. By increasing the number of RPs' does this correspond with an increase in outflow?

3.3.7.2 Design

For the most part the design of this experiment was exactly the same as that for the first experiment, par two elements. The first change belonged to increasing the number of RPs' to five, and secondly was the introduction of a new inflow range that had to be introduced in order for the PP to operate with more than one RP active.

3.3.7.3 Data Collection Procedure

This was again much the same as for 'Experiment 1' with a few minor differences. These involved how the RPs' were activated and it took much longer to obtain results. All but one RP was crimped, leaving just one 'active'. An inflow was set, (e.g. 30l/min) and the outflow through the one RP was captured in the same manner as the previous experiment. Once those readings were taken and without altering the inflow the second RP was un-crimped and hence active. Approximately one minute was given so the system could stabilize to a constant outflow; outflow readings were then taken by discharging both RPs' into the measuring cylinder. This was repeated for all RPs', inflows and PHs', again 5 readings were taken for each outflow so as to limit the variability.

3.3.7.4 Problems Encountered

The original inflow range was insufficient to support more than one RP and so to remedy this, a new inflow range was introduced using another pipe. This meant there were two inflow pipes discharging into the Header Tank (HT), one with a flow meter and one without. Unfortunately no flow meter was suitable to be fitted to the new pipe, so it was deemed sensible to open the valve to full bore and label this inflow 'x'. The pipe with the flow meter was then used as a gauge to alter the inflow, i.e. the new inflows were 'xl/min', 'x+30l/min', 'x+35l/min' and finally 'x+40l/min'.

The inflow ‘x’ was measured by allowing it to fill up a container of known volume and recording the time for it to do so. As the water inflow ‘x’ was being fed from a water tank on the roof of the laboratory there were concerns that this inflow might be variable as the water head changes. The laboratory had a pump which replenished this water into the water tank, but it was unknown if the frequency of pumping was constant or at particular intervals. To address this, while measuring ‘x’ there was a 2 minute gap before another measurement was taken; with there being 5 measurements in total. In doing this any variations due to changes in water head would reveal themselves. There were no changes, the inflow ‘x’ was found to be constant at a value of 92l/min; therefore the inflows suitable for this experiment were 92, 122, 127 and 132l/min.

3.3.8 Analysis Methods

In general, after the raw data was tabulated it was then graphically illustrated by a series of plots including bar-chats and line-charts. Where appropriate the Pearsons' R^2 correlation coefficient has been provided. This value provides an interpretation of how one variable affects the other; and is useful during the analysis of the Pulser Pump (PP) to determine which variables are more critical.

3.4 SUMMARY

This chapter illustrated the philosophy, approach and strategies behind the provisions undertaken in designing, building and testing the two experiments to obtain answers to the research questions and ultimately accomplish those objectives defined in Chapter 1. The following chapter will present the findings of those experiments and provide analyses.

4 Analysis and Synthesis of Results

This section aims to provide an Analysis of those results collected in ‘Chapter 3: Methodology’ for the both ‘Experiment 1’ and ‘Experiment 2’. Preceding this will be an analysis of the ‘Prototype Test’, which was explained briefly in the previous chapter. During experimentation written observations were collected to describe the behavior of the Pulser Pump (PP) and these will also be called upon to supplement the findings and aid in explaining the results. By the end of this chapter a solid research foundation for the PP will be built, with clear areas where further work could be undertaken.

4.1 PROTOTYPE TEST

Introduced in the previous chapter, this test was simply a proof of concept and frankly, it didn’t work. Upon starting the PP the inflow was steady and slow but immediately water began leaking from the flange fitting, the rubber sleeve connecting two pieces of Perspex and plastic downpipe together and all the elbow joints (Table 1, Ref: 2, 4 & 7). As the water reached the roof of the Separation Chamber (SC) it began leaking through the silicone seal connecting the Perspex top to the main housing of the SC. Furthermore, the pump failed to lift any water. On all accounts of the leakage it was down to insufficient tightening of the fittings, it was thought that the leakage was the reason for the pump not working due to the driving force, namely the air, escaping. Appropriate tightening measures such as a chain wrench for the elbow joints and jubilee clips for the rubber sleeve were put in place. Turning the system back on no leakage occurred but the pump still failed to work.

At this stage it wasn’t thought that there was a lack of air, namely because it couldn’t escape through the joints and seals, and as the water level in the SC rose to the Perspex top there were slugs of air and water rapidly rising through the Riser Pipes (RP). However, this didn’t last long as seconds after the first set of slugs were witnessed this was replaced by constant water flow. Quoting Chapter 3.3.4 it was noted that “no pre-defined Pumping Height (PH) was set” and in actual fact the RP was set to some arbitrary distance below water-level in the Header Tank (HT), thus the RP filled with water due to the water head generated from the elevation of the HT. To compound this issue the water level in the SC failed to reduce from the Perspex top of the SC, which contradicted the notion of the cyclic pressurisation and depressurisation process; this suggested there was an insufficient volume of air to reduce the water-level.

The problem lied within insufficient inflow; the simple garden hose was not providing enough water with sufficient velocity to keep the air entrained down the length of the Perspex-Plastic pipe (Table 1, Ref 3 & 5). Air naturally rises through water because it is less dense and so it is reasonable to assume that if the volume of falling water isn't sufficient to trap the air and carry it down the pipe then the air will either escape or not be sufficiently compressed.

To remedy this, the garden hose pipe was removed and replaced with a pipe connected to the laboratory pipe bank. When a flow meter was fitted (Figure 31), this provided a maximum inflow of 40l/min. Despite not knowing the inflow from the hose pipe it was obvious that the new inflow was significantly greater. The effect of this change was immediate; the water-level was observable in the Perspex pipe, where previously the water level resided just above the rubber sleeve connecting the two downpipes. The process of air-entrainment was clearly seen through the Perspex pipe; this at least proved air was making it to the SC and the system ran as intended.

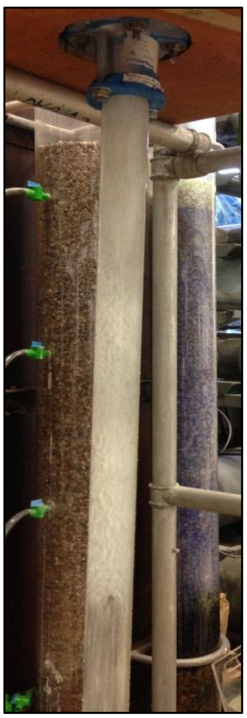

Figure 37: Typical View Through Perspex Pipe

Figure 39: Close-Up of Air in Perspex Pipe. System On.

Figure 38: Close-Up of Air in Perspex Pipe. System Off.

Figure 37 shows the typical view in the Perspex pipe while the system was running; Figure 39 shows a close up of the air-bubbles in the water. Figure 38 represents a picture taken immediately after the system was turned off as this provided a better illustration of the air trapped in the water. Ideally, this is better viewed through a video; please see 'Video 1' on the attached CD in Appendix B – Results.

4.2 EXPERIMENT 1

Recalling Section 3.3.5 this experiment was designed to answer Research Questions 1 and 2, being:

1. By increasing the water inflow, does this correspond with an increase in outflow through the Riser Pipe (RP)?
2. By increase the pumping head, does this correspond to a decrease in outflow through the RPs?

In Chapter 3: Methodology of this report it was noted that some of the data between ‘Experiment 1’ and ‘Experiment 2’ contained similarities and so data found separately could be brought together to extend the analysis. One such similarity concerns the Inflow/Outflow rates using a single Riser Pipe (RP). In ‘Experiment 1’ only 3 inflow rates were tested (30, 35 and 40l/min) but as explained in the Methodology section these inflows were insufficient for testing multiple RPs’. As such, the necessity to increase the range of inflows for ‘Experiment 2’ also brought about the possibility of applying these new inflows to the results of ‘Experiment 1’. The physical differences were 1 RP versus Multiple RPs’ and this caused concern over whether or not this would exhibit differences in the outflow results. Before merging the data-sets it was appropriate to validate if indeed any differences occurred between ‘Experiments 1 and 2’; this validation consisted of crimping the four out of five RPs’ to ensure water only flowed through a single active RP, measuring this flow and comparing it with the flow found in ‘Experiment 1’.

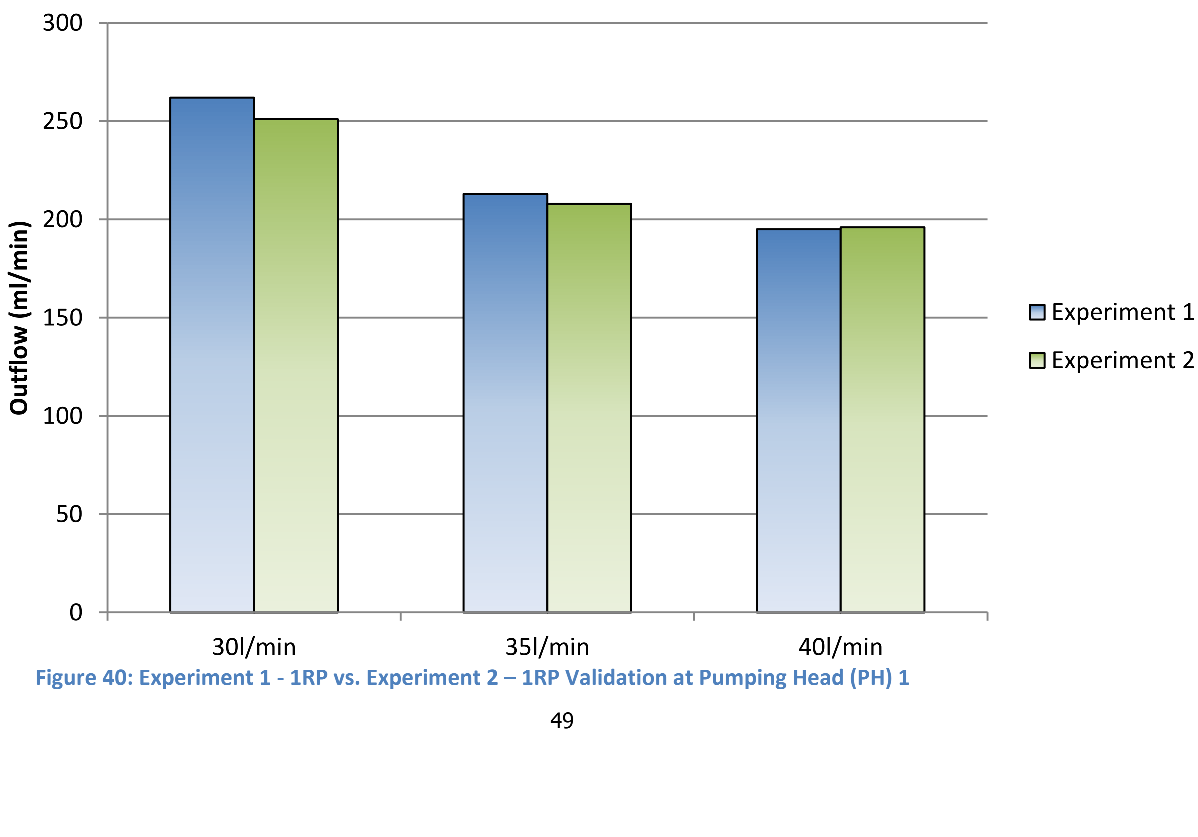

Figure 40: Experiment 1 - 1RP vs. Experiment 2 – 1RP Validation at Pumping Head (PH) 1

With respect to Figure 40 this represents the inflow rates and the corresponding outflow rates for a single RP in both experiments at Pumping Height 1 (PH 1). The results clearly show little variation worth mentioning (< 10ml); a figure that could have easily been put down to human error. For all intents and purposes it was believed this was a sufficient threshold of difference of validation that it was appropriate to utilize the results from 'Experiment 2', in the analysis of 'Experiment 1'. In retrospect it would have been useful to repeat this validation at all of the eight PHs, or at least another height at the other end of the spectrum but with constrained time this would have been difficult to achieve. The raw data for this plot has been provided in Table 7.

The outcome of this experiment which was detailed in Chapter 3: Methodology has been illustrated in Figure 41 overleaf. The inflow ranges introduced during 'Experiment 2', and previously verified here are also shown in this figure; the raw data for this plot can be found in Table 10 of Appendix B - Results

Be aware that when the Pumping Height (PH) is zero, this is corresponding to the water level in the Header Tank (HT), i.e. for PHs' 7 & 8, which are below zero, this means that the water in the RPs' never goes above the water level in the HT. Conversely, the remaining PHs' are above zero, meaning that they pump above the water level in the HT.

Consider Research Question 1 upon Figure 41, it is clear that as the inflow increases the outflow decreases. The results match the hypothesis; and as discovered in Chapter 1: Literature Review this is believed to be due to the flow regimes. The most efficient flow regime was found to be slug flow and during the experimentation when observations were made slug flow was in abundance at a lower flow rate of 30l/min, and as the inflow increase the amount of slugs being pumped trailed off. In particular it was noted that altering the inflow rate affected the frequency of slugs, i.e. at lower inflows there was a consistently high frequency of slugs being pumped, but at higher inflows there were periods of slug flow and periods of what appears to be churn flow. See 'Video 2' on the attached CD in Appendix B – Results for an example of this. On increasing the inflow, the efficiency reduces because this increases the volume of air entrained into the water and the amount it is compressed. When the air shoots up the RP this greater volume and compression of air dispels the water along the internal wall of the RP and so barely lifts any water. It is easy to visualize that a slower slug of air lifts more water than a fast churny flow. Ofcourse, the same can be said for lower inflow rates, where the volume and degree of air compression is insufficient to form a slug and instead the air resides in a state of bubbly flow, which lifts minimal, if any, water.

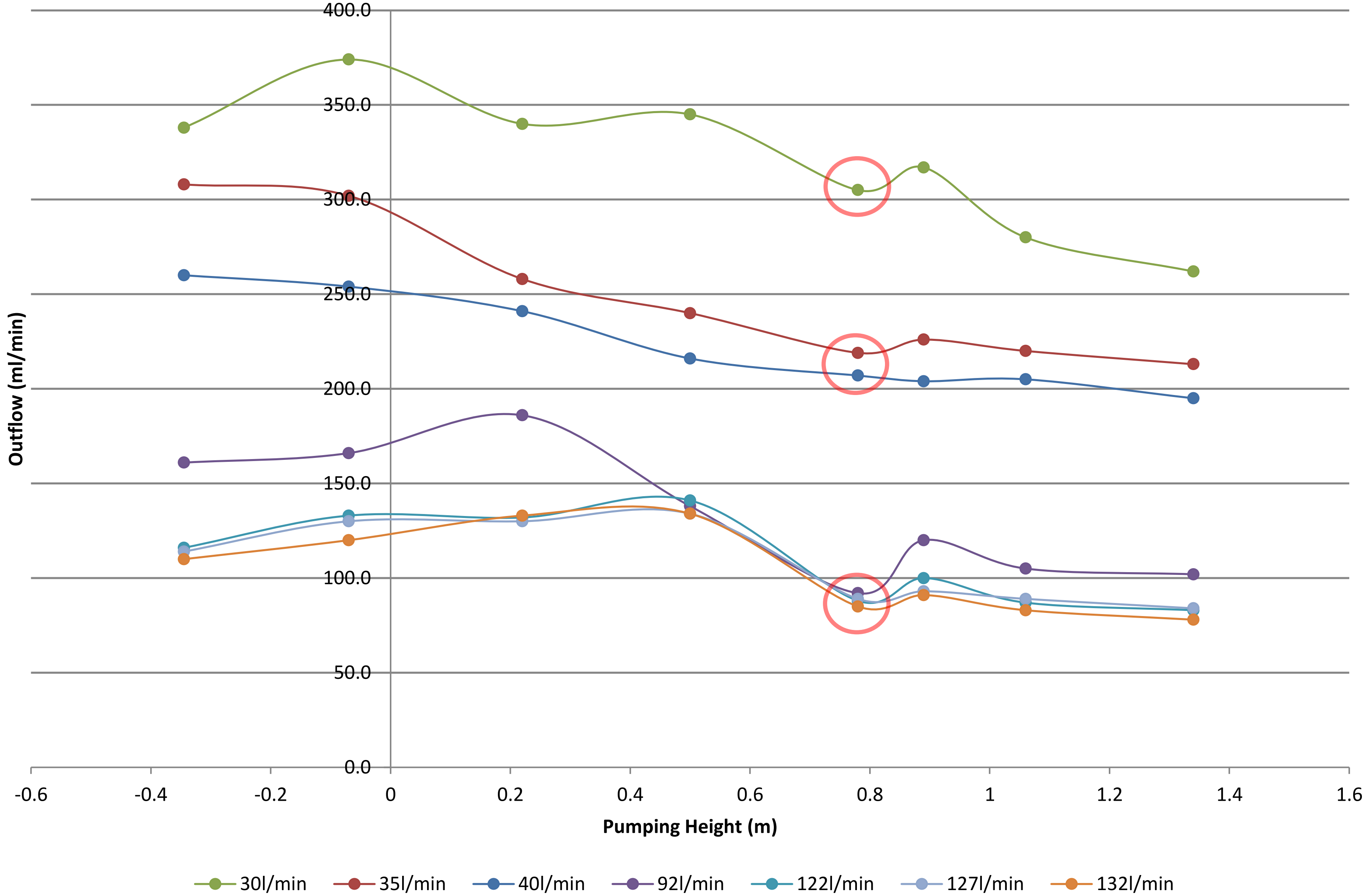

Figure 41: Experiment 1 - Relationship between Pumping Height and Outflow

Initially it is clear that all inflow rates typically follow the same trend, that is, as the pumping height increases the outflow decreases; this is in agreement with the results provided by Dacho (2012) in Figure 9. The results in Figure 41, clearly show significant change in outflow over a relatively small change in PH. Referring to Figure 42 which isolates the linear trendlines of the data and Table 2, the R^2 values are presented, the minimum being 51% and the maximum being 95%. This tells us two things, first that the strength of the Inflow-Outflow relationship can be highly variable, but secondly, if it doesn't vary then the strength between the two can be as high as 95%. To clarify, this means that 95% of the changes in y-variable, namely outflow can be explained by the x-variable, Pumping Height (PH). Therefore, the PH is one of the critical variables in the Pusler Pump (PP) operation, if not the most critical.

One may expect that because the air is lifting the slugs of water due to the density differences (air rises through water), then irrespective of PH it will always be able to lift the water, since the air wouldn't just stop rising through the RP. An analogy may be to consider an air-bubble at the bottom of a sea; the air-bubble will continue to rise by dispelling the water above it until it breaches the surface, no matter the depth of the sea. In this experiment the air-slug slows, and will stop if the PH is too large. It may be theorized that as the PH increases so does the length of contact the water slug has with the wall of the RP. It is possible that the friction slows the water down and seeing as the air-slug can't dispel the water as it is constrained in a small diameter tube (unlike in a sea) it comes to a halt because the frictional component is too great. The friction coefficient of the rubber tubing was unknown, but when the system was turned off some of the water formed droplets on the internal walling of the RP and stayed suspended; this shows that the frictional coefficient was sufficient to suspend the weight of the water droplets.

This slowing down and inevitable halting of the air and water flow in the RPs' was observed across all PHs'; it was also observed that despite the system halting, an increase in the air would encourage flow through the RPs'. So if the air and water mixture slowed down and failed to rise, over time it would gradually speed up and 'work' for a split second. This must be due to an accumulation in the volume of air at the bottom of the RPs' that overcome the frictional resistance that would currently be laboring the system.

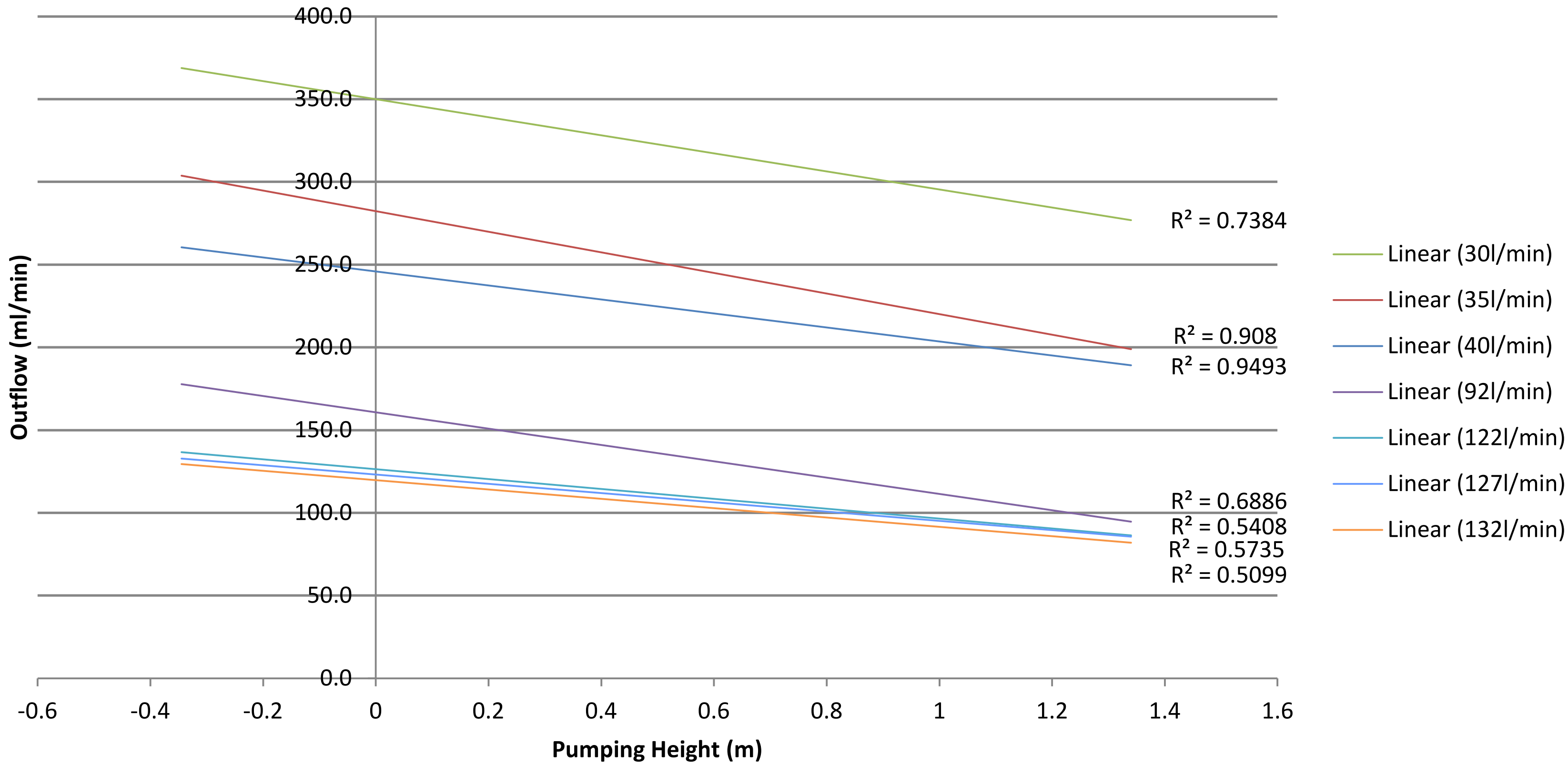

Figure 42: Trendlines and Associated Pearsons' R2 of Figure 29 Data

Table 2: Inflow and R^2 Values

	Pearsons' R^2	
Inflow (l/min)	Value	Percentage (%)
30	0.7384	74%
35	0.9080	91%
40	0.9493	95%
92	0.6886	69%
122	0.5408	54%
127	0.5735	57%
132	0.5099	51%

To supplement this theory 'Video 3' on the attached CD in 'Appendix B – Results' shows a static slug of water with air trying to break through the surface, it can be clearly seen that the meniscus (a function of the surface tension in water) is holding the air back, ironic since surface tension encourages the formation of slugs. Interestingly, the larger slug of water begins to decompose into smaller slugs of water, which are able to be lifted by the air; it is a balancing act between the weight of the water, surface tension and friction against the buoyancy of the air-bubble.

Figure 43 shows the relationship between the inflow against both the outflow and the efficiency. The 'Efficiency' of the system is defined by Equation 4.2.1.

Eqn: 4.2.1 $\frac{Outflow\ (l)}{Inflow\ (l)} \times 100$

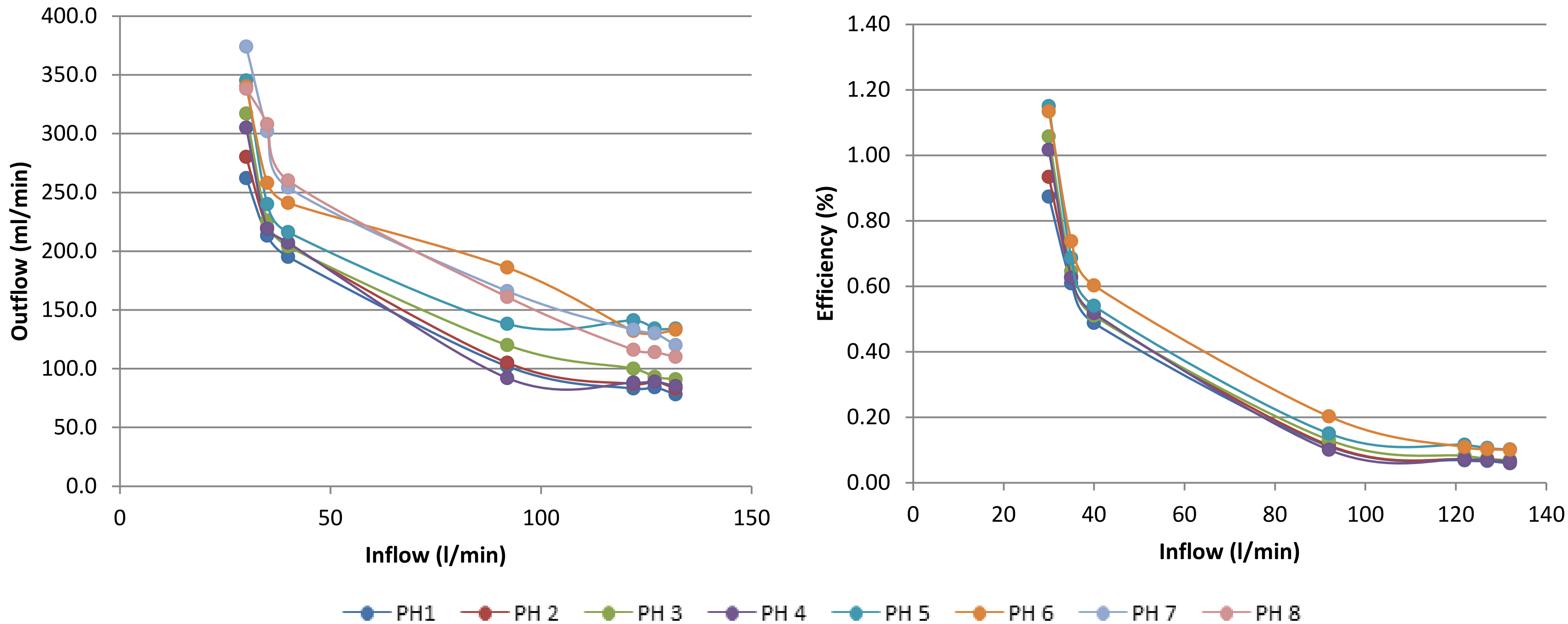

Figure 43: Experiment 1 - Inflow vs. Outflow/Efficiency

Much of the previous explanation can be applied here, simply put the efficiency decreases as the inflow increases due to the transitions between the flow regimes. It is also clear that a lower Pumping Height (PH) is more efficient. With reference to Table 3 we see that the highest efficiency is 1.15% for this particular setup. For the purposes of this analysis it was deemed appropriate to neglect Pumping Heads (PH) 7 & 8 out of the 'Efficiency' plot (Figure 43) as these PHs' were below the water level in the Header Tank (HT) and so it wasn't actually efficient in any regard because the water wasn't being pumped above that water level.

Table 3: Inflows and Associated Efficiencies

	Efficiency (%)					
Inflow	**PH1**	**PH2**	**PH3**	**PH4**	**PH5**	**PH6**
30	0.87	0.93	1.06	1.02	1.15	1.13
35	0.61	0.63	0.65	0.63	0.69	0.74
40	0.49	0.51	0.51	0.52	0.54	0.60
92	0.11	0.11	0.13	0.10	0.15	0.20
122	0.07	0.07	0.08	0.07	0.12	0.11
127	0.07	0.07	0.07	0.07	0.11	0.10
132	0.06	0.06	0.07	0.06	0.10	0.10

These efficiencies will be compared with 'Experiment 2' and the minimum required daily demand of water for basic health. During the experimentation a range of flow regimes were observed, photographs proved difficult to capture and differentiating between the different flow regimes also proved challenging. However, it was possible to capture the following images; Figure 45 shows the Pulser Pump (PP) operating in the efficient slug flow regime while Figure 44 shows the PP operating in what appears to be the churn flow regime.

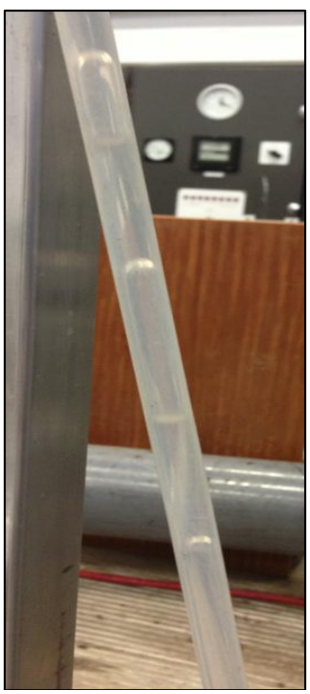

Figure 45: Experiment 1 - Single RP Slug Flow

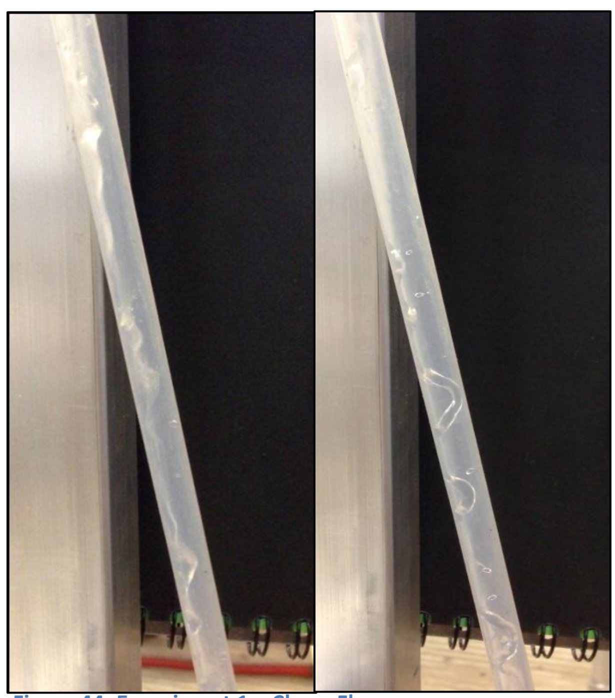

Figure 44: Experiment 1 – Churn Flow

After exploring the causes as to why the outflow changes with Pumping Height (PH) we can now consider anomalous results. It is important to try and differentiate between those results that are anomalous and those that are due to the natural variability that was witnessed. With reference to Figure 41, three sets of anomalous results have been highlighted. Interestingly, before the introduction of the new flow rates for ‘Experiment 2’ these highlighted points went unnoticed due to what was believed to be experiment variability. However, after witnessing the drop in the higher flow rates to a much more pronounced degree then this error was identified easily across all the inflow ranges. The only thing in common with these points is that the Pumping Height (PH) used was different to the others. In Chapter 3: Methodology it was mentioned that ladder steps were used as discrete intervals for PHs’ and a mesh was attached to the ladder to provide the ability to introduce mid-range PHs’. The dip corresponds to PH4, which was the only mid-range PH and it was observed that when hooked into the mesh the Riser Pipe (RP) had a tendency to crimp, and inhibit the water flow. See Figure 46 to illustrate this.

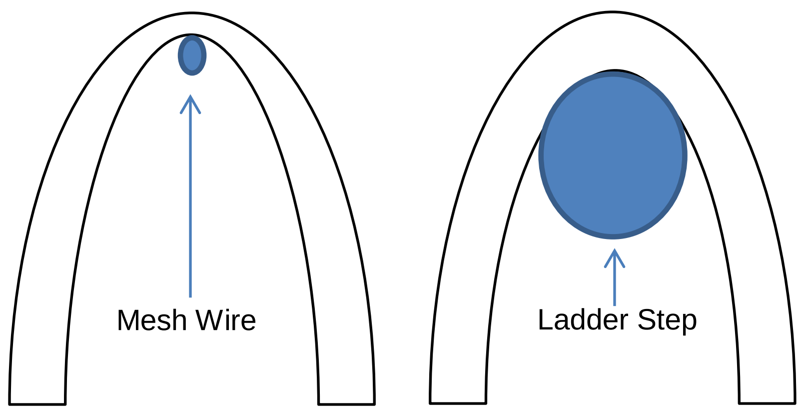

Figure 46: Mesh-Ladder Comparison

4.2.1 Observations

An interesting observation was made concerning the effects on the Pulser Pump (PP) system when altering the inflow. If one was to turn the system on at a high inflow rate first and then reduce this inflow rate then it took a significant length of time for the system to respond to the new flow, the outflow through the RPs’ decreased and the system appeared to stall as the slugs became static. To remedy this all tests started off with the slower flow of 30l/min and then increased; this prevented the system from stalling and so testing was much more efficient.

During testing it was also observed that the water level in the Perspex-Plastic pipe (Table 1, Ref 3) varied with the inflows. When the inflow was set to 40l/min and the RPs' set to PH2 the water-level differed by approximately 0.35m, when this inflow was reduced to 35l/min the difference was 0.05m, and at 30l/min there was no observable change in water-level. To add to this at 40l/min there was what appeared to be a column of air rising up the Perspex-Plastic pipe, and when this breached the surface of the water it caused a sudden drop in water-level. The same was apparent for 35l/min, but the column of air was noticeably smaller and again at 30l/min there was no observed column of air. This pairs up with two things, the variation in the water-level and the fact that 30l/min was more efficient than 35 and 40l/min inflows. It could have been due to an over-abundance of air; increasing the inflow increases the volume of air but if the air cannot be utilised in the RP to lift the water then it must escape somehow. By these observations it would appear to be that the more stable the system, i.e. when the air-entrained is not wasted then the more optimal the pumping is. So, if the water level in the Perspex-Plastic pipe remains constant, or with little variation this suggests a 'right amount' of air with a more efficient flow. Certainly when one considers 30 and 35l/min the water level in the Perspex-Plastic pipe was much more stabilized, and these actually corresponded with almost perfect slug flow and higher discharge out of the RP, giving some credence to the theory. See 'Video 4' on the attached CD in Appendix B – Results.

On a few occasions if the system did stall, with no slug movement and no outflow discharging from the RPs' then an unusual observation was made. The water flowing through the main outflow pipe exiting the SC (Table 1, Ref: 6) was normally very loud as it hit the below ground drainage ditch, but when the system stalled it was incredibly silent and the water looked 'smoother', as opposed to 'rough'. Whether this was some form of transition between turbulent and laminar flow is unknown; if it was, then no pumping occurs during a laminar flow type. In any regard, it may be beneficial for future research to consider this as it may help minimize the already temperamental nature of this system.

The air coming from the RPs' was very cool, with respect to Chapter 1: Literature Review this effect was seen, and utilised in the trompe. The water acts to absorb the heat of the air-bubble and the result is cool air, this is an area of the PP which could be utilised in warm climates to cool inhabitants.

4.3 EXPERIMENT 2

Recalling Section 3.3.7 this experiment was designed to answer Research Question 3, being:

3. By increasing the number of RPs does this correspond with an increase in outflow?

The plot on the following page (Figure 47) illustrates the Inflow-Outflow relationship for each pumping height across all the ranges of inflows. As explained previously in Chapter 3: ‘Methodology’ there was significant trouble with enabling three or more Riser Pipes (RPs’) to become active. It is clearly visible on the bar-chart when and where a new RP becomes active as represented by sudden series of peaks in the Outflow. Across the entire inflow range a second RP only becomes active when it pumps up to the pre-defined height of Pumping Height 5 (PH 5), which corresponds to 0.5m above the water level in the Header Tank (HT). We also see that the third RP only activates when at higher inflow rates than the initial 92l/min and when the PH is sufficiently low enough. In fact, during this experiment the third RPs’ only activate when the system isn’t actually pumping above the water level in the HT and there is a very high inflow (at least 122l/min). In a general sense this leads to the relationship that to activate more RPs’ the PH must decrease and the inflow increase.

However, discretion must be exercised to that relationship for the following reasons. First, and as mentioned earlier, only PHs’ 7 and 8 activated three RPs’ but these are below the water-level in the HT, and so aren’t actually pumping. Second, there is only a narrow band of results to which the relationship belongs. Thirdly, and perhaps most crucial, by considering the outflows with two RPs’ then at 92l/min of inflow this corresponded to the greatest outflow throughout each PH, when compared to the remaining outflows. Recalling ‘Experiment 1’, it was discovered that there is an optimal inflow which would correspond to the highest efficiency; it is probable that these results are on the ‘tail-end’ of this relationship. Despite this being subtle evidence it is plausible when one considers the necessary inflow range jump from 40l/min in ‘Experiment 1’ to 92l/min in ‘Experiment 2’; there is a ‘blind-zone’ of 52l/min. Thus it would be expected that by decreasing the inflow to a value below that of 92l/min this would yield an even higher efficiency with only two RPs’. To active three or more RPs’ the results would suggest to increase the inflow, but this was not possible with this laboratory setup. However, ‘Video 5’ shows five RPs’, three of which are un-crimped, clearly there is enough air in the system as water is lifted through two of these and the water slugs in the third RP are bobbing slowly; suggesting an insufficient volume of air to support the third RP.

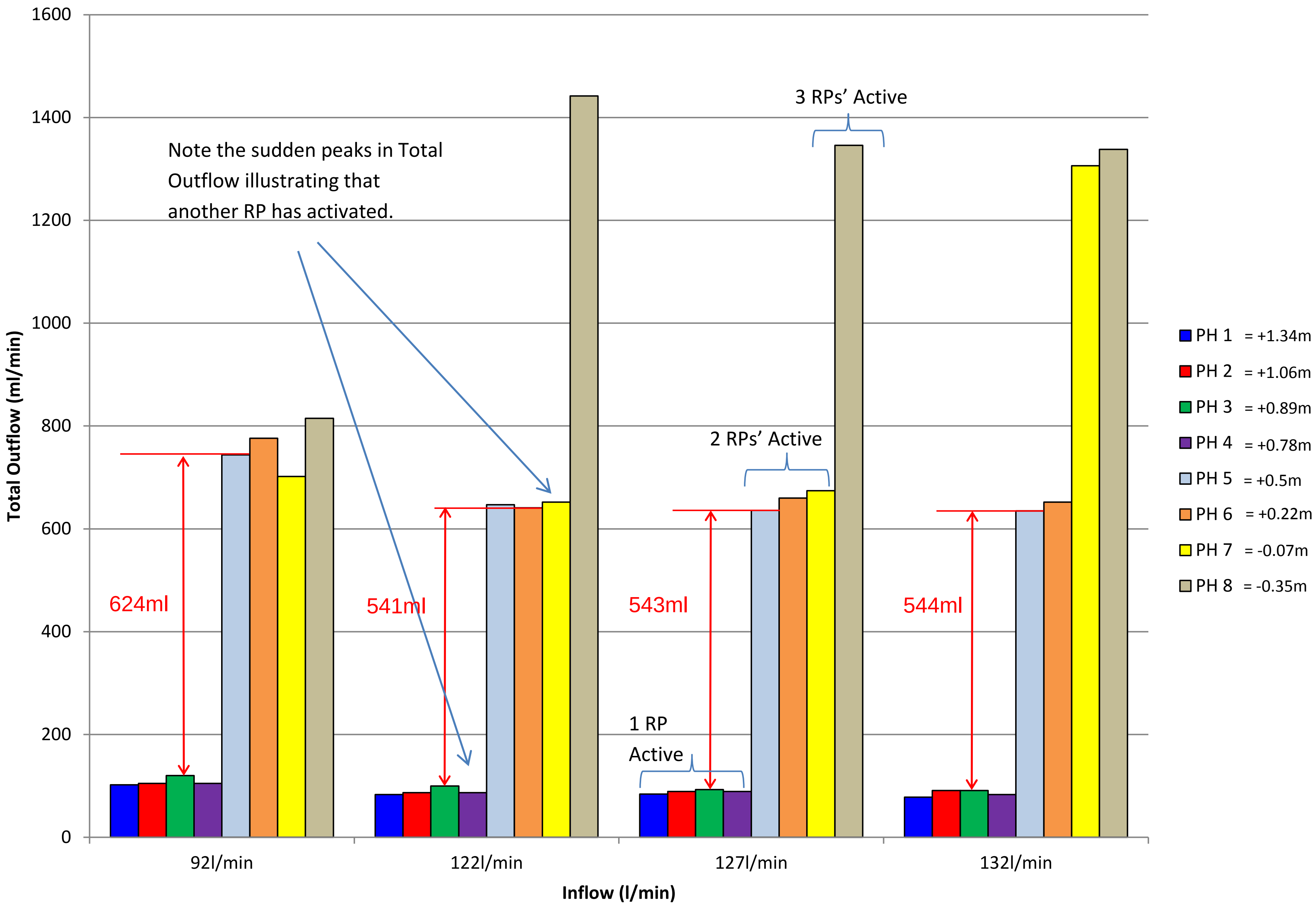

Figure 47: Inflow-Outflow Relationship for Each Pumping Height (PH)

The red lines on Figure 47 illustrate the smallest difference between the Inflow-Outflow relationship when one RP is active, compared to when two RPs' are active. Rather than the largest difference, the smallest difference was chosen (neglecting PHs' 7 & 8) as this would represent the minimum gain when two RPs' become active. Interestingly, and as is emulated in the graphs on pages 81 and 82 when two RPs' become active it doesn't simply double the outflow as was expected. Consider the smallest differences from Figure 47 and using the equations 4.3.1, 4.3.2 and 4.3.3 the following table (Table 4) was generated.

4.3.1 $$Smallest\ Difference = Smallest\ Outflow\ from\ 2\ RP - Largest\ Outflow\ from\ 1\ RP$$

4.3.2 $$Growth\ Factor = \frac{Smallest\ Difference}{Largest\ Outflow\ from\ 1\ RP}$$

4.3.3 $$Minimal\ Efficiency = \frac{Minimum\ Outflow\ with\ 2\ RPs'\ Active}{Inflow} \times 100$$

Table 4: Two RP Growth Factors, Neglecting PHs' 7 & 8

Inflow (l/min)	Smallest Difference (ml)	Growth Factor	Minimal Efficiency
92	624	5.20	0.81
122	541	5.41	0.53
127	543	5.84	0.50
132	544	5.98	0.48

In some cases the outflow increase with two RPs' was almost 6 times greater than that when a single RP was used; a huge difference. The explanation for this lies with the notion of an optimal inflow and thus air volume. We know that at 92l/min the outflow through a single RP is much smaller than that of 30, 35 and 40l/min (Figure 41) which essentially means that 92l/min of inflow provides too much air to which can be utilised in that single RP. So, when a second RP is activated some of that excess air can be utilised; so both RPs' become more efficient because the volume of air in each one is lower than that of a single RP to a suitable amount whereupon slug flow has been encouraged. This can certainly be reinforced when one considers that the lowest inflow in Table 4, 92l/min has the smallest growth factor; this inflow is more efficient than the others, and so when a second RP is active it also grows by the lesser amount.

Table 5 compares the minimum efficiencies across ‘Experiment 1’ and ‘Experiment 2’ so as to clearly see whether or not increasing the number of Riser Pipes (RPs’) positively affects the outflow of the system. It is necessary to compare the efficiencies because it must not be forgotten that in order to activate more RPs’ and greater inflow must be used. Minimal efficiencies were used in order to illustrate the minimum outflow which can be expected from the PP, and subsequently compared with the minimum daily demand on the forthcoming page.

Table 5: Minimal Efficiencies of Experiment 1 and Experiment 2

	Minimal Efficiency (%)		
Inflow (l/min)	**Experiment 1**	**Experiment 2**	**Growth Factor**
92	0.10	0.81	8.10
122	0.07	0.53	7.57
127	0.07	0.50	7.14
132	0.06	0.48	8.00

As can be seen from Table 5 it is clear that using multiple RPs’ has the ability to greatly increase the volume of outflow, in fact the typical growth factor is between 7 and 8. Figure 48 is an illustration depicting how again, like ‘Experiment 1’ the Pumping Height (PH) is a crucial variable that affects multiple RPs’ the same as a single RP, as would be expected.

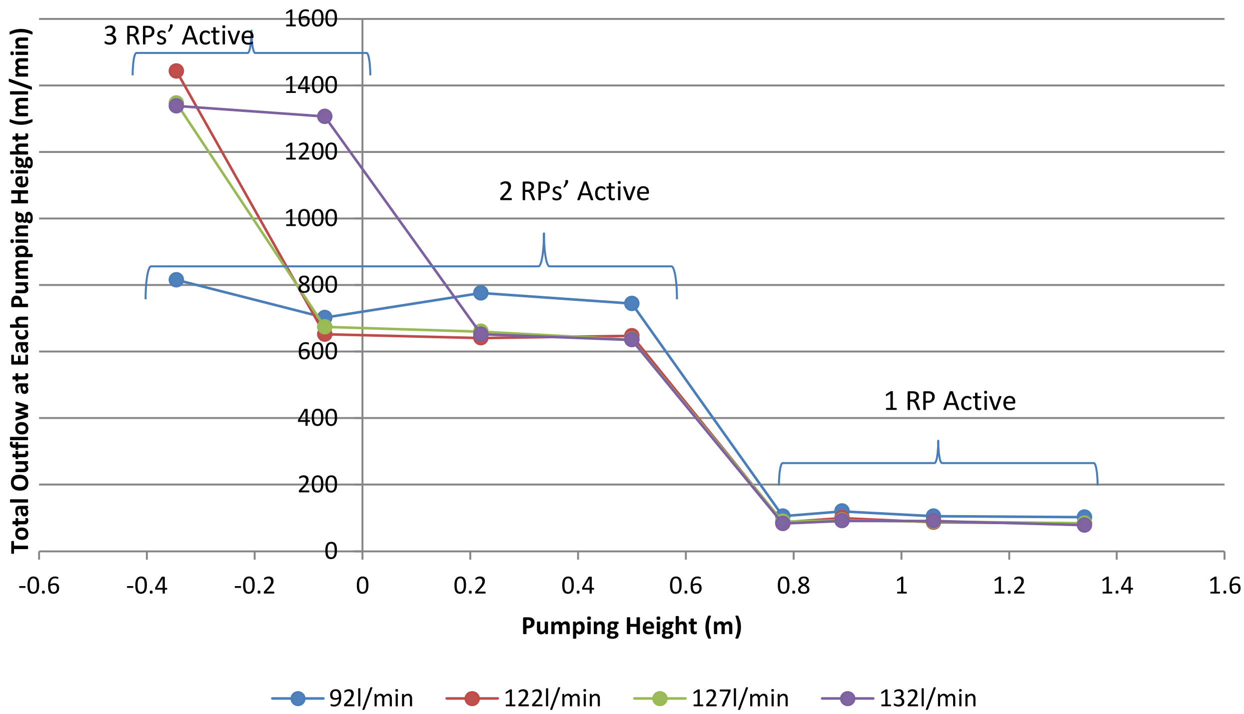

Figure 48: Experiment 2 - Pumping Height vs. Total Outflow at Each Pumping Height

Recalling Chapter 2: Literature Review it was discovered that a minimum quantity of water for basic health was 20l/c/d (Howard and Bartram, 2003); considering the maximum efficiency from Table 5, being 0.81% with 92l/min, at PH5 (approx. +0.5m);

$$Inflow\ Each\ Day = 92 \times 60 \times 24 = 132{,}480 l/day$$

$$Outflow\ Each\ Day = 132{,}480 \times 0.01 \times 0.81 = 1073 l/day$$

$$Number\ of\ People\ Satisfied = \frac{1073}{20} = 53$$

Considering the minimal efficiency from Table 5 (absolute worst case scenario), being 0.06% with 132l/min, at PH1 (approx. +1.35m);

$$Inflow\ Each\ Day = 132 \times 60 \times 24 = 190{,}080 l/day$$

$$Outflow\ Each\ Day = 190{,}080 \times 0.01 \times 0.06 = 114 l/day$$

$$Number\ of\ People\ Satisfied = \frac{114}{20} = 5$$

The values derived here are the minimum and maximum counterparts of the most inefficient setup of the PP; so these are the absolute bare minimum figures. It's important to note that these figures are based on the relatively small-scale laboratory experiment conducted within this report, not on a fully optimized system, but still, the PP can satisfy the minimum requirements. The traits found here, such as the importance of balancing the inflow with the number of RPs', and the high factor increases when a new RP was activated (See Figure 47) will lead to a more optimized solution and so it could be fully expected that the PP can satisfy a small village or town.

However, the biggest issue remains with the PPs' most critical variable, the Pumping Height (PH). In both experiments the PHs' were small and it must be rationally considered whether or not the lifting potential is actually worth the effort undertaken to setup a PP system when compared with traditional water-pumping methods. For the PP to be running optimally it must have a certain inflow, a certain number of RPs', a maximum height to which the water is pumped and an air and water-tight Separation Chamber (SC). All this will require significant setup costs such as material and labour where location and topography are crucial to both the operation and the practicalities. However, once installed optimally, water will always be available and there would be a small chance of the pump breaking down, thus maintenance costs will be minimal.

4.3.1 Observations

A series of observations were made during this experiment; it was found that when one RP was active there was minimal slug flow at 92l/min, but when two RPs' were activated both responded immediately and utilised slug flow conditions. This aligns, and somewhat confirms what was mentioned previously about why the growth factors are so high when using another RP.

Despite only being able to get outflow volume readings for three RPs' when they were below zero PH, there was an instance where three RPs' were observed to be working at above zero PHs' on the highest inflow of 132l/min. However, it was very intermittent and lasted a maximum of approximately 20 seconds; this variability didn't allow the outflow to be measured effectively. This does indicate that to activate more RPs' an increase in inflow would be required.

Before the new inflow range (92, 122, 127 & 132l/min) was introduced in order to get 'Experiment 2' to run with two RPs', a thinner Perspex pipe (approx. 20mm ID) with holes was placed down into the Perspex-Plastic downpipe. The hope here was that as the water flowed past the holes and the bottom of the pipe it would entrain more air and provide a greater potential to lift water through the RPs'. However, this actually stemmed the vortex flow (probably because the pipe was too large), prevented sufficient air-entrainment and the system failed to pump even with one RP.

Similar to 'Experiment 1', unless the inflow was turned on gradually it would cause the whole system to stall and not run at all, but unlike 'Experiment 1' this was not complemented with a quiet and 'smooth' main outflow. Considering the Perspex-Plastic pipe was of small diameter (63mm OD), then perhaps by shocking the system with a sudden high inflow this 'drowns the vortex', and prevents it from forming. Thus, only a very limited amount of air would be entrained which is insufficient to lift the water in the RPs'.

In the analysis of 'Experiment 1' it was noted that the water-level in the Perspex-Plastic tube altered with the inflow, and the higher the inflow the increase in variation of this water-level. The same was witnessed here; at 132l/min the difference was 1.2m, as oppose to 0.35m at 40l/min giving further validation to the concept that an over-abundance of air reduces the efficiency of the system. Again, it can be noted that for both Experiments an inflow of 132l/min yields the highest variation in water-level along the tube and the lowest efficiency. From both 'Experiments 1 and 2' it is clear that an optimal inflow exists.

4.4 ISSUES AFFECTING RESULTS

The only issue that stands-out to affect the results of 'Experiment 1' and 'Experiment 2' is the method by which the water flowing from the RPs' was captured. For ease, the RPs' were looped over the ladders and left to hang into the below-ground drainage pit where the water could be collected; as oppose to collecting the water at the actual height it was pumped to. This was never considered an issue until a check at the end of the experimentation determined that in fact, this had an effect on the results. The check involved comparing the outflows at 35l/min for each PH under two conditions; one being that the water was collected at the bottom (as with in all tests) and the second, being that the water was collected level with the height it was pumped to. Table 6 shows the outcome of that test, with Figure 49 providing a graphical illustration of those differences.

It is clearly shown that the adjusted condition of collecting water directly at the PH level increased the outflow by approximately 83.4ml/min. Initially, the reasons for the differences was thought to be due to a siphon effect, whereby the water in the 'down' part of the RP was acting to suck more water with it. However, if this were true the results would have been an over-estimate, which is a stark contrast of those shown in Figure 49.

Table 6: Summary Table Based on Table 8 and Table 9.

	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Difference (ml/min)	55.0	72.0	66.0	81.0	104.0	88.0	101.0	100.0
Average (ml/min)	83.4							

More realistically it is likely to be a combination of multiple variables including frictional resistance, the method of measurement, and possibly opposite air pressure. The frictional resistance along the length of the 'down' part of the RP will act to slow down the water and hence outflow over the period of measurement. By measuring the water discharge at the bottom of the looped RP it takes time for the water to fall and accumulate into the measuring cylinder, much longer than if it were measured directly at the PH level. Therefore, more water is actually discharged into the measuring cylinder in the given time of 60 seconds when measured directly at the PH level, rather than the bottom. Finally, since air rises it is possible that an opposite air pressure may have inhibited the flow; the extent is likely minimal since the air rising from the SC is compressed and will overcome the naturally uncompressed air. See Figure 50 for an example of this.

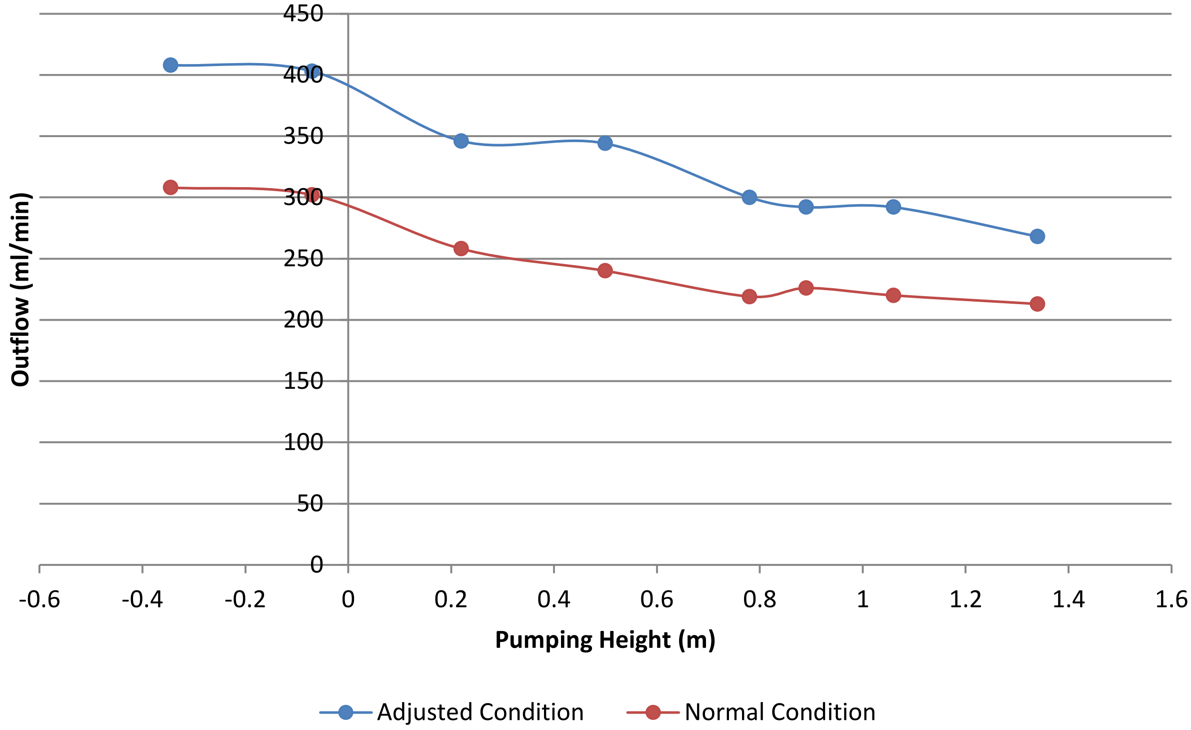

Figure 49: Plot of Table 6, Comparison to Identify the Effect of Siphonage

With regards to Siphonage, it is also possible that the water flowing from the plastic pipe (Table 1, Ref: 6) acted to suck more water away from the SC. This in turn could also have affected the results; probably by reducing the measured outflow from the RPs. Unfortunately, due to time-constraints the effects of this, if any, were not checked.

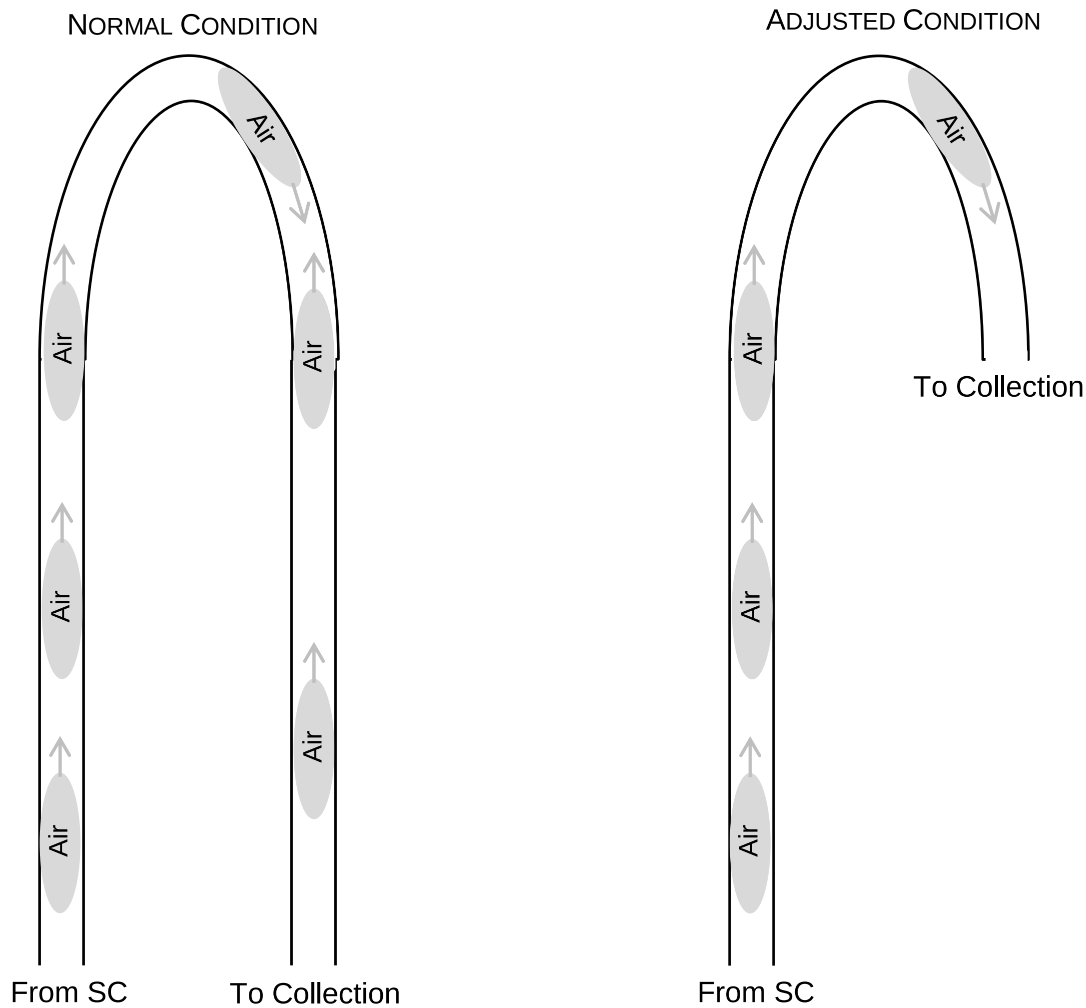

Figure 50: Comparison of Potential Opposite Air Pressure Among Different Collection Conditions

4.5 SUMMARY

This chapter presented the results of both 'Experiment 1' and 'Experiment 2', and provided an analysis of those results to better clarify the current murky understanding of the PP. In summary, all three research questions were answered and their associated hypotheses were found to be correct; refer to section 3.3 to see these; potential errors were also acknowledged. The following chapter will bring closure to this report and relate the work completed herein with those objectives stated in Chapter 1.

5 Discussions and Conclusions

The original objectives of this report, as defined in Chapter 1: Introduction were;

1. Review the current progress of investigations on the PP and identify the areas for testing.
2. Provide a working laboratory model where the areas for testing as identified in Objective 1 can be executed.
3. Assess the results and provide a brief evaluation to the potential suitability/applicability of the PP in developed and developing countries.

Taking a broad perspective, all of these objectives have been achieved in their respective sections of this report apart from an element of the third objective which is discussed later. During Chapter 2: Literature Review, the current work on the Pulser Pump (PP) and all relevant material to its' operation were investigated. It was discovered that only a very minimal amount of literature had been published specifically about the pump (1 report); its' content, including discussions and analysis were sub-par and in some instances were wholly incorrect. However, this contained recommendations for testing which have been upheld here, such as providing a rigid testing regime and conducting many more tests with a wider range of inflows and pumping heights (PHs'); this laid the ground-work for completing Objective 2. In any case it was clear that a comprehensive report was a necessary starting point for future research.

Experiments were designed and a laboratory model built to carry out the recommendations suggested in the report by Dacho (2012) and other elements found during the course of the literature review, such as the use of multiple Riser Pipes (RPs'). White (B. 2012a) aided in the design of those experiments and the lab model. The results were collected and various observations were made that have not been considered in any previous works. During Chapter 4: Analysis and Synthesis of Results these observations were presented, the results were analysed and the most critical variable to the PP efficiency was found to be the Pumping Height (PH). The hypotheses associated with each research question were found to be true. In general, this report found that:

1. By increasing the PH this corresponds with a decrease in outflow
2. By increasing the inflow this corresponds with a decrease in outflow
3. By increasing the number of RPs' this corresponds with an increase in outflow
4. By optimizing those listed above, the PP has the potential to support a large number of people with at least the minimum quantity of water for basic health

This verified the raw results (not the interpretations) of Dacho (2012), and the level of analysis and investigation of the 3rd outcome has provided a strong future research foundation and pushed the level of the current understanding. This work is highly significant in the context of the PP. However, with reference to Objective 3 it is still a necessity to consider if the PP has a place in developed or developing countries; in retrospect this element of the objective wasn't achievable. There are many questions that need to be answered with regard to the PPs' viability in different situations, which is easily another independent research path. It would be inappropriate to begin this research path unless further laboratory research has been conducted first. As such, this report provides the verification and the groundwork for that future laboratory research and therefore, currently no definite answer to the PP applicability can be given; this is explained in further detail in Chapter 4: Analysis and Synthesis of Results.

5.1 Limitations and Recommendations

The main limitation of this investigation is the suitability of the PP in real situations, it is presented briefly but due to high time-constraints, in-depth evaluations are missing. As such, further work may like to build upon the experiments and concurrently introduce the applicability aspect further.

Other limitations include the narrow band of Pumping Heights (PHs') and inflows used, especially the 'blind-zone' where a large range of these inflows were missing as described in Chapter 4. The effect of this limitation has been an inability to illustrate the PPs' behavior over a consistent and extensive range of variables. Unfortunately, much of this was due to many of the unknown aspects of the PP system, the availability of materials, budget constraints, time constraints and concerns over health and safety. A further limitation is the under-estimation error in outflow when collecting the water from the RPs' as has been discussed.

From the observations made and method undertaken, there are two clear principles which should be adhered to when future work is undertaken;

1. Ensure Separation Chamber is air and water-tight, along with all joints and seals
2. Collect water directly at the PH level to negate effects discussed in Section 4.4.

From the literature reviewed, and the analyses undertaken a clear set of five recommendations have been produced which will further this work;

1. The lengths of the RPs' that were inside the SC were of fixed length; it may be interesting to see how different length tubing is affected with a change inflow. When a higher inflow is used there is a greater volume of air, and perhaps this pushes the water-level in the SC down further, which may engage these longer lengths and lead to a greater efficiency.

2. Try multiple, smaller intake pipes. The vortex generated in the Header Tank (HT) sucks in and entrains air. The velocity of the vortex increases as the radius decreases; multiple fast spinning vortices may entrain a greater volume of air and could lead to greater efficiency. An alternative may be to incorporate a venturi collar along the downpipe (Table 1, Ref: 3 & 5); the venturi will increase the velocity of the water and this may allow more air to be carried down into the SC.

3. Try and maximize the potential PH, this is the most crucial and arguably the most useful variable, the effects might be more easily observed by minimizing the height between the HT and the SC. Also, the SC must be pressurised, alter the height of the pipe which induces the pressure (Table1, Ref 6) and see how this affects the operation.

4. Observe the effectiveness of the pump if the RPs' are placed at an angle to the vertical. In a real situation it may not be possible to arrange them vertically.

5. The air drives the PP, and so there is a benefit to discovering the volume of air that is being entrained in the system and how this is affected by combinations of other variables. It may be that an optimal volume of air is found.

To conclude, it is hoped that this report will bring the relatively unknown PP to the wider audience whereupon the potential in the PP can be investigated further. The research undertaken within this report and the steps outlined above will help to push the boundaries of this pumping technique; at which point a comprehensive evaluation can be made to determine if indeed there is a place for this technology in our world.

Word Count (exc. Headings, Captions, References and Appendices): 15,711

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7 Appendices

7.1 APPENDIX A – METHODOLOGY

7.1.1 Separation Chamber Detail

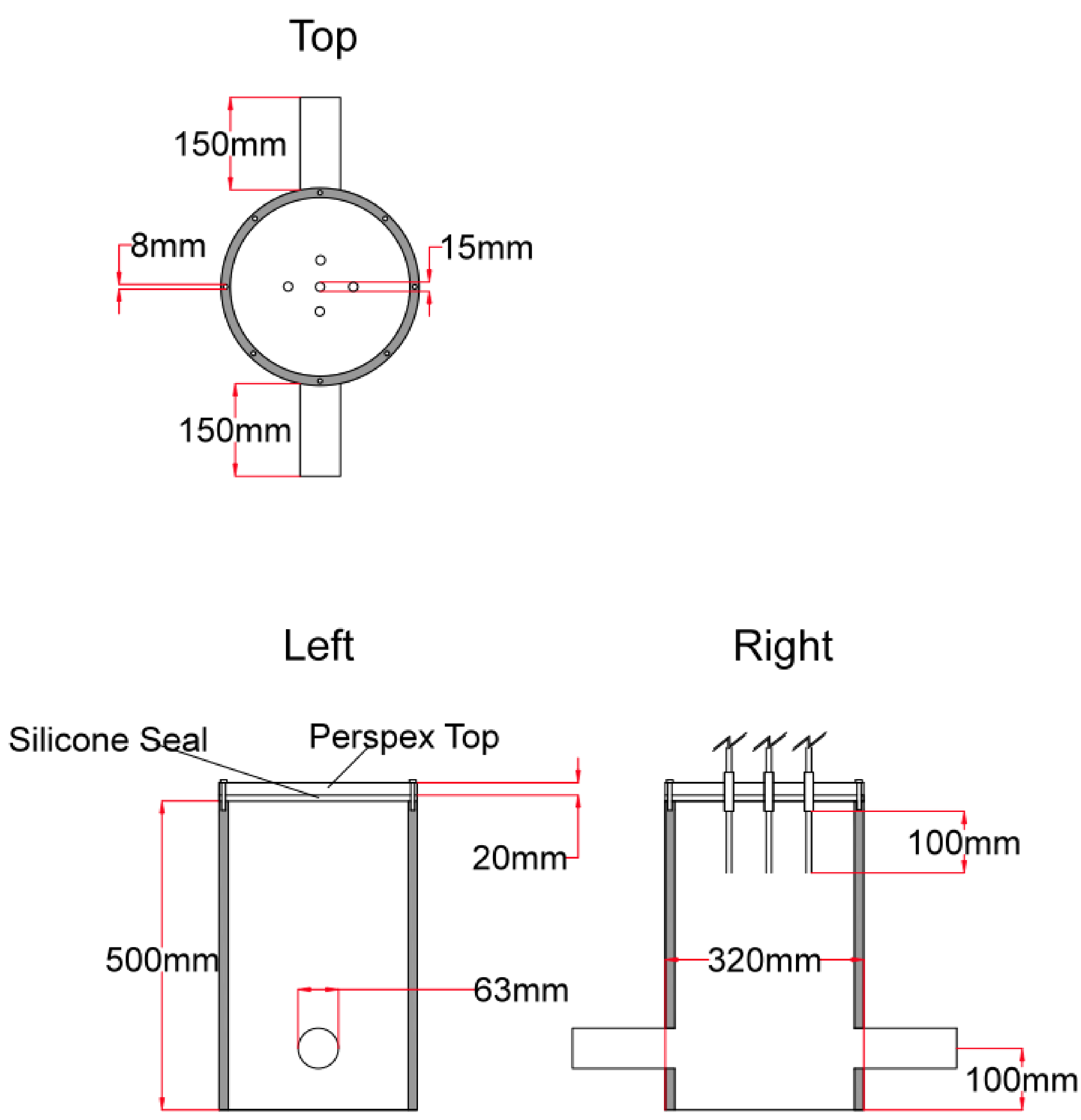


Figure 51: Separation Chamber Detail

7.2 Appendix B – Results

The purpose of this appendix is to provide the raw data that was used to plot the graphs in Section 4: Analysis and Synthesis of Results and supplement arguments where needed.

7.2.1 Validation of Experiment 1 and 2 Data-Merge

Table 7: Validation of Experiment 1 and 2 Data-Merge

	Inflow		
Experiment	30l/min	35l/min	40l/min
1	262	213	195
2	251	208	196

7.2.2 Siphon Effect

Table 8: Adjusted Condition (Minimal Siphon Effect)

35l/min	**PH1**	**PH2**	**PH3**	**PH4**	**PH5**	**PH6**	**PH7**	**PH8**
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	280	290	300	305	360	330	410	400
TEST 2	260	300	290	300	360	350	400	400
TEST 3	280	300	280	290	330	340	395	420
TEST 4	260	280	290	305	330	350	400	410
TEST 5	260	290	300	300	340	360	410	410
Average	268	292	292	300	344	346	403	408

Table 9: Normal Condition (With Siphon Effect)

35l/min	**PH1**	**PH2**	**PH3**	**PH4**	**PH5**	**PH6**	**PH7**	**PH8**
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	210	220	240	240	235	280	310	310
TEST 2	215	220	215	210	240	255	290	300
TEST 3	230	220	230	205	245	245	310	310
TEST 4	210	215	220	220	240	260	300	310
TEST 5	200	225	225	220	240	250	300	310
AVERAGE	213.0	220.0	226.0	219.0	240.0	258.0	302.0	308.0

7.2.3 Experiments 1 & 2 Raw Data

Table 10: Experiment 1 Raw Data

30l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	240	280	330	300	350	325	380	350
TEST 2	260	280	300	290	355	340	390	310
TEST 3	270	280	295	300	350	340	380	340
TEST 4	280	270	350	320	340	345	350	350
TEST 5	260	290	310	315	330	350	370	340
AVERAGE	262.0	280.0	317.0	305.0	345.0	340.0	374.0	338.0

35l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	210	220	240	240	235	280	310	310
TEST 2	215	220	215	210	240	255	290	300
TEST 3	230	220	230	205	245	245	310	310
TEST 4	210	215	220	220	240	260	300	310
TEST 5	200	225	225	220	240	250	300	310
AVERAGE	213.0	220.0	226.0	219.0	240.0	258.0	302.0	308.0

40l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	190	210	215	210	210	250	250	270
TEST 2	195	200	215	205	200	230	250	260
TEST 3	195	205	210	205	240	245	260	260
TEST 4	200	210	180	205	220	240	250	240
TEST 5	195	200	200	210	210	240	260	270
AVERAGE	195.0	205.0	204.0	207.0	216.0	241.0	254.0	260.0

92l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	105	105	120	90	135	190	165	160
TEST 2	100	105	120	90	135	180	170	160
TEST 3	100	105	115	95	150	190	145	165
TEST 4	105	110	130	90	135	180	175	160
TEST 5	100	100	115	95	135	190	175	160
AVERAGE	102	105	120	92	138	186	166	161

122l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	90	90	105	85	155	130	135	110
TEST 2	85	85	95	80	135	135	130	110
TEST 3	75	85	100	95	150	135	135	130
TEST 4	80	90	100	95	135	130	130	110
TEST 5	85	85	100	85	130	130	135	120
AVERAGE	83	87	100	88	141	132	133	116

127l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	85	95	85	75	125	130	130	120
TEST 2	90	85	85	95	145	130	130	115
TEST 3	75	90	105	95	145	130	130	110
TEST 4	90	85	100	90	120	125	130	110
TEST 5	80	90	90	90	135	135	130	115
AVERAGE	84	89	93	89	134	130	130	114

132l/min	PH1	PH2	PH3	PH4	PH5	PH6	PH7	PH8
Head (m)	1.34	1.06	0.89	0.78	0.5	0.22	-0.07	-0.345
TEST 1	80	75	90	85	125	135	130	110
TEST 2	90	90	95	85	145	135	130	110
TEST 3	70	95	80	90	145	130	110	115
TEST 4	70	75	100	85	120	135	115	105
TEST 5	80	80	90	80	135	130	115	110
AVERAGE	78	83	91	85	134	133	120	110

Table 11: Experiment 2 Raw Data

Pumping Head 1

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
92l/min	1	105	100	100	105	100	102
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	90	85	75	80	85	83
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
127l/min	1	85	90	75	90	80	84
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	80	90	70	70	80	78
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 2

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
92l/min	1	105	105	105	110	100	105
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	90	85	85	90	85	87
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
127l/min	1	95	85	90	85	90	89
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	75	90	95	75	80	83
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 3

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
92l/min	1	120	120	115	130	115	120
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	105	95	100	100	100	100
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
127l/min	1	85	85	105	100	90	93
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	90	95	80	100	90	91
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 4							
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
92l/min	1	90	90	95	90	95	105
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	85	80	95	95	85	87
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
127l/min	1	75	95	95	90	90	89
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	85	85	90	85	80	83
	2	0	0	0	0	0	0
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 5							
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
92l/min	1	135	135	150	135	135	138
	2	600	620	620	590	600	606
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	155	135	150	135	130	141
	2	450	500	520	530	530	506
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
127l/min	1	125	145	145	120	135	134
	2	420	510	520	520	540	502
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	125	145	145	120	135	134
	2	470	520	500	480	535	501
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 6

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
92l/min	1	190	180	190	180	190	186
	2	545	640	555	605	605	590
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	130	135	135	130	130	132
	2	505	515	495	500	530	509
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
127l/min	1	130	130	130	125	135	130
	2	520	540	540	530	520	530
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	135	135	130	135	130	133
	2	520	525	510	520	520	519
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 7							
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
92l/min	1	165	170	145	175	175	102
	2	610	600	580	590	620	600
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	135	130	135	130	135	133
	2	545	510	500	530	510	519
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
127l/min	1	130	130	130	130	130	130
	2	560	535	530	560	535	544
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	130	130	110	115	115	120
	2	490	520	500	500	510	504
	3	710	640	680	700	680	682
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Pumping Head 8							
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
92l/min	1	160	160	165	160	160	161
	2	690	620	620	660	680	654
	3	0	0	0	0	0	
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
122l/min	1	110	110	130	110	120	116
	2	510	530	520	490	560	522
	3	720	780	860	860	800	804
	4	0	0	0	0	0	
	5	0	0	0	0	0	

Inflow	No. of Risers	Test 1	Test 2	Test 3	Test 4	Test 5	Average
127l/min	1	120	115	110	110	115	114
	2	500	480	460	560	420	484
	3	780	860	600	720	780	748
	4	0	0	0	0	0	
	5	0	0	0	0	0	
Inflow	**No. of Risers**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Average**
132l/min	1	110	110	115	105	110	110
	2	500	520	500	480	500	500
	3	800	750	740	700	650	728
	4	0	0	0	0	0	
	5	0	0	0	0	0	

7.2.5 Experiments Video CD

7.2.6 Inflow vs. Outflow Plots

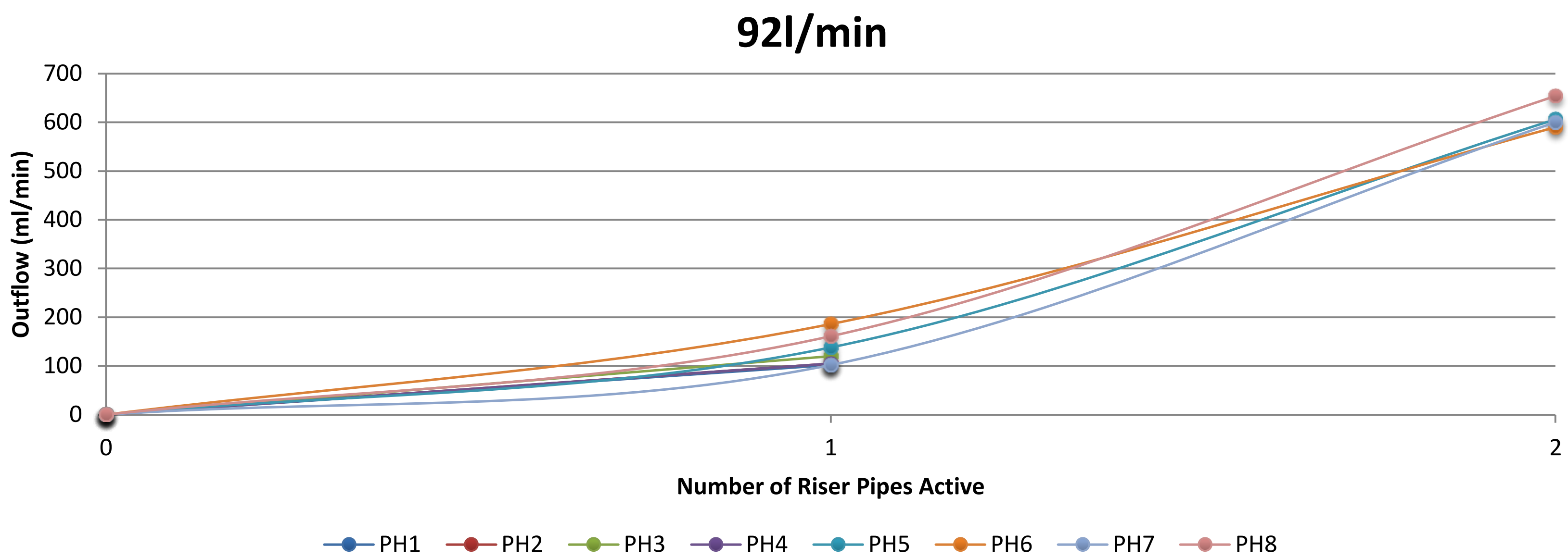


Figure 53: Experiment 2 - 92l/min. Risers Active vs. Outflow

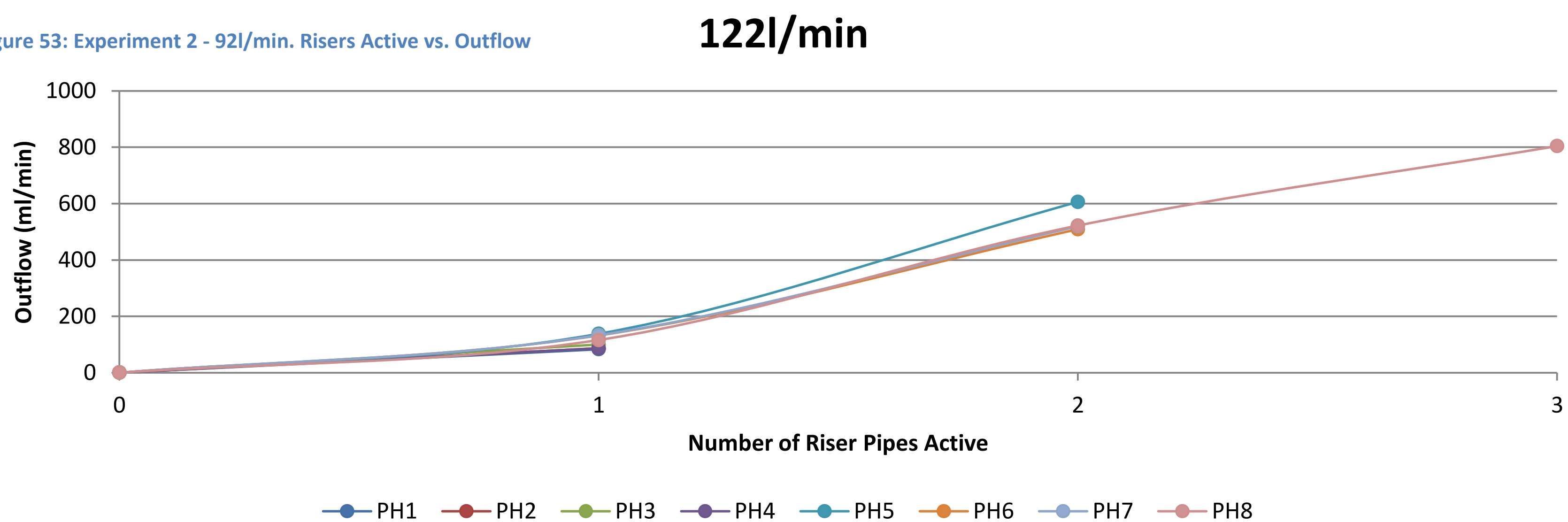


Figure 52: Experiment 2 - 122l/min. Risers Active vs. Outflow

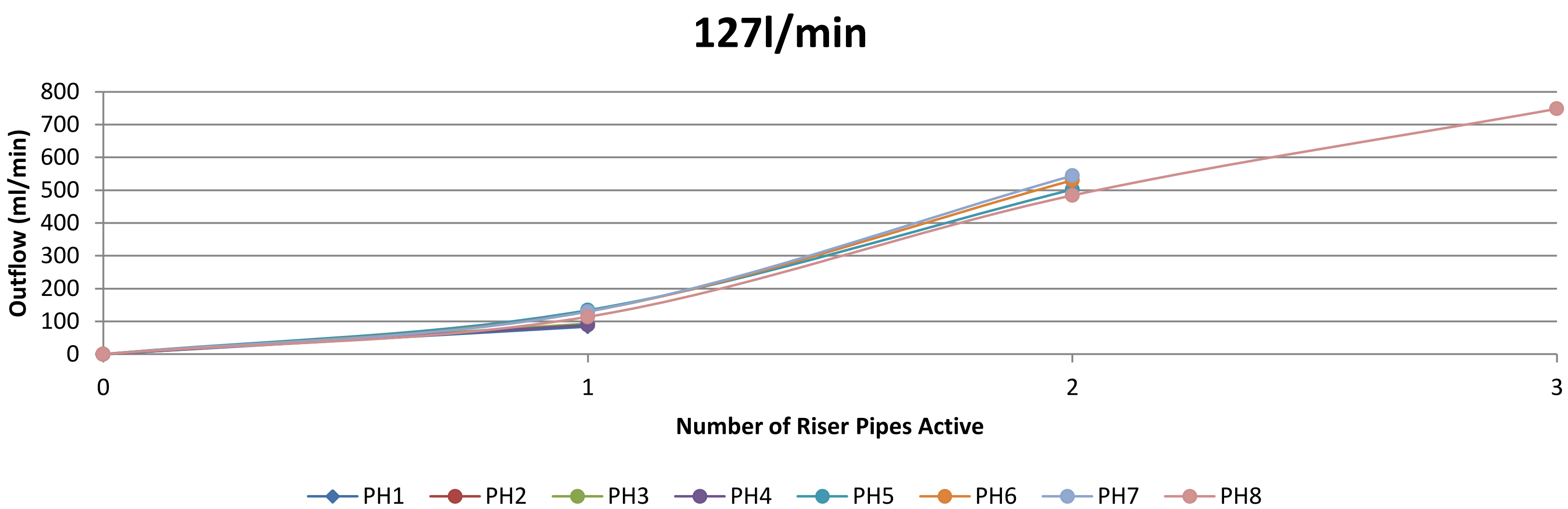


Figure 54: Experiment 2 - 127l/min. Risers Active vs. Outflow

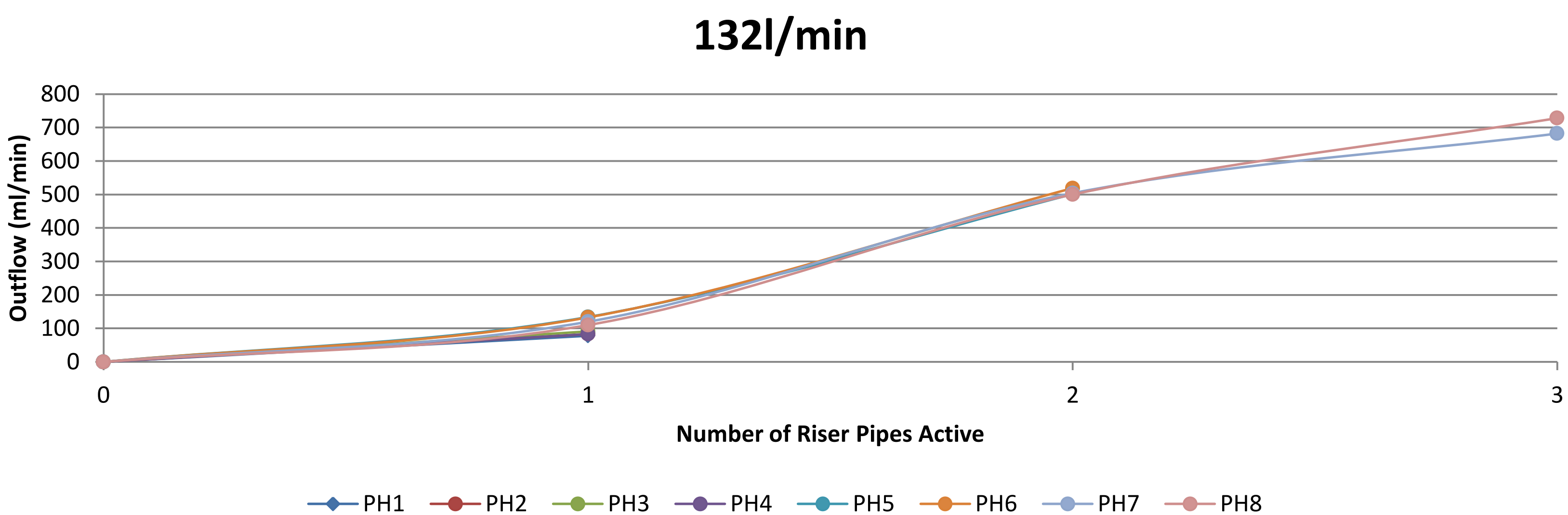
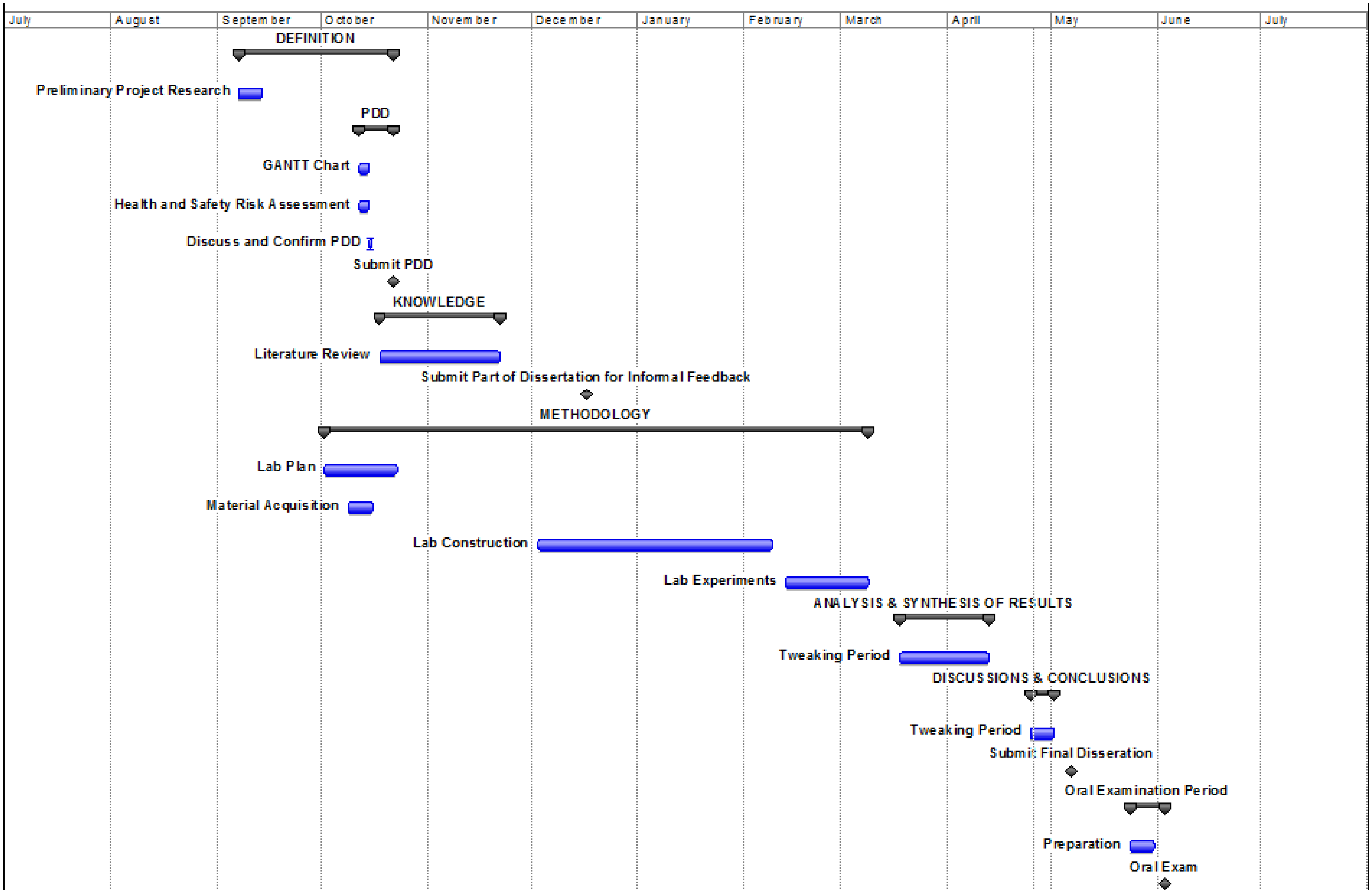


Figure 55: Experiment 2 - 132l/min. Risers Active vs. Outflow

7.3 APPENDIX C – TIME MANAGEMENT



7.4 APPENDIX D – PROJECT DEFINITION DOCUMENT (PDD)

Name of Supervisor: Brian Skinner

Name of Student: Michael Turner

Project Title: Investigating the Pulser Pump

Aim: A laboratory investigation into critical variables of the Pulser Pump in an attempt to improve it's output & assess its' suitability/applicability in developed and developing countries.

Objectives:

1) Review the current progress of investigations on the Pulser Pump and identify areas for testing.

2) Provide a working model where areas for testing identified in Objective 1 can be executed.

3) Assess my results and provide an in-depth evaluation to its' potential suitability/applicability for situations in developed and developing countries.

Methodology:

1) Correspondence with Brian White, the creator of the Pulser Pump and an examination of existing literature.

2) Develop a lab plan and testing regime, with guidance from Brian White, approved by Supervisor (Brian Skinner).

3) Assess results and judge the pumps suitability/applicability in developed and developing countries. Share results with Brian White and ask for feedback, discuss with Brian Skinner. Identify areas for future research to develop the pump.

Resources: PVC-U piping and fittings. Clear plastic hoses. Scaffolding. Water Tank. Air-tight chamber. Air pressure gauges.

Health & Safety for PDD: YES

Anticipated Outcomes: A dissertation that:

i) Broadens/Develops the existing knowledge of the Pulser Pump.

ii) Determines an optimal pumping configuration.

iii) Evaluates the pumps practical suitability/applicability in developed and developing countries. Provides clear areas for future investigation.

Signed: M. E. Turner ....(Student) Brian H. Skinner ....(Supervisor)

Date: 19/10/12

7.5 Appendix E – Risk Assessment

u/9

Loughborough University

Assessment No. MT-FYRP-2012(1)

Risk Assessment Record

School	Civil and Building Engineering

Item Description	Laboratory Test of the Pulser Pump
Location	Sir Frank Gibb Hydraulics Lab
Date	Monday 22nd October 2012

Highest Risk Rating	[redacted] **Medium/** [redacted]* *delete as appropriate from highest rating on page 7
Review Date	**May 1st 2013**

Assessor	Michael Turner (A914871)		
Comments	M.Turner3-09@student.lboro.ac.uk		
Signature	M.E.Tu	**Date**	22.10.2012

Supervisor	Brian Skinner		
Comments	I believe that he has considered all risks and has planned appropriate precautions.		
Signature	Brian H Skinner	**Date**	24/10/2012

Safety Officer	Wayne Lord	OK GEOFF RUSSELL	
Comments		G.Russell 25/10/12	
Signature	[signature]	**Date**	26/10/12

Method statement

The box below should indicate what you are going to do, when and where you are going to do it and, if appropriate, who with. This method statement can then be used to analyse and address the specific risks inherent with the planned work.

For all undergraduate and MSc projects, a signed version of the Project Definition document should be attached. Where work is to be conducted abroad, you are also required to include an itinerary and attach a completed Travel Authorisation Form together with FCO guidance.

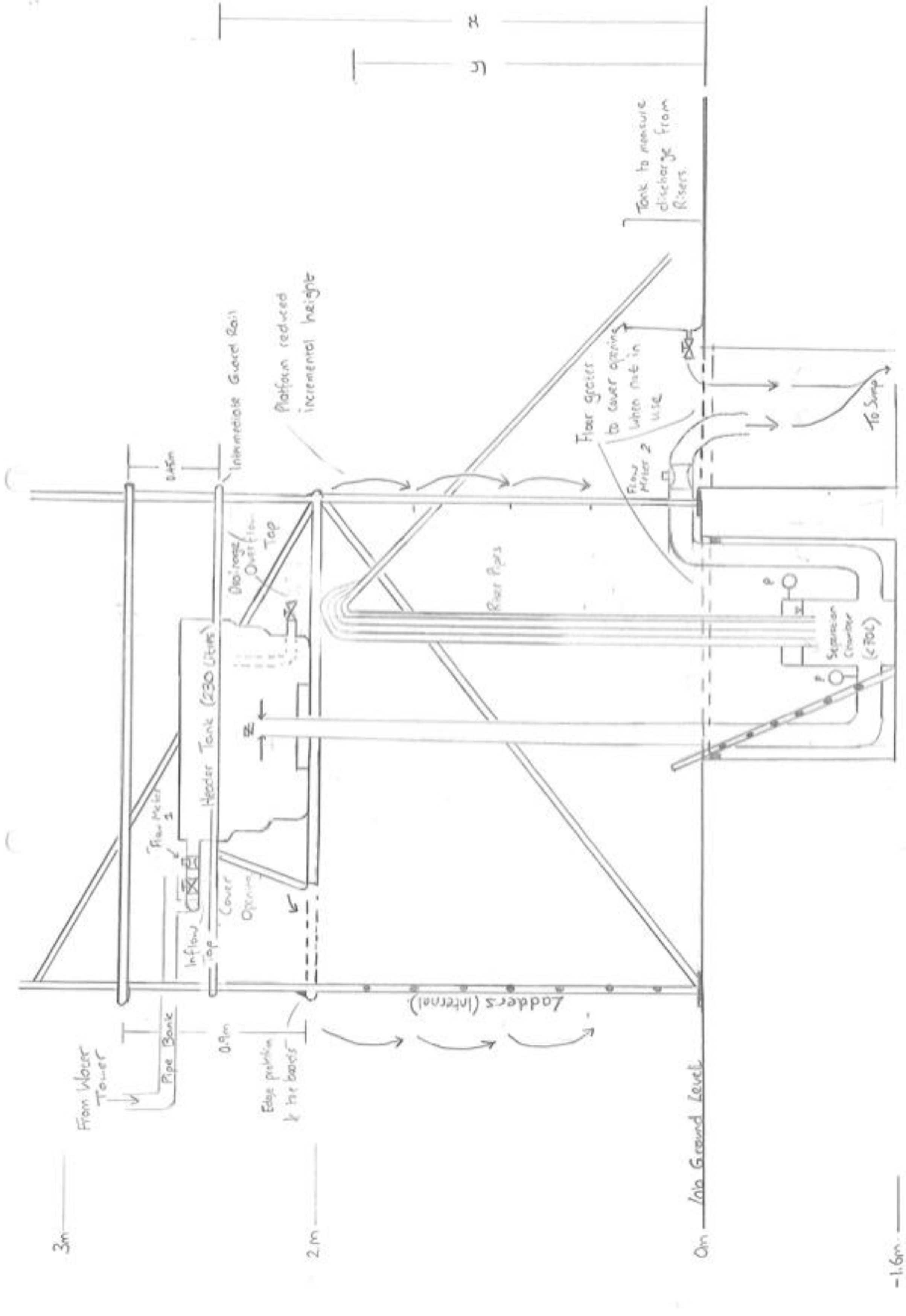
Method statement:	General: I shall be building and testing a Pulser Pump in the water laboratory that shall consist of an elevated tank of water (Header Tank) at approximately 2m high, an air-tight container (Separation Chamber) below ground level (-1.6m) and numerous pipes/fittings. The Header Tank will tap into the laboratorys' water tower. The Header Tank will be elevated by the use of tower scaffolding that will allow a user to alter it's elevation above the ground to the maximum of 2m. Access to the tower scaffolding and it's platform will be by use of an internal ladder, the entrance hole of which will be covered by a platform hatch. Access to the below ground Separation Chamber will be provided by a ladder; the entrance hole of which will be covered when not in use by the exisitng floor grates. A single pipe will emerge vertically from the base of the Header Tank that will carry water into the Separation Chamber; an elbow joint shall mediate the transition from vertical to horizontal flow. An outflow pipe connected to the side of the Separation Chamber shall take water from the Pulser system into an adjacent water storage tank underneath the laboratory, which in turn will flow into the Sump Tank. A series of small diameter clear plastic tubes (Riser Pipes (vertical and possibly inclined)) will demonstrate the Pulser effect by transporting slugs of air and water. The Riser Pipes will extend sequentially to numerous fixed heights below the Header Tank and will be tied to the scaffolding to ensure vertical flow. The discharge from the Riser Pipes will be measured by the outflow entering a standard water tank and in turn depositing into the laboratorys' below-ground water storage tanks, and then into the Sump Tank. Any water entering the Sump Tank will be pumped into the main water tank on the roof of the laboratory ready for re-use. Construction: Upon aquiring materials necessary for my project PVC-u pipes will need to be cut and pipe-fittings glued. The scaffolding should already be in place and will need a hole of approximately 70mm in diameter to be drilled into the platform base to allow for the emergent vertical pipe from the Header Tank.

Method statement

The box below should indicate what you are going to do, when and where you are going to do it and, if appropriate, who with. This method statement can then be used to analyse and address the specific risks inherent with the planned work.

For all undergraduate and MSc projects, a signed version of the Project Definition document should be attached. Where work is to be conducted abroad, you are also required to include an itinerary and attach a completed Travel Authorisation Form together with FCO guidance.

Method statement:	Tests Conducted: Once the system is running the tests conducted will include measuring the discharge from the Riser Pipes by using a graduated tank. Also measured is the height difference (x) between the water level in the Header Tank and the water level in the pipes at ground level coming from the Separation Chamber. Flow rates will be recorded by using a flow meter (1) on entry to the Header Tank from the Pipe Bank and a flow meter (2) installed on the main water pipe flowing from the Separation Chamber into the adjacent below-ground water storage tank. Finally, the last measurements to be recorded shall be the pressures at the base of the vertical pipe (before it enters the Separation Chamber) and the pressure in the Separation Chamber; these will be recorded via pressure guages. Access to the below ground pressure guages will be provided by a ladder. Test variables include altering the elevation height of the Header Tank (x), the pipe diameter that extends inside the Header Tank (z), and the height that the Riser Pipes extend (y). Potential for Further Testing: Dependent on the success of my testing and time-constraints I may retrofit a Venturi collar/air-pipe into the side of the pipe that extends vertically downwards from the Header Tank. The purpose of this will be an attempt to entrain more air into the system and again, as in the general description this will not take place any higher than 2m. Header Tank Capacity = 230 litres Separation Chamber Capacity < 70 litres Please see the following page for a diagram of the proposed layout.


3m
2 m
0m
-1.6m
Ground Level
From Water Tower
Pipe Bank
0.9m
Edge protection & toe boards
Ladders (internal)
Inflow Tap
Cover Opening
Flow Meter 1
Header Tank (230 Litres)
0.45m
Intermediate Guard Rail
Drainage/Overflow Tap
Riser Pipes
Platform reduced incremental height
Floor grates to cover opening when not in use
Flow Meter 2
Separation Chamber (<70L)
To Sump
Tank to measure discharge from Risers.
x
y

Personnel at Risk

The Health & Safety at Work Act requires that you ensure, so far as is reasonably practicable, the health and safety of yourself and others who may be affected by what you do or fail to do. Indicate using the groups listed below the individuals (restricted high-risk users) and numbers of people (e.g. with restricted user privileges or unrestricted access) who may be at risk from the hazards. Classify the *maximum* level of activity/exposure to the equipment to be permitted for each group/individual using the categories indicated below.

Activity/Exposure Categories

1. Reconfiguration (high exposure)
2. Maintenance
3. Normal use
4. Unsupervised observation
5. Supervised reconfiguration
6. Supervised normal use
7. Supervised observation
8. Prohibited (no exposure)

Personnel Groups

Group	Individuals/Numbers	Activity/Exposure
Academic Staff	Brian Skinner	Normal use
Technical Staff	Mick Barker	Reconfiguration
Research Staff	None	Normal use
Project Students	Michael Turner	Normal use / Reconfiguration ~~Normal use.~~
Others	[enter details]	Prohibited

Hazard Checklist

Indicate below whether or not a hazard is present for *each* type listed.

Category 1: Machinery & Work Equipment: Mechanical Hazards

Type	Yes	No	Type	Yes	No
Crushing	☐	☒	Impact	☐	☒
Shearing	☐	☒	Stabbing/puncture	☒	☐
Cutting/severing	☒	☐	Friction/abrasion	☐	☒
Entanglement	☒	☐			
Drawing-in/Trapping	☐	☒	Other mechanical hazard(s)	☐	☒

Category 1: Machinery & Work Equipment: Electrical Hazards

Type	Yes	No	Type	Yes	No
Direct contact	☐	☒	Source of ignition	☐	☒
Indirect contact	☐	☒	Electrical test labels current	☒	☐
Electrostatic phenomena	☐	☒			
Short circuit/overload	☐	☒	Other electrical hazard(s)	☐	☒

Category 2: Workplace

Type	Yes	No	Type	Yes	No
Slips/trips/falls on a level	☒	☐	Localised cold surfaces	☐	☒
Falls from a height	☒	☐	Storage and stacking	☐	☒
Falling/moving objects/materials	☒	☐	Confined work area (knocks)	☐	☒
Striking objects	☐	☒	Confined space/lack of oxygen	☐	☒
Localised hot surfaces	☐	☒	Other workplace hazard(s)	☐	☒

Category 3: Hazardous Substances

Type	Yes	No	Type	Yes	No
Toxic fluids	☐	☒	Corrosive substances	☐	☒
Toxic gas/mist/fumes/dust	☒	☐	Irritants/sensitising substances	☑	■
Flammable liquids	☐	☒	Oxidising substances	☐	☒
Flammable gas/mist/fumes/dust	☒	☐	Explosive substances	☐	☒
High pressure gas/fluid	☐	☒	Biological substances (infection)	☐	☒
High pressure fluid injection	☐	☒	Other substance hazard(s)	☐	☒

Category 4: Work Activity

Type	Yes	No	Type	Yes	No
Highly repetitive actions	☐	☒	Visual fatigue (e.g. >3 hours VDU)	☐	☒
Stressful posture	☐	☒	Poor workplace design	☐	☒
Awkward/heavy lifting/handling	☐	☒	Use of hand tools	☒	☐
Mental overload/stress	☐	☒	Other work activity hazard(s)	☐	☒

Risk Assessment Record Assessment No. MT-FYRP-2012(1)

Category 5: Work Organisation

Type	Yes	No
Contractors/service	☐	☒
Other work organisation hazard(s)	☐	☒

Category 6: Work Environment

Type	Yes	No
Significant noise	☐	☒
Significant vibration	☐	☒
Poor/excessive lighting	☐	☒
Hot/cold ambient temperature	☐	☒
Poor ventilation	☐	☒
Other work environment hazard(s)	☐	☒

Category 7: Other Hazard Types

Type	Yes	No
Violence	☐	☒
Stress	☐	☒
Drugs	☐	☒
Substance abuse	☒	☐
Other hazard(s)	☐	☒

Category 8: Outdoor Work

Type	Yes	No
Outdoors on campus	☐	☒
Outdoors off campus	☐	☒
Overseas fieldwork	☐	☒
Site visit: construction	☐	☒
Site visit: non-construction	☐	☒
Other hazard(s)	☐	☒

Other Hazards: Radiation

Type	Yes	No
Radiation: Lasers	☐	☒
Radiation: Electromagnetic effects	☐	☒
Radiation: Ionising/non-ionising	☐	☒
Other radiation hazard(s)	☐	☒

Risk Assessment Record

Hazard Assessment

Describe the hazards identified above on the following pages. For each hazard assess the risk to health and safety using the risk rating formula and categories indicated below.

Risk Calculation

Severity	×	Probability	=	Risk
Major = 3 (e.g. death, major injury as per RIDDOR, irreversible health damage)		High = 3 (where certain or near certain harm will occur)		High = 6,9
Serious = 2 (e.g. injuries causing >3 days absence or reversible health damage)		Medium = 2 (where harm will frequently occur)		Medium = 2,3,4
Minor = 1 (e.g. first ad treatments and other lost time)		Low = 1 (where harm will seldom occur)		Low = 1

Hazard Risk Rating 1 of 3

Activity	Groups at risk	Hazard Description	Controls in place	Severity	Probability	Risk	Action needed? Yes	No
Reconfiguration	Technical Staff	Cutting/Severing - Reconfiguration of PVC-u pipes	Vice and Gloves	Minor	Low	Low	☐	☒
Reconfiguration	Technical Staff Project Students	Entanglement of wiring used in machinery for cutting/drilling.	Tidy work area	Minor	Low	Low	☐	☒
Reconfiguration	Technical Staff Project Students	Stabbing/Puncture when cutting/drilling using hand tools or machinery.	Vice and Gloves	Minor	Low	Low	☐	☒
Normal use	All	Slips, Trips, Falls on a Level	Tidy work area. Designated walking and working area boundaries.	Minor	Low	Low	☐	☒

Add Row Delete Row

Assessr

Hazard Assessment

Describe the hazards identified above on the following pages. For each hazard assess the risk to health and safety using the risk rating formula and categories indicated below.

Risk Calculation

Severity	×	Probability	=	Risk
Major = 3 (e.g. death, major injury as per RIDDOR, irreversible health damage)		High = 3 (where certain or near certain harm will occur)		High = 6,9
Serious = 2 (e.g. injuries causing >3 days absence or reversible health damage)		Medium = 2 (where harm will frequently occur)		Medium = 2,3,4
Minor = 1 (e.g. first ad treatments and other lost time)		Low = 1 (where harm will seldom occur)		Low = 1

Hazard Risk Rating 2 of 3

Activity	Groups at risk	Hazard Description	Controls in place	Severity	Probability	Risk	Action needed? Yes	No
Normal use	All	Falls from a height (scaffold tower, below-ground storage tanks)	Tower scaffolding, Ladders, Guard Rails, Intermediate Rails, Toe Boards, Covers for open holes when not in ues	Serious	Low	Medium	☐	☒
Normal use	All	Falling/moving objects/materials	Tower scaffolding platform with Toe Boards/Edge Protection, Guard Rails. Steel clamps	Serious	Low	Medium	☐	☒
Reconfiguration	Technical Staff Project Students	Toxix gas/Mist/Fumes/Dust occuring from using solvent cement	Well ventilated area	Minor	Low	Low	☐	☒
Reconfiguration	Technical Staff Project Students	Flammable gas/Mist/Fumes/Dist occuring from using solvent cement	Well ventilated area, no naked flames.	Serious	Low	Medium	☐	☒

Risk Assessment Record

Hazard Assessment

Describe the hazards identified above on the following pages. For each hazard assess the risk to health and safety using the risk rating formula and categories indicated below.

Risk Calculation

Severity	×	Probability	=	Risk
Major = 3 (e.g. death, major injury as per RIDDOR, irreversible health damage)		High = 3 (where certain or near certain harm will occur)		High = 6,9
Serious = 2 (e.g. injuries causing >3 days absence or reversible health damage)		Medium = 2 (where harm will frequently occur)		Medium = 2,3,4
Minor = 1 (e.g. first ad treatments and other lost time)		Low = 1 (where harm will seldom occur)		Low = 1

Hazard Risk Rating 3 of 3

Activity	Groups at risk	Hazard Description	Controls in place	Severity	Probability	Risk	Action needed? Yes	No
Reconfiguration	Technical Staff Project Students	Use of hand tools when cutting PVC-u pipes	Vice and Gloves	Minor	Low	Low	☐	☒
Reconfiguration	Technical Staff Project Students	Substance Abuse from solvent cement	Well ventilated area	Serious	Low	Medium	☐	☒
~~Reconfiguration~~				~~Minor~~	~~Low~~	~~Low~~	☐	☒
~~Reconfiguration~~				~~Serious~~	~~Low~~	~~Medium~~	☐	☒

Add Row | Delete Row

Asse

Risk Reduction

Physical

Determine whether the risk to health and safety can be reduced by modifications to the equipment or workspace, especially for those hazards identified as having medium to high risk. List planned action and completion dates below.

Hazard	Action to be taken	Responsible Personnel	Completion Date
Chemical	Collect Safety Data from J. Bhuptani	Student.	Before use

Risk Assessment Record Assessment No. MT-FYRP-2012(1)

Procedural

Determine and indicate below whether acceptable levels of risk to health and safety can only be achieved when equipment use must follow prescribed procedures, and/or where use must be restricted to specified personnel. Prepare and attach user guides, user restriction and other HSE documents as appropriate. Contact the School Safety Officer for guidance/assistance as necessary.

Item	Yes	No
Does the equipment/process need an operating procedure document?	☐	☒
• If yes, has one been prepared and appended to this form?	☐	☐
Must protective equipment be worn to use the equipment/process safely? (cf. Personal Protective Equipment (PPE) regulations)	☒	■
• If yes, have the users been adequately notified?	☒	☐
• If yes, is suitable protective equipment available for all potential users/observers?	☒	☐
Should the use of this equipment be restricted to certain qualified personnel?	☐	☒
• If yes, has a list of permitted users been prepared, appended to this form and displayed near the equipment?	☐	☐
Is training required to use the equipment/process safely?	☐	☒
• If yes, have all identified users been adequately trained?	☐	☐
Does the equipment have a CE mark?	☒	☐
• If not, does the equipment need a separate Machinery Risk Assessment?	☐	☐
• If yes, has one been prepared and appended to this form?	☐	☒
If a lifting hazard has been identified is a manual handling assessment required?	☐	☒
• If yes, has one been prepared and appended to this form?	☐	☐
If hazardous substances will be in use, is a COSHH form required?	☒	■ See J. Bhuptani
• If yes, has one been prepared and appended to this form?	☐	☒
Does the equipment involve the use of lasers?	☐	☒
• If yes, has a laser description form been completed and appended to this form?	☐	☐