Self-Installation of Drip Irrigation Emitters for Prototype Emitter Testing

by

Eric Johnson

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

Bachelor of Science in Mechanical Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2016

Signature redacted

Author ....

Department of Mechanical Engineering
May 6, 2016

Signature redacted

Certified by ....

Amos Winter
Assistant Professor of Mechanical Engineering
Thesis Supervisor

Signature redacted

Accepted by ....

Anette (Peko) Hosoi
Professor of Mechanical Engineering
Undergraduate Officer

Self-Installation of Drip Irrigation Emitters for Prototype Emitter Testing

by

Eric Johnson

Submitted to the Department of Mechanical Engineering
on May 6, 2016, in partial fulfillment of the
requirements for the degree of
Bachelor of Science in Mechanical Engineering

Abstract

In this thesis, I tested methods of adhering factory-made drip emitters to the interior of short segments of piping. Different types of adhesive and pipe material combinations were tested, and I selected three combinations for further testing. Performance similar to factory-installed drip emitters was achieved at low pressure, but the necessary watertight seals repeatedly burst at higher water pressures. Alterations to the drip emitter and installation procedure are recommended to increase reliability and resilience of the installation.

Thesis Supervisor: Amos Winter
Title: Assistant Professor of Mechanical Engineering

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Drip irrigation is a method of irrigating farms which provides a localized source of water to the roots of individual plants through a drip emitter installed at each plant. The overall system of a drip irrigation installation includes a pump to provide pressure to the water source, a filtration system, a pressure regulator, pipes leading to all plants, and the emitters. The main advantage of a drip irrigation system is that it significantly reduces water and fertilizer consumption by localizing the water application directly to the roots of each plant.

In addition to reducing water consumption, drip irrigation systems are ideal for farms with non-level land or irregular shaping. Soil erosion is lowered, as well as weed growth, as water is only applied to the desired plants instead of the whole field. The leaves of plants remain dry, which reduces the possibility of pests and disease to crops, and fertilizer can easily be introduced to the system at high efficiency by using water-soluble fertilizers in the irrigation system.

This type of system is particularly beneficial to small-holder farmers, those holding two hectares of land or less. In 2013, there were 2.5 billion of these small farmers globally, with 99 million in India. [1] These farmers are critical to developing nations and provide over 80 percent of consumed food in their countries. [2] In India, 80 percent of water consumption is for agricultural purposes, and as global population and water scarcity increases, the need for more efficient farming techniques will become more and more apparent. Within 20 years, current trends would see 60 percent of aquifers in India in critical condition, with 60 percent of irrigated Indian agriculture relying on that groundwater. [3]

However, while drip irrigation can reduce water consumption by 70 percent and fertilization consumption by 40 percent, whilst increasing crop yield by 50 percent when compared to flood irrigation, it has only been widely adopted in developed countries. [1,4] The main reason for this is the high costs of the irrigation system, a high portion of which is the power needed to provide pressurized water to the piping. Introducing a drip irrigation system consuming little enough power to be powered by solar panels would greatly increase the feasibility of these systems in developing nations. [3] To lower the power consumption, an ideal method is to the lower the activation pressure of the individual drip emitters, thereby lowering the required overall pressure to be provided by the pump.

Allowing small-scale irrigation to be more widely adopted may also provide poverty alleviation to developing countries. Low-cost, low-power, and water-efficient irrigation would allow farmers to grow more profitable and marketable crops, while lowering their expenses. [3]

Until recently, the design of emitters for irrigation has not been informed by any mathematical model, with limited testing performed to minimize the activation pressure. Work has now begun on mathematical analysis of drip emitters, and more optimal flow paths are being designed to reduce the activation pressure of these emitters. [1,2,4]

However, inline emitters are generally installed into piping in a factory setting. The polyethylene pipe is heat formed with the emitter already in place within the piping, rather than the piping being produced separately. After the pipe is formed, the drip emitter is pressed into the still-hot pipe, and as the pipe cools, and the emitter and pipe are bonded together.

This method of manufacturing, while ideal for mass production, is not feasible for the installation of individual prototype emitters in a laboratory setting. This thesis explores a laboratory method of installing individual emitters into a short section of pipe, approximately 15-20cm long, to allow the testing of new flow paths in prototype emitters, with a focus on the type of adhesive used to install the emitter. To verify the results and ensure the emitter has been installed correctly with all necessary seals, the flow rate at various pressures will be compared with a factory-installed emitter of the same specifications. Then, recommendations will be made to improve the process to attempt better and more reliable emitter installation for future experiments. The overall purpose of this experiment is to provide a means of installation and testing of prototype drip emitters in a laboratory environment, and, as such, it includes sufficient detail to reproduce the installation process by others.

Chapter 2

Experimental Design

In order to test prototype inline drip emitters, it is necessary to adhere the emitter to the inside of a pipe with at least five centimeters of uniform flow around the emitter for accurate results. For this experiment, five types of adhesive and two types of pipe were chosen to test the seal that an adhesive supplies between a high-density polyethylene (HDPE) emitter and a segment of piping.

Flexible piping was used for this experiment, as emitters are installed in flexible piping in practice, and because the flexibility provides a better fit between the two pieces should the radii of curvature not be exactly identical. Polyethylene piping was chosen in order to match the material of piping used in practice, and, additionally, transparent PVC piping was chosen to be able to observe the spread of adhesive inside the pipe.

2.1 Adhesive Selection

To begin, five adhesive possibilities were chosen to provide a wide range of adhesive types. They are summarized in Table 2.1.

Each of these five adhesives was first tested by adhering an emitter to each of the two types of piping. All samples were clamped for at least 15 minutes, and left to dry for 24 hours. After drying, the strength of the bond was subjectively tested to provide a preliminary selection of adhesive/pipe combinations for further testing.

Adhesive	**Adhesive Type**
Loctite Epoxy Plastic Bonder	Acrylic epoxy
SCIGRIP 16 10315	Acrylic cement
J-B Weld 50133 Plastic Bonder Structural Adhesive	Urethane resin
Weld-On 10077 Clear Regular Bodied Contact Adhesive	Polyethylene contact adhesive
Super Glue Plastic Fusion Epoxy Adhesive 15277	Acrylic epoxy

Table 2.1: Selected Adhesives

With the PVC piping, as could be expected by examining the specification documents of each of the adhesives, none provided a particularly strong bond between the pipe and the emitter. However, the J-B Weld Plastic Bonder provided a sufficiently strong bond to seal against water and hold the emitter in place, and this combination was thus chosen to provide at least one sample where the adhesive spread and water flow could be observed through the transparent piping. On the polyethylene piping, both the J-B Weld Plastic Bonder and the Weld-On 10077 Contact Adhesive provided a sufficient bond and seal to be selected for further testing, with the Contact Adhesive providing the strongest bond found overall.

The Loctite Epoxy Plastic Bonder, SCIGRIP 16 10315, and Super Glue Plastic Fusion Epoxy Adhesive 15277 did not provide sufficient bonding between the drip emitters and selected piping materials. In all tests with these adhesives, the emitter was too easily dislodged even by gentle handling of the pipe, and it was clear that the adhesives would not withstand the necessary water pressure in the experiment.

To summarize, the three combinations of piping and adhesive selected are, with abbreviations noted in parentheses:

1. PVC piping + J-B Weld Plastic Bonder (PVC+JB)

2. Polyethylene piping + J-B Weld Plastic Bonder (PE+JB)

3. Polyethylene piping + Weld-On 10077 Contact Adhesive (PE+WO)

2.2 Apparatus and Method of Testing

For the bond between the emitter and pipe to replicate the factory-installed bond, a watertight seal must be created at all boundaries indicated by red lines in Figure 2-1.

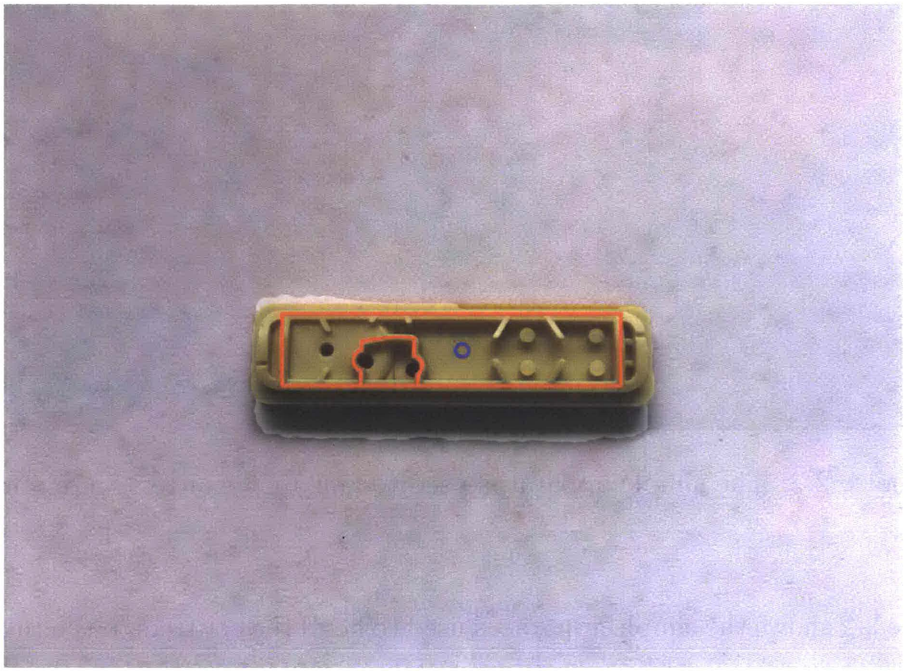

Figure 2-1: A drip emitter, with necessary seals outlined in red, and drill hole location marked in blue.

In addition to these seals, there must also be free water flow maintained in all areas that are not sealed, which requires careful application of adhesive while gluing the emitter. Thinner adhesives, such as the Weld-On 10077, can simply be applied in a single coat to the interior of the pipe which provides adhesive at all necessary points of contact. Thicker adhesives, such as J-B Weld Plastic Bonder, were applied to the outlined areas of the emitter using a small paintbrush, before being pressed inside the pipe.

An additional consideration while gluing is that the adhered side of the emitter has a specific radius of curvature. The pipes chosen match this curvature as closely as possible; however, as mentioned before, flexible piping was chosen to allow small deformation of the pipe and provide a better seal.

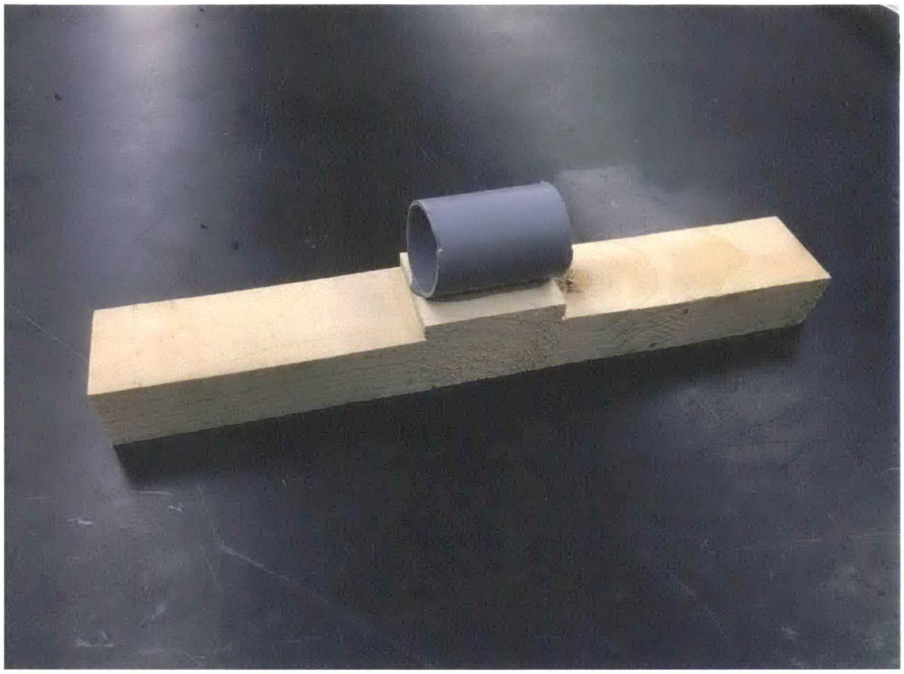

Figure 2-2: The simple apparatus used to glue drip emitters to piping.

Figure 2-2 shows the simple apparatus used to bond the emitters to the tubing. An emitter is loosely adhered to a small metal rod (through means of tape, putty, or other removable adhesive), adhering surfaces are roughened slightly with fine sandpaper, and the emitter and/or interior of the pipe is coated with adhesive. As mentioned prior, the thin adhesive was applied in an even coat to the interior of the pipe, while the thick adhesive was applied to the desired areas on the emitter using a small paintbrush. The metal rod is then inserted into the pipe, the emitter pressed against the pipe, and then clamped into place. Figure 2-3 shows an apparatus with a emitter clamped in for drying.

The grey rigid section of piping was placed to help conform the piping to the emitter, by minimizing the flattening of the pipe as pressure is applied. After being clamped in place for at least one hour, the pipe and emitter are removed and left to dry for at least 24 hours. After drying, a hole of 2mm diameter is drilled in the pipe to allow water to flow from the emitter output. The location of this hole is shown in Figure 2-1 as a blue circle. In the case of opaque (polyethylene) piping, the location

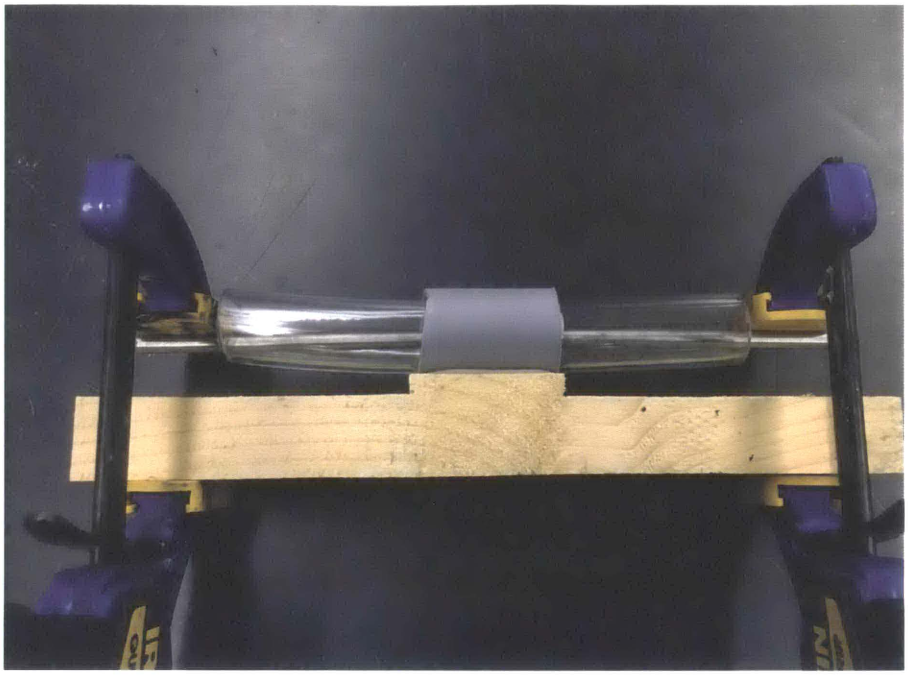

Figure 2-3: An apparatus with a drip emitter inserted and clamped for drying.

of the emitter can be found by measuring the length from one end of the pipe to the end of the emitter, and adding the length to the desired point of the emitter.

The pipe is then attached to a water source on one end, and the free end of the pipe sealed with a plug. Using a compressed air water tank with a pressure regulator, water pressure is applied to the pipe ranging from .2 to 1.4 bar, in .1 bar increments. The water is allowed to flow from the emitter for two minutes, at which point the total water emitted is measured, and converted to a flow rate in liters per hour.

2.3 Flow Rate of Factory Installed Emitters

To provide a baseline upon which to measure the flow rate of self-installed emitters, factory-installed emitters were tested under the same conditions. The emitter used for all experiments is the Jain Turbo Cascade Pressure Compensation (PC), with a specified flow rate of approximately 3.8 Lph. This emitter is specified to perform at the desired flow rate between .49 and 3.92 bar.

The baseline experiment on these emitters in factory-installed piping was performed as above, measuring the flow rate from .2 to 1.4 bar in .1 bar increments. Note that although these emitters can operate up to 3.92 bar, the purpose of this experiment is only to provide methods of testing future prototype emitters s of low-pressure emitters, and thus performing the experiment up to the maximum pressure (1.4 bar) of the test setup is sufficient. The results of three trials of this baseline testing are shown in Table 2.2.

	Flow Rate (Lph)		
Pressure (bar)	Trial 1	Trial 2	Trial 3
0.2	2.94	2.82	2.91
0.3	3.66	3.60	3.69
0.4	4.20	4.32	4.23
0.5	4.30	4.32	4.32
0.6	4.32	4.32	4.32
0.7	4.34	4.35	4.35
0.8	4.32	4.35	4.35
0.9	4.30	4.32	4.32
1.0	4.26	4.32	4.32
1.1	4.23	4.26	4.26
1.2	4.23	4.23	4.26
1.3	4.25	4.23	4.26
1.4	4.20	4.23	4.26

Table 2.2: Factory-Installed Emitter Flow Rates

Although the steady flow rate is slightly above specification, the important characteristic of a steady flow rate once pressure is above .49 bar is clearly present. This characteristic is the most important characteristic to observe for in the self-installed emitters, as it indicates that the pressure-compensation of the emitter is functioning correctly and all seals are present.

2.4 Testing of Self-Installed Emitters

With the three selected pipe/adhesive combinations, five iterations of each combination were tested, for 15 trials of testing in total. As described, all adhesives were clamped in the apparatus for at least one hour, and left to dry for at least 24 hours. The samples were tested progressively after each iteration, so small modifications to factors such as the amount of adhesive applied were varied as the experiment progressed to attempt to improve results. Results of these experiments are described in the next chapter.

Chapter 3

Results and Discussion

Tables 3.1 and 3.2 display the results of each of the 15 trials of pipe and adhesive combinations. All 15 trials are displayed in Table 3.1, and trials which succeeded in functioning correctly have their flow rates detailed in Table 3.2. Dashes in Table 3.2 signify a significantly large flow rate, such that it is clear a section of the watertight seal between the drip emitter and pipe has broken.

Pipe+Adhesive	**Trial**	**Result**
PVC+JB	1	Failure Mode 2
	2	Failure Mode 1
	3	Failure Mode 1
	4	See Table 3.2
	5	See Table 3.2
PE+JB	1	Failure Mode 1
	2	Failure Mode 1
	3	Failure Mode 2
	4	See Table 3.2
	5	See Table 3.2
PE+WO	1	See Table 3.2
	2	Failure Mode 1
	3	See Table 3.2
	4	See Table 3.2
	5	See Table 3.2

Table 3.1: Individual Trial Results

	Flow Rate (Lph)							
	PVC+JB		PE+JB		PE+WO			
P (bar)	4	5	4	5	1	3	4	5
0.2	2.70	2.73	2.75	2.64	2.87	2.85	2.82	2.85
0.3	3.45	3.36	3.46	3.33	3.55	3.56	3.50	3.54
0.4	4.15	4.24	4.20	4.23	4.28	4.26	4.24	4.24
0.5	4.18	–	4.20	4.23	4.31	4.29	4.27	4.25
0.6	4.20	–	4.22	4.26	4.30	–	4.25	4.30
0.7	4.20	–	4.23	4.26	4.30	–	4.25	4.32
0.8	4.23	–	4.22	4.26	4.28	–	4.27	4.32
0.9	–	–	4.25	4.24	–	–	–	4.30
1.0	–	–	4.22	–	–	–	–	4.29
1.1	–	–	–	–	–	–	–	4.26
1.2	–	–	–	–	–	–	–	–

Table 3.2: Flow Rate Results of Semi-Successful Trials

3.1 Failure Modes

Failures in this experiment occurred in three main ways, as described below.

Failure Mode 1: Failure Mode 1 is defined as when a sufficient seal between the emitter and pipe is not achieved. This is characterized by either the emitter becoming unattached from the pipe, or higher flow rates than normal, with no pressure compensation (i.e., flow increases proportionally with pressure). This was generally caused by an insufficient amount of adhesive applied, or, in the case of the PVC Piping, a weak bond between the two substrates.

Failure Mode 2: In a few cases with the thicker J-B Weld adhesive, no water was emitted from the emitter even at pressures as high as 1 bar. In these cases, extraneous adhesive blocked a free flow portion of the emitter, effectively sealing it closed. A example instance where significantly more adhesive than necessary was applied, and is visible through the transparent PVC piping, is shown in Figure 3-1.

Failure Mode 3: Similar to Failure Mode 1, this mode occurs when there is no longer a watertight seal between the emitter and piping. However, Failure Mode 3 involves the breakage being induced by the water pressure, when there previously was a good seal. All Trials in Table 3.2 ended in this Failure Mode, with the flow rate significantly increasing where dashes appear in the table.

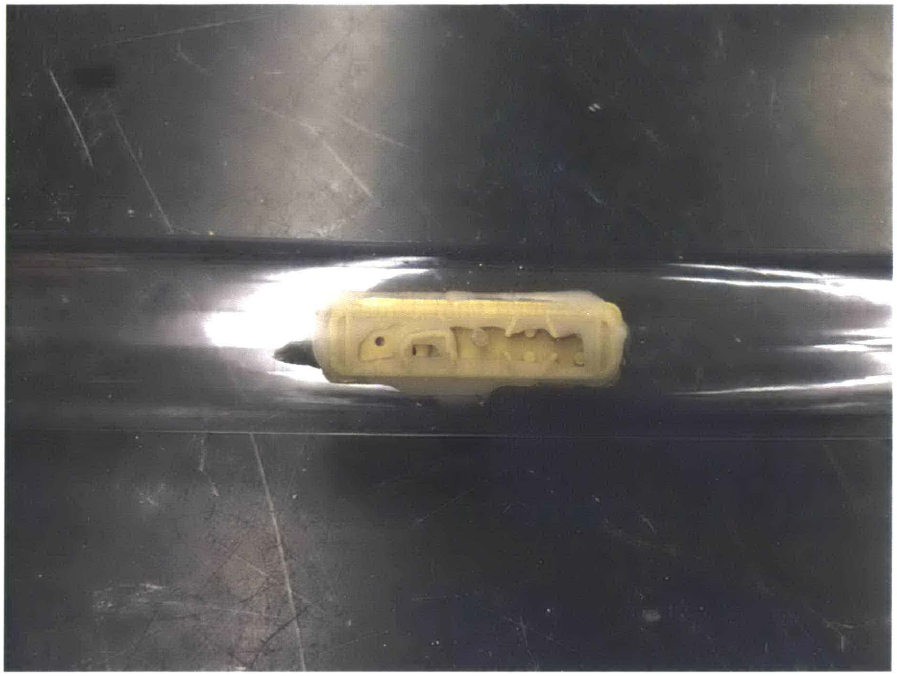

Figure 3-1: A glued drip emitter, with flow blocked by extraneous adhesive

3.2 Discussion

Of the three combinations, polyethylene piping with the Weld-On 10077 Contact Adhesive was the most reliable, creating an initial seal in four of the five trials. Meanwhile, the other two combinations only initially sealed in two of their five trials. It is hypothesized that this is mainly due to the ability to apply the thinner adhesive in a uniform coat to the interior of the piping. By using this method, all desirable surfaces are uniformly adhered, and no extraneous adhesive is pushed up into the emitter to block flow. Thus, if material (and thus adhesive) changes are introduced, it is recommended that thinner adhesives be used for the best results.

Another observation to note is that the steady flow rate for the self-installed emitters was, on average, slightly lower than the factory-installed emitters. This effect was also seemingly more significant with the usage of the thicker adhesive than with the thinner adhesive. Although there is not sufficient data to fully evaluate this effect, it is recommended that further testing be done if exact flow rate is a critical measurement. In any case, this effect only seemed to alter the steady flow rate, not the activation pressure of the emitter.

Clearly, later trials were more successful than earlier trials. This fact is most likely attributed to fine-tuning the amount of adhesive applied when observing the failures of previous trials. In general, it seemed that thinner Weld-On, even when applied in great excess, did not plug the drip emitter and result in Failure Mode 2. Therefore, it is recommended when using thin adhesives for this purpose to apply as much as necessary to create a strong bond. As mentioned, the thinner adhesive also did not seem to greatly effect the steady flow rate.

With the thicker J-B Weld adhesive, it is difficult to apply enough adhesive to securely attach the drip emitter while applying little enough to avoid blocking the water flow. A small paintbrush is highly recommended to apply adhesive to directly to the emitter, with great care taken only to apply adhesive where necessary. It is also then extremely important to press the drip emitter straight down onto the piping; inadvertent sliding of the drip emitter after application will serve both to reduce the amount of effective adhesive, thereby weakening the bond, and also introduce the risk of adhesive being pushed up into the ports of the drip emitter.

Once initially bonded, all trials failed before the maximum tested pressure of 1.4 bar, with a seal breaking and resulting in high water flow out of the drilled hole in the pipe. Among the three pipe/adhesive combinations, there was no notably significant difference in terms of how high of a pressure the adhesive could withstand. Still, given the more reliable install of polyethylene piping with Weld-On 10077 Contact Adhesive, it is the most recommended combination. Suggestions for possible improvements to the process to surpass this limitation are discussed in the next section.

3.3 Future Improvements

Of course, there is not much reason to install factory-made emitters inside custom piping; the flow rates of factory-made emitters are easily found in their specifications. However, if it is desired for some reason, it would likely be helpful to apply a second coating of adhesive around the perimeter of the emitter. Particularly with the thinner adhesives, which can seep into any cracks to block them off, this may help with providing a stronger watertight seal.

However, the purpose of this experiment is to provide a method of testing prototype emitters. As such, the prototype emitters can be designed to be better suited for this adhesive method. It would be recommended to increase the surface area of the adhering surface of the emitter, by simply extended the plastic outward to contact more of the pipe. In addition, if possible, it may be beneficial to use a more bondable material such as ABS when producing prototype emitters. Of course, if different materials of emitter are chosen, different pipe materials and/or adhesives should be chosen to provide the strongest bond. Still, the recommendation for thinner adhesives or solvents stands to ensure even coverage of the emitter.

In this experiment, flexible piping was chosen largely to allow for small deformations of the piping to conform to the emitter and provide a watertight seal. A drawback of this is that if the pipe deforms unintentionally, either by water pressure or rough handling, it is easy to dislodge the emitter from adhesive. For new prototype emitters, it is recommended to choose a rigid pipe wherever possible. This may make the emitter/pipe bond less susceptible to rough handling of the pipe, as well as the pipe deforming due to water pressure.

Chapter 4

Conclusion

In this thesis I detail a method of installing drip emitters into short segments of piping in order to evaluate their water flow output. This experiment used factory-made emitters, and compared the performance of those emitters in factory-installed and self-installed piping.

This work proves that this method is a feasible method for testing prototype drip emitters, and can be used to evaluate the performance of new low-activation-pressure flow paths. Of course, there are still many improvements to this method which can be investigated, and my suggestions for many of these alterations are detailed in Section 3.3.

With this work, practical testing on newly designed drip emitters in laboratory settings can be performed, greatly decreasing the turnaround time for new drip emitters. It is my hope that my work will benefit and expedite the production of low-activation-pressure emitters, allowing for drip irrigation systems to be used worldwide in developing countries. These systems have the power to greatly decrease water usage and fertilizer usage in farms in developing countries, as well as increase revenue to the farmers growing those crops, lifting them out of poverty.

Bibliography

[1] Narain, J., and Winter, A., 2016. "Mathematical Models of Compliant Membranes for Inline Drip Emitters," Proc. ASME 2016 International Design Engineering Technical Conference, Charlotte, NC, pp. 1-5.

[2] Taylor, K., Shamshery, P., Wang, R., and Winter, A., 2015. "A Mathematical Model for Pressure Compensating Emitters," Proc. ASME 2016 International Design Engineering Technical Conference, Charlotte, NC, pp. 1-9.

[3] Kuntz, L., 2013, "Wick Irrigation Systems for Subsistence Farming," B.S. thesis, Massachusetts Institute of Technology, Cambridge, MA.

[4] Shamshery, P., Wang, R., Tran, D., and Winter, A., 2016. "Modeling the future of irrigation: a parametric description of pressure compensating drip irrigation emitter performance," PLOS ONE, San Francisco, CA, pp. 1-14.