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3D printed relief valve analysis and validation

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3D PRINTED RELIEF VALVE ANALYSIS AND VALIDATION

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

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May 2018

ABSTRACT

Additive Manufacturing allows for faster, lower cost product development including customization, print at point of use, and low cost per volume produced. This research uses Stereolithography produced prototypes to develop an improvement to an existing product, the internal pressure relief valve of a positive displacement pump. Four 3D printed prototype assemblies were developed and tested in this research. The relief valve assemblies consisted of additive manufacturing produced pressure vessel components, post processed, and installed on the positive displacement pump with no additional machining. Prototype designs were analyzed with Computational Fluid Dynamic simulation to increase flow through the valve. The simulation was validated with performance testing to reduce the cracking to full bypass pressure range of the valve. By reducing this operational range of the valve, the power requirement of the pump drive system could be reduced allowing for increased energy efficiency in pump drive systems.

Performance testing of the 3D printed relief valves measured pump flow, poppet movement within the valve, and discharge pressure at operational conditions similar to existing applications. The Stereolithography prototype assemblies performed very well, demonstrating a 56% reduction in the pressure differential of the cracking to full bypass stage of the valve. This research has demonstrated the short term ability of additive manufactured produced components to replace existing metal components in pressure vessel applications.

Keywords: Additive Manufacturing, Stereolithography, Prototype, Internal Pressure Relief Valve, Positive Displacement Pump

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has been approved as meeting the thesis requirement for the

Degree of Master of Science

Date Dr. Scott Giese, Thesis Committee Chair

Date Dr. Julie Zhang, Thesis Committee Member

Date Dr. Doug Shaw, Thesis Committee Member

Date Dr. Patrick Pease, Interim Dean, Graduate College

DEDICATION

This research is dedicated to Kim, my cat, my friends, and my family.

ACKNOWLEDGEMENTS

This industry based research would not have been possible without the support of Viking Pump, Inc., a unit of the IDEX Corporation. This research was empowered by actions of Joe Thompson, Director of Engineering and Targeted Growth. I would like to thank Scott Kunkle, Luke Homewood and Ken Kibbee of the Viking Pump Product Engineering Lab. I would like to thank Josh Burke and Kyle Benning of the Viking Pump Application Engineering Department for their guidance in the development of the test specifications of this research. The designs presented in this paper could not have been developed without the CAD design skills developed with Justin Pierce and Brett Manternach over my 9 year career in the Engineering Department of Viking Pump. I would like to thank Cameron Neff for his mentoring developing my CFD simulation skill set.

I would like to express my sincere thank you to my advisor, Dr. Scott Giese and the members of my thesis committee Dr. Julie Zhang and Dr. Doug Shaw, for their support, knowledge and valued input to my thesis work. I would also like to thank the members of the Department of Technology at the University of Northern Iowa.

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DEFINITION OF TERMS

Internal Relief Valve (IRV): A device used to provide over pressure protection in positive displacement pumps.

Poppet: The device internal to the relief valve, providing the sealing surface of the valve, that moves axially to open at predetermined pressure.

Relief Valve Cracking Pressure: The pressure at which a relief valve begins to open and bypass fluid through the valve.

Relief Valve Bypass Pressure: The pressure at which a relief valve is fully open and the flow of the pump is fully directed through the relief valve.

Pump Slip: The decrease of positive displacement pump flow as pressure increases due to internal clearances of the pump.

Stereolithography (SLA): An additive manufacturing technique to create an object layer by layer with a UV curried photoactive resin.

Fused Deposition Modeling (FDM): A 3D printing technique used to build an object layer by layer with a thermoplastic.

Linear Variable Displacement Transducer (LVDT): A sensor with an electrical transducer to measure a current proportional linear position.

Seconds, Saybolt Universal (SSU): A measure of kinematic viscosity.

CHAPTER 1

INTRODUCTION

When developed over a century ago, the gear within a gear positive displacement pump was pioneering technology receiving the highest award for rotary pumps at the Panama-Pacific International Exposition (Industrial Development and Manufacturers' Record, 1916). The technology overcame performance limitations of existing pumps, yet presented another challenge. Positive displacement pumps require a relief valve to prevent an overpressure system failure in the event of a reduction in discharge flow. The performance curve an internal relief valve is shown in Figure 1. The curve shows the performance of a relief valve in relation to the pump flow and differential pressure. The cracking and bypass pressure are identified on the performance curve.

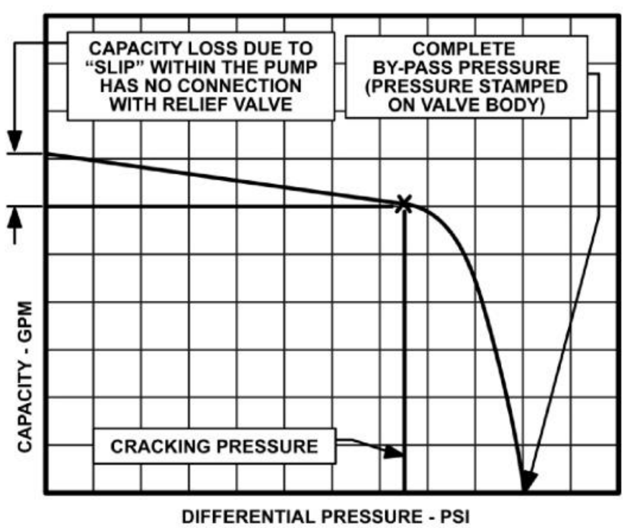

Figure 1: Performance Curve for a Relief Valve (with Permission from Viking Pump)

The primary focus of this research is to investigate the performance of an internal relief valve for a positive displacement pump, propose an improvement to flow conditions in the cracking to full bypass pressure range of the valve based on flow simulation and validate the performance improvement with 3D printed prototypes. Computer Aided Design (CAD) generated exploded views of the prototype assemblies, with internal components labeled, are shown in Figure 2 and Figure 3 (valve mounting hardware not shown for clarity).

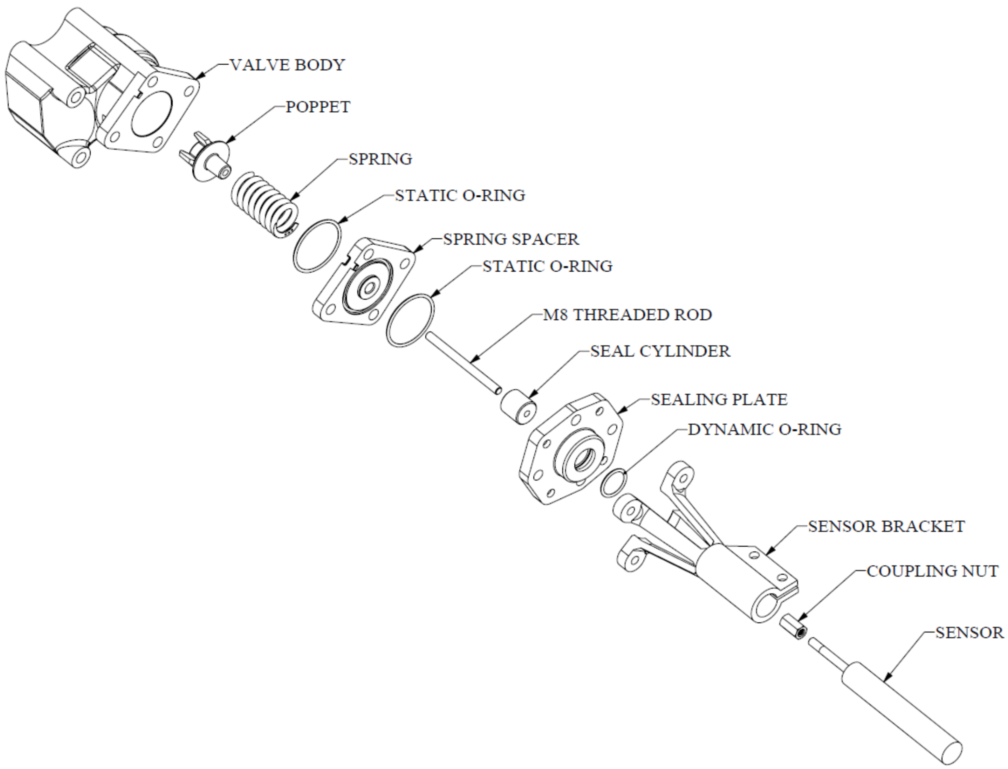

Figure 2: Test Prototype Assembly Components

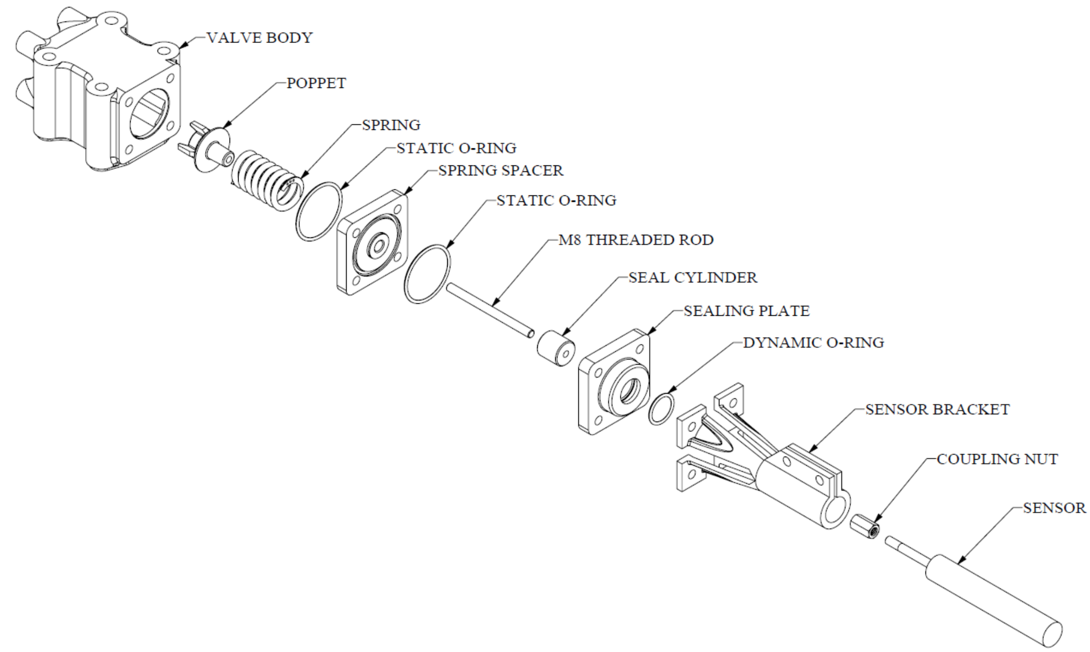

Figure 3: Reference Prototype Assembly Components

A representation of production relief valve that is the subject of this research is shown opposite the shaft in the cut-a-way of a positive displacement pump, Figure 4. The spring driven poppet is shown in the closed position, with the relief body at a 90° bend to inlet of the valve. In a static state, the fluid flow through the valve geometry does not influence the performance of the valve. As the spring loaded poppet begins to open, the fluid flow through the valve will be affected by the geometry of the valve. In order for the cracking to bypass pressure of the valve to be reduced, without changing the spring or poppet, the velocity of the fluid traveling through the poppet would need to be increased. The performance of the existing product internal relief valve is calculated with proprietary values of spring rate, pump flow, discharge pressure, fluid temperature and viscosity. For the internal relief valve studied in this research, the published performance of the cracking to full bypass pressure differential is 52 psi. This value of the standard valve performance will be used to evaluate the performance of the 3D printed prototype valves.

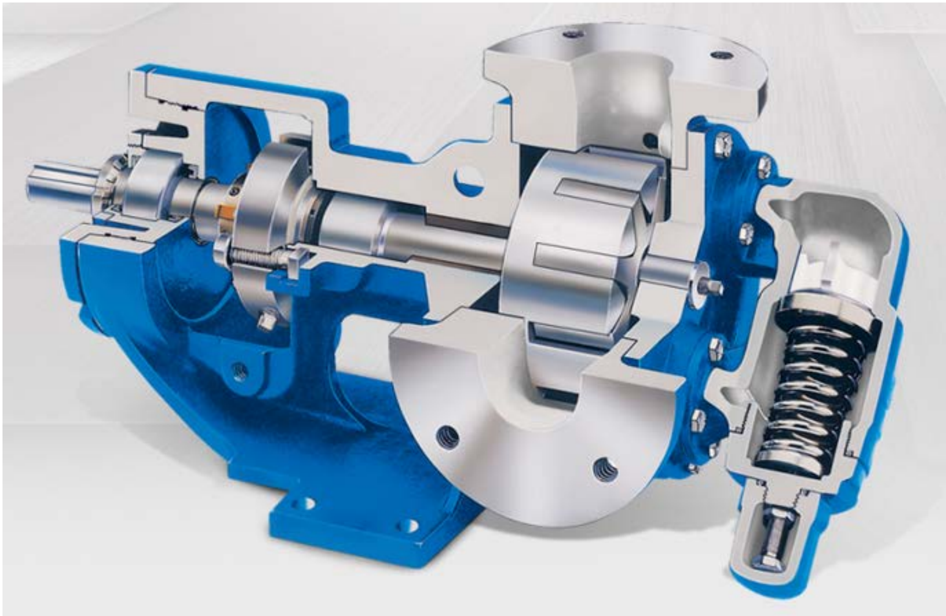

Figure 4: Viking Pump Universal Series 'Cut-a-way' (with Permission from Viking Pump)

Statement of the Problem

This research examines the ability of additive manufacturing to produce prototype assemblies to replace existing assemblies. The prototypes will improve the cracking to bypass operation of an internal relief valve. Validation of the prototypes will utilize Computation Fluid Dynamics (CFD) simulation and performance testing of a positive displacement pump in which the additive manufactured prototype valve is installed and connected.

Statement of Purpose

The production of prototypes for testing is a costly and time consuming process in new product development. This research will demonstrate the ability of additive manufacturing to produce prototypes which will reduce the cracking to bypass pressure differential, with changes to the wetted valve component geometry. Additive manufacturing has the benefit of customization, allowing for design changes. Variants of two primary prototype designs will be tested. Developing customizable end use components that can manufactured at the point of use, allows for application specific products to be produced for pressure vessel applications.

Statement of Need

The design of the internal relief valve in positive displacement pumps has changed very little. A relief valve that was designed prior to adoption of computer simulation lacks design optimization. The design of an internal relief valve can be optimized with simulation, and tested to validate the simulation; a more efficient valve can be developed. The internal flow of the valve will be revised, based on the simulation results; by methods that additive manufacturing hardware can produce that would not be possible with the metal components. This research validates the use of additive manufactured produced prototypes in the design development of an improvement to an existing product.

Statement of Hypothesis Questions

Can additive manufacturing produce relief valve components with short term operating conditions similar to traditionally manufactured components?

Can the geometry of an additive manufactured valve be optimized to reduce the cracking to full bypass stage differential pressure required to operate the valve?

Statement of Questions to be Answered

Can additive manufacturing produce components of a test valve for a positive displacement pump?

Can the geometry of the test valve be optimized based on flow conditions to reduce the cracking to bypass pressure differential in the valve?

Can additive manufacturing techniques be used to produce prototype valves that perform similarly compared to the existing products?

Research Limitations

The research presented has studied the performance of 3D printed prototype valves with simulation and physical testing using a single fluid, No. 40 Lube Oil. The test fluid was chosen due to the fluid viscosity of 1,188 SSU and was readily available in the test facility. The prototype assemblies have been tested under one operating condition, with a positive displacement pump producing 30 gallons per minute of flow. The prototype assemblies use the production relief valve spring and poppet, with the compressed spring length of the existing production relief valve. The research presented provided a proof of concept for improving an existing product design. While the goal of this research was to demonstrate the applications of 3D printing in the development of new products, the intent was not to validate the extended performance of the prototype valves with endurance testing.

CHAPTER 2

LITERATURE REVIEW

An overview of the principles of the positive displacement pump, relief valves, and Stereolithography material properties are presented in this review. The review incorporates research employing Computation Fluid Dynamics simulation and examines attempts to improve a component of a positive displacement pump, and the validation of the proposed improvement.

Cavitation

Cavitation is the formation and collapse of air cavities in liquid, which over time can damage internal components of a positive displacement pump. Two operating conditions of an external gear pump, one without cavitation, and one with cavitation were studied (Campo, Castilla, Raush, Gamez-Montero, & Codina-Macia, 2014). The validation of the predicted flow was done with Time-Resolved Particle Image Velocimetry, which measured the velocity of suspended particles the test fluid with high speed photography. A high outlet pressure, which should not produce cavitation, and an inlet condition of low pressure, below the atmospheric mean, which should produce cavitation were studied. The results showed that cavitation affected the volumetric efficiency of the pump at the operating viscosity.

In this research, the author performed a numerical analysis of a flow with cavitation, and validated the simulation with physical testing. By demonstrating the ability to predict cavitational flow, design variations of inlet geometry could be developed to reduce this damaging flow condition.

Design Variations of Gerotor Pumps

Design variations of Gerotor pumps, internal gear pump without the crescent dividing the outer rotor from the inner idler, were evaluated on discharge flow and torque values of rotating components by controlling pump displacement and geometric conditions (Bilyeu, 2006). The study used variations of 3D modeled inlet and outlet boundary conditions, and multiple teeth of Gerotor gear set and attempted to predict the flow at various speeds. The predicted flow data was measured against tested flow within 7%.

In this example of improving an existing product with simulation, the author studied design variations of the inlet and outlet port flow conditions. The simulation was validated with performance testing.

Improved Lobe Pump Profile

A lobe pump rotor profile was developed that improved theoretical pump performance (Kang, Y.-H. & Vu, 2014). Rotor profiles were evaluated by volume calculation and flow field analysis, and varying the number of lobes. Results were validated by comparing calculated values against published data. The improved epicycloidal-circular-epicycloidal rotor profile obtained a theoretical performance of 56% higher than the tested profile.

This research to improve the profile of the rotating lobes to increase the flow of a positive displacement pump relied on published pump performance data to validate the simulation the reference simulation, without performance testing the proposed improvement.

Improving the Volumetric Efficiency of an External Gear Pump

The volumetric efficiency of a positive displacement external gear pump is dependent on the operating speed and delivery pressure (Borghi, Zardin, & Specchia, 2009). This relationship was investigated with a mathematical model previously published, and compared with experimental data to show an increase in volumetric efficiency with the application of axially balanced hydraulically bearing blocks to limit pump slip and improve pump efficiency.

The modeled operation the positive displacement pump was successfully predicted with physical testing, validating the model used in the research.

Improving the Cracking to Bypass Performance of an Internal Relief Valve

The performance of a positive displacement pump internal relief valve has been studied with computational fluid dynamics (Henry, 2015). The research shows that the 90° bend on the inlet condition of the valve causes an area of high velocity to develop in the area in front of the poppet. The higher velocity causes an uneven distribution of the force on the spring driven poppet. The research provides insight on the flow conditions of the internal relief valve.

In this research, the flow of a similar internal relief valve is studied. Although this research recommends improvements to optimize valve performance, no analysis was carried out on the proposed improvements, and prototypes of the proposed improvement were not produced. The simulation results were validated with existing performance data.

Failure of Sealing Surfaces of Internal Relief Valve

The primary causes of failure of the sealing surface on metal to metal pressure relief valves are the surface characteristics and deformation of the geometry surface under pressure (Geoffroy & Prat, 2004). Using CFD analysis of the sealing surface to determine the leakage path of pressure relief valves, the parallel gap assumption of laminar viscous incompressible fluid flow was challenged with a theoretically modeled surface.

A possible mode of failure of the 3D printed internal relief valve was the sealing surface between the valve body and the poppet. This research provides insight in the performance requirements of these surfaces, and was relevant in the selection of the material properties of the prototype valves.

Stability of Relief Valve to Prevent Poppet Chatter

The operation of a spring driven poppet pressure relief valve in a hydraulic circuit was modeled to determine the cause of instability of the valve (Licsko, Champneys, & Hos, 2009). The instability of the valve was defined by the chatter like movement between the poppet sealing surface and relief valve body. The research authors examined the flow rate and system damping coefficient parameters. Linear stability analysis identified when the relief valve operation would become unstable.

This research expanded the relationship between flow and relief valve instability, a concern in the development of the 3D printed valve prototypes. The research examined how a dividing flow impacts the instability of the valve.

Optimizing Performance of a Relief Valve

The operational parameters of pressure drop, maximum stress and mass of a double-eccentric butterfly valve were studied to optimize performance (Kang, S., Kim, Kim, & Kim, 2014). A shape optimization of the valve disc was performed using the effect analysis of design variables to improve performance. The effect analysis was made by evaluating each design variable response, and determined that the disc thickness has the greatest effect on the flow and structural performance of the valve.

The research utilized Computational Fluid Dynamics to determine the pressure and stress distribution of the flow through a valve that operates with an axial rotation perpendicular to the flow. The design variations presented provide insight into the flow of the valve.

Optimizing External Gear Pumps

The relationship of the inlet and outlet displacement port chamber geometry was studied in an attempt to optimize the groove design relative to volumetric efficiency (Gulati, Vacca, Ivantysynova, & Lumkes, 2015) for positive displacement gear pumps. The proposed improvements minimize flow fluctuations, minimize internal pressure peaks, minimize localized cavitation and maximize volumetric efficiency. The optimization was done by determining the tooth space volume to the porting grooves, and developing geometric conditions which represent similar volumes, and performing Computational Fluid Dynamic simulation. The optimized inlet and outlet conditions show a reduction of 58% in the pressure ripple energy compared to the reference condition.

This research presented a method for optimizing the geometry of the machined features that reduce the cavitation of a positive displacement pump. The author improved the performance of the gear pump by simulating and testing a reference and prototype design.

Material Properties of Photopolymer Stereolithography Resins

In the review of material properties of Additive manufacturing, the author examined the predominant mechanical test methods (Dizon, Espera Jr., Chen, & Advincula, 2018). The review of stereolithography resins examined three part orientations, tested for tensile strength. The review demonstrated that the stereolithography process is broadly isotropic, with a slight increase in the tensile strength for parts fabricated at a 45° angle. The review demonstrated that photopolymer resins achieve the highest tensile strength of 10,000 psi with a curing temperature of 60°C (140°F). The review also examined the optimal wavelength of light for the post processing curing and found that a 60 minute exposure to a 405 nanometer wavelength light produced the greatest increase in tensile strength of 6,000 psi.

The development of materials for Additive Manufacturing continues to expand. The photopolymer selected in this research was not included the literature review, although material data of a similar resin was presented. The resin selected has been developed specifically for prototypes requiring high strength and a smooth surface.

CHAPTER 3

PROTOTYPE DEVELOPMENT

The proposed solution to increasing the fluid velocity in the valve was to eliminate the 90° orientation of the poppet axis to the inlet flow condition. The current inlet condition of the valve requires the fluid to travel through curved geometry, causing an irregular flow on the valve poppet as it is opening. By eliminating the 90° bend in the inlet condition of the valve, the velocity of the fluid should be increased decreasing the cracking to bypass range of the relief valve. A design variant of the existing relief valve geometry with an extended volume in front of the poppet will also be studied. The current production valve assembly has used two variations of size, a large valve and a small valve. This research examined the 'small valve' with production hardware, a spring and poppet, with two design variations.

Prototype Designs

The Stereolithography (SLA) was used to create the valve prototypes. The SLA 3D printing technology was selected because of the design criteria of dimensional accuracy, surface finish, and isotropic properties required for pressure vessel applications. Two design variations of two prototype valves have been developed. Two test prototype designs examine the flow relative to the poppet axis; see Figure 5 and Figure 6.

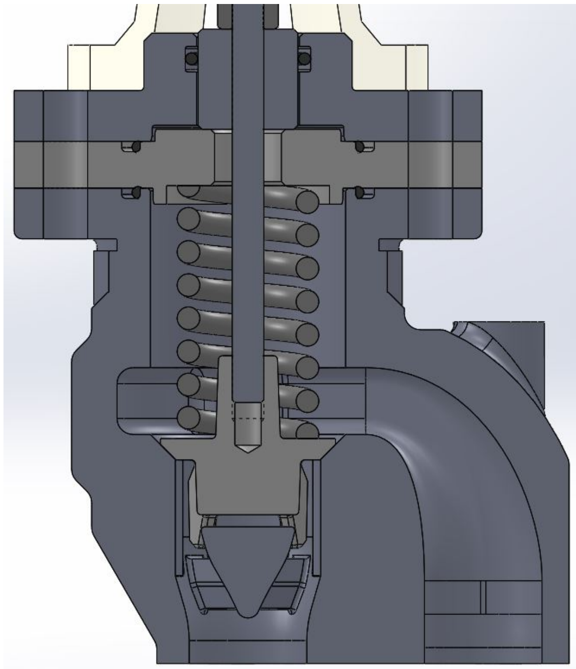

Figure 5: Test Prototype Design ‘A’

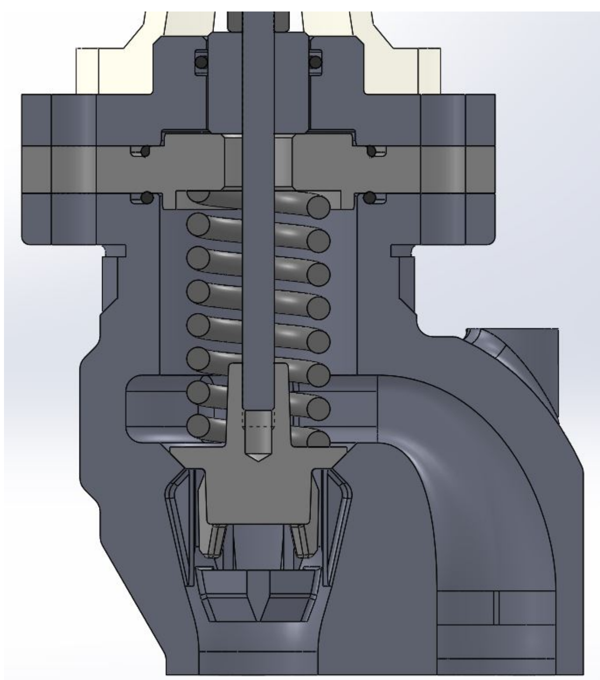

Figure 6: Test Prototype Design ‘B’

The reference prototype simulated the inlet and outlet condition of the 'standard product' valve, and test two design variations of the inlet volume, 1.70 in^3, as shown in Figure 7 and 2.70 in^3, as shown in Figure 8.

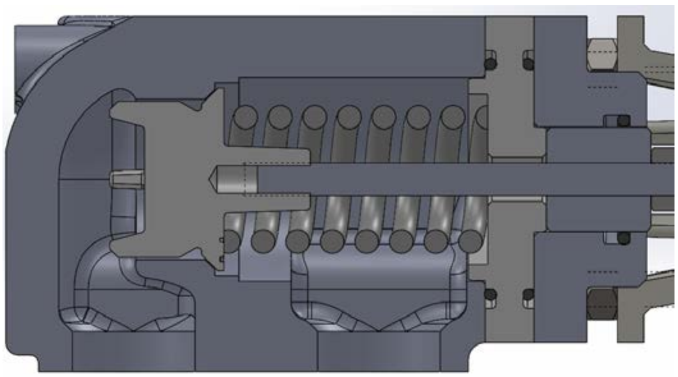

Figure 7: Reference Valve with Inlet Volume of 1.70 in^3

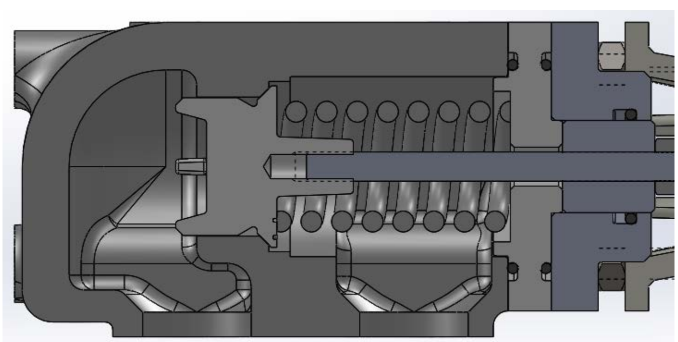

Figure 8: Reference Valve Ext. with Inlet Volume of 2.70 in^3

The test prototypes examined the inlet flow condition parallel to the axial movement of the poppet. Two versions of prototype were developed using valve body geometry to optimize fluid flow on the poppet.

Each prototype valve consists of three additive manufactured parts, consisting of the valve body, a spring spacer, and a dynamic O-ring sealing plate. The dynamic O-ring sealing plate of the Reference Valve is shown on the build plate of the SLA printer in Figure 9.

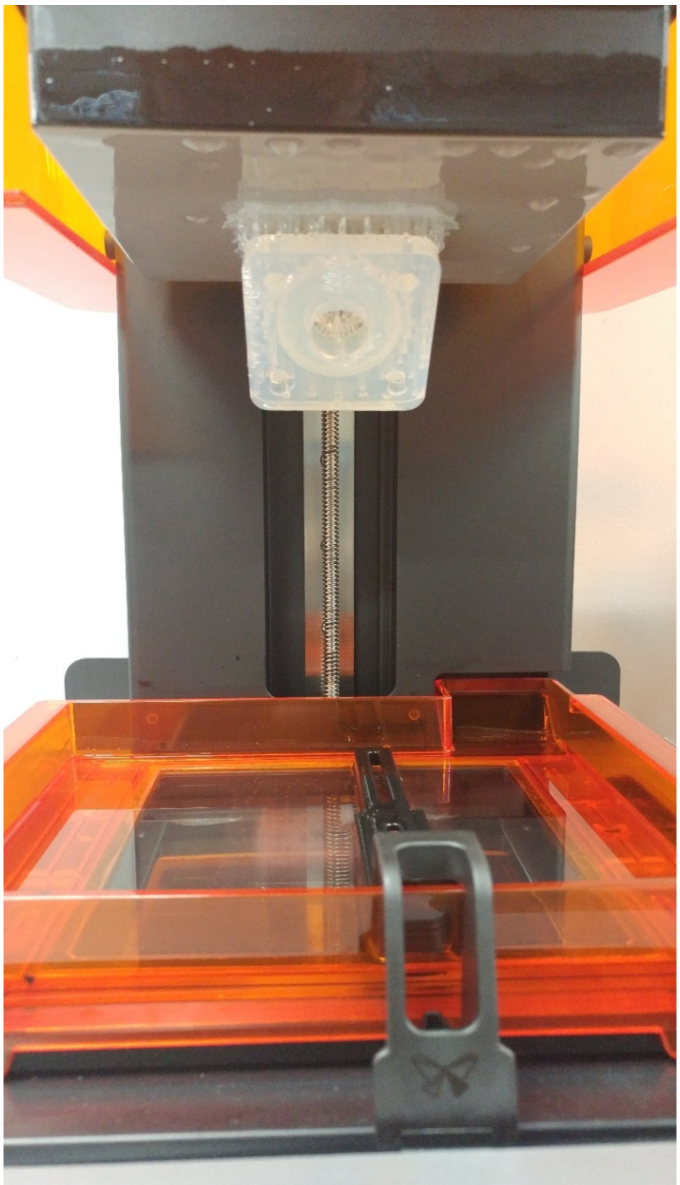

Figure 9: SLA Part Production

The primary design change from the production valve was the removal of the adjusting screw to change the spring compression on the poppet. This change was a requirement of the additive manufacturing process, as the production of tapped threads was not the focus of this research. The design change to a fixed length spring reduced the assembly complexity of the valve, and highlighted a benefit of the additive manufacturing process, customization. The fixed spring spacer, shown in Figure 10, attached to the valve body can be dimensionally adjusted to produce a required spring force on the poppet for a given fluid pressure. The assembled Reference Valve Extended prototype is shown in Figure 11.

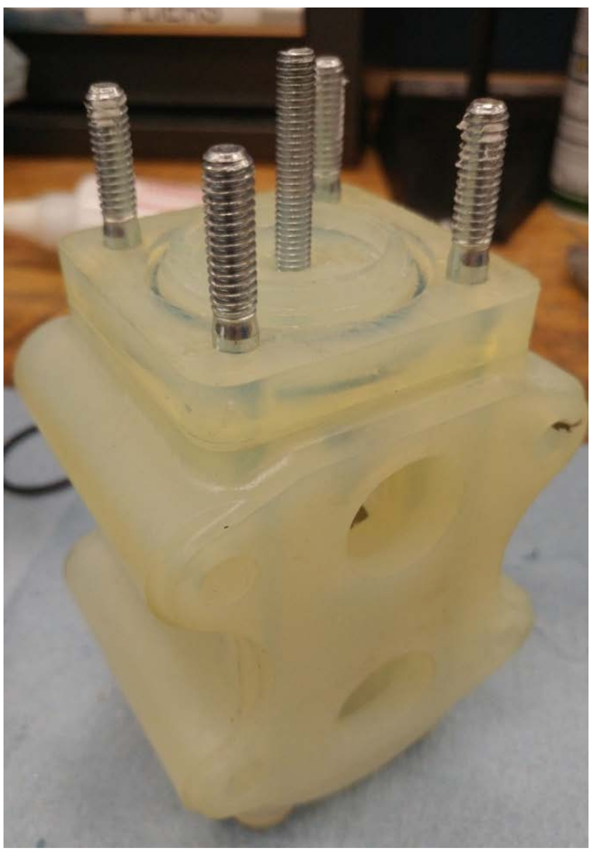

Figure 10: Fixed Length Spring Spacer

Figure 11: Assembled Reference Valve Extended

The prototype valves were attached to the pump with readily available commodity hardware, and used the existing valve sealing gasket. Each prototype valve was designed to measure the movement of the poppet with a Linear Variable Displacement Transducer (LVDT) sensor. The prototype valves were not intended to operate for long periods of time in full bypass. Each valve has been designed with no additional machining required. The net form printed valve parts require minimal post processing to remove the generated support structures, see Figure 12: SLA Support Structures. After an Isopropyl alcohol wash, a curing process with a 405 nanometer ultraviolet light is required for the part material properties to fully develop, see Figure 13: UV Curing SLA.

Figure 12: SLA Support Structures

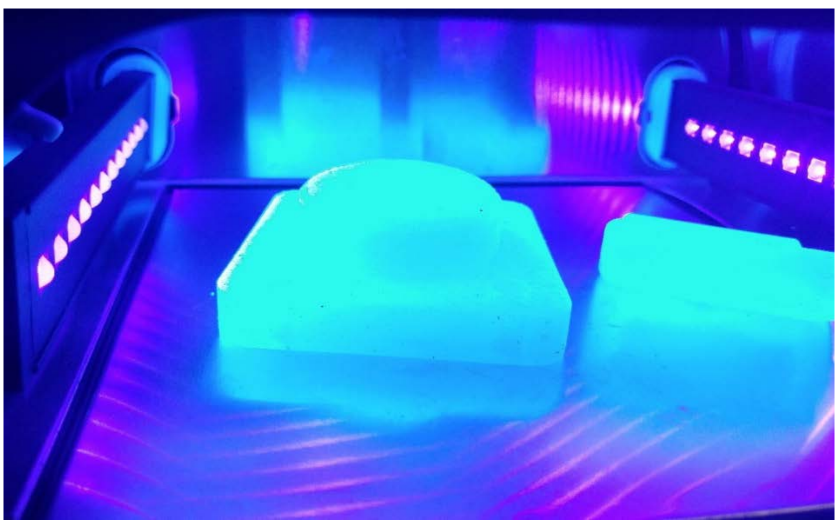

Figure 13: UV Curing SLA

Prototype Material Properties

The photopolymer selected for the prototype parts is similar in material properties and end use applications as polyethylene (PE). This material was selected due to the high wear and impact resistance. Polyethylene is currently used in positive displacement pumps requiring corrosion resistance. The impact strength of the prototype valve was critical due to the pressure oscillations of the valve poppet that are required for the valve to operate. The resin has a post cured IZOD impact strength of 2.05 ft-lbf/in and the resin has an ultimate tensile strength of 4.61 ksi. (FormLabs, 2017). While the low Young's Modulus of the material could have allowed the valve to deform at very high pressures and provide inaccurate sensor measurement, the same elongation prior to failure presented a benefit for pressure vessel prototypes allowing for visible warning prior to catastrophic failure. The material supports an operational temperature of 110°F (FormLabs, 2017). This operational temperature limits the product application of the prototype valves. If the valve were to operate in full bypass for an extended period of time, the fluid in the pump would increases in temperature.

CHAPTER 4

SIMULATION RESULTS

Initial Simulations

Initial simulations were used to develop design iterations of the valve for prototype testing. The initial simulations provided insight into the flow conditions of the valve at full bypass. The flow condition of 30 GPM would occur through valve when the flow of the PD pump was eliminated. The poppet lift distance was estimated based on previous testing. The discharge pressure was estimated based on existing application conditions of the production valve. The boundary conditions of the simulation are shown in Table 1.

Table 1

Boundary Conditions of Initial Simulation

Flow	Pressure	Poppet lift
30 GPM	120 psi	0.020”

The first design iteration of the test valve produced an area of erratic flow in front of the poppet which reduced the calculated velocity through the poppet, see Figure 14. The CAD geometry was altered to optimize the fluid flow through the poppet, by reducing the volume in the area in front of the poppet in an attempt to produce a well-directed flow with a high velocity through the poppet.

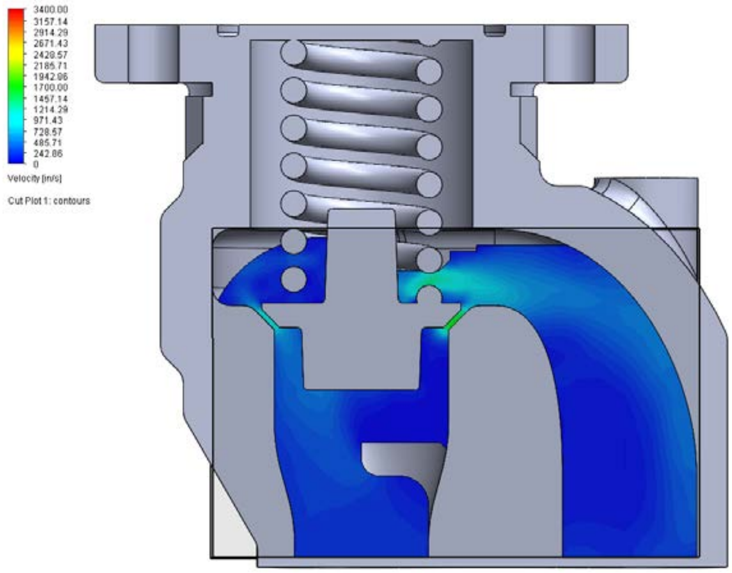

Figure 14: Initial Simulation Results Prototype Valve

Prototype test design ‘A’ was developed in response to the simulation data. By adding a nozzle to modify the area of erratic flow, the simulations showed an increase to the velocity of the fluid traveling through the poppet, as shown in Figure 15. By reducing the volume available for the fluid flow, a smooth flow condition was simulated within the valve.

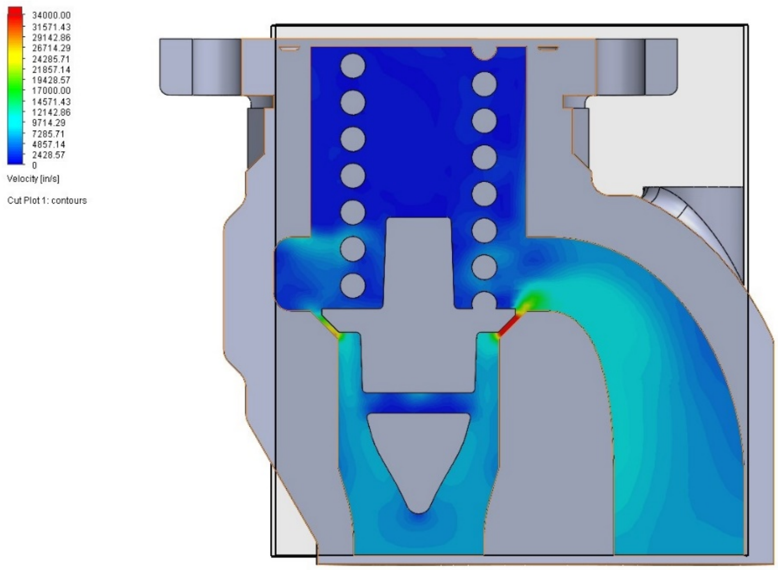

Figure 15: Initial Simulation Prototype Design 'A'

<u>Revised Simulation</u>

The initial simulation results did not accurately reflect the performance of the test valves. The simulation results showed an increased velocity of fluid flow through the poppet that was not measured with physical testing. Testing demonstrated that attempting to improve valve performance in the full bypass stage was ineffective. The simulation boundary conditions were revised to attempt to improve the valve performance in the cracking stage.

The simulation boundary conditions for the valve were revised based on test data. The revised simulation boundary conditions tested the valve geometry at the cracking stage of the valve performance. The revised boundary conditions are shown in Table 2.

Table 2

Revised Simulation Boundary Conditions

Flow	Pressure	Poppet lift
0.6 GPM	71.8 psi	0.005”

Simulations were performed on all four design variations of the prototypes. The simulation results that demonstrated the greatest improvement in the velocity through the poppet were the Reference Valve Extended. The simulation of the existing product geometry is shown Figure 16. The flow conditions show similar properties, as previous research (Henry, 2015), including the area of high velocity flow in front of the poppet.

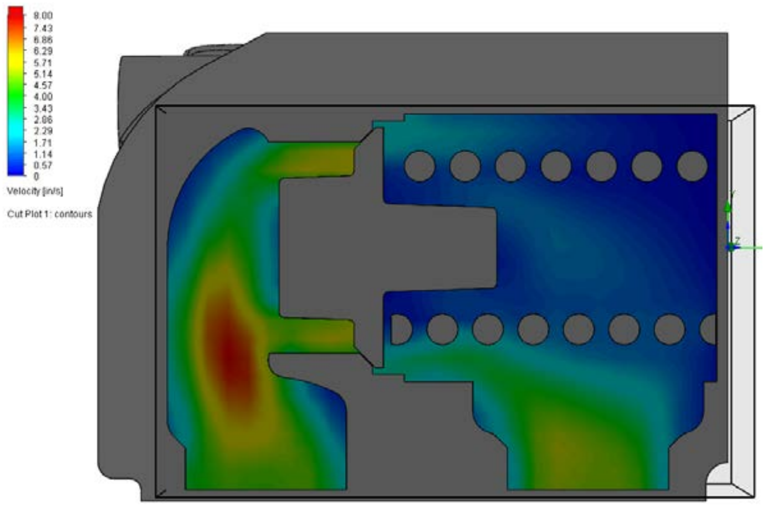

Figure 16: Revised Simulation Reference Valve

The simulation results for the Reference Valve Extended are shown in Figure 17. The simulation results show a similar area of high velocity in the 90° bend, and two areas of high velocity fluid flow in the area of the poppet. The intent of the simulation section of this research is to produce a result that shows an increase velocity of the fluid moving through the poppet area, and validate the result with physical testing.

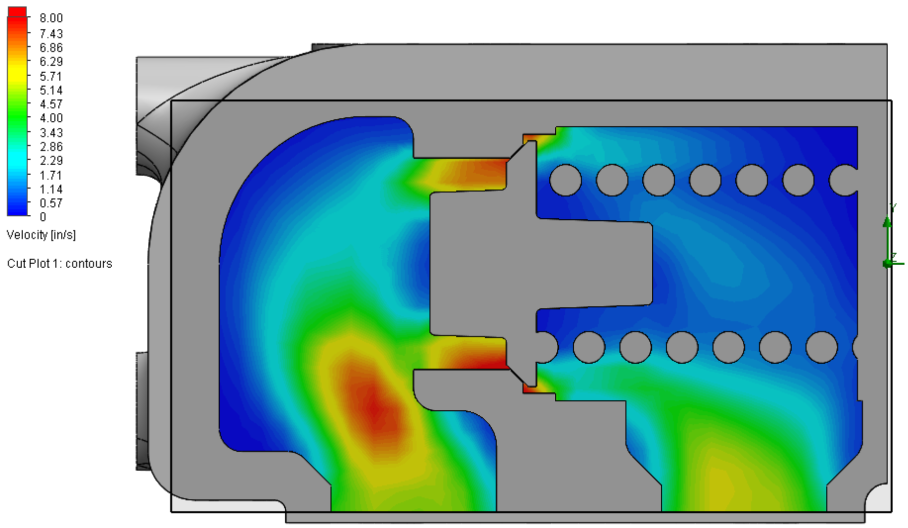

Figure 17: Revised Simulation Reference Valve Extended

Test Valve ‘A’, Figure 18, shows an area of high fluid velocity in front of the poppet. The area of high velocity is incorrectly located to increase the cracking to bypass performance of the valve.

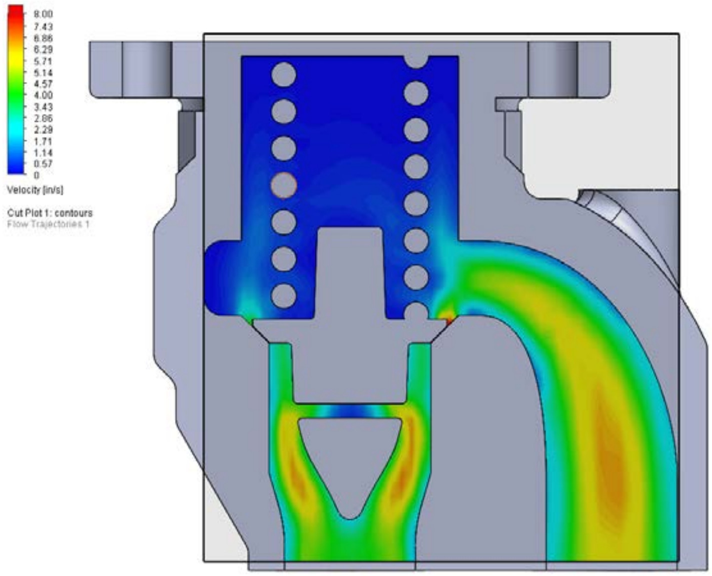

Figure 18: Revised Simulation Test Valve 'A'

<u>Test Valve 'B'</u>

Test Valve 'B' demonstrates an increase to the velocity of the fluid moving through the poppet area, and produces a fluid flow with greater uniformity, see Figure 19. Although the velocity of the fluid at the poppet was less than that of the simulation results of the Reference Valve Extended, the simulation shows the greatest uniformity of flow in the poppet area of the simulation results.

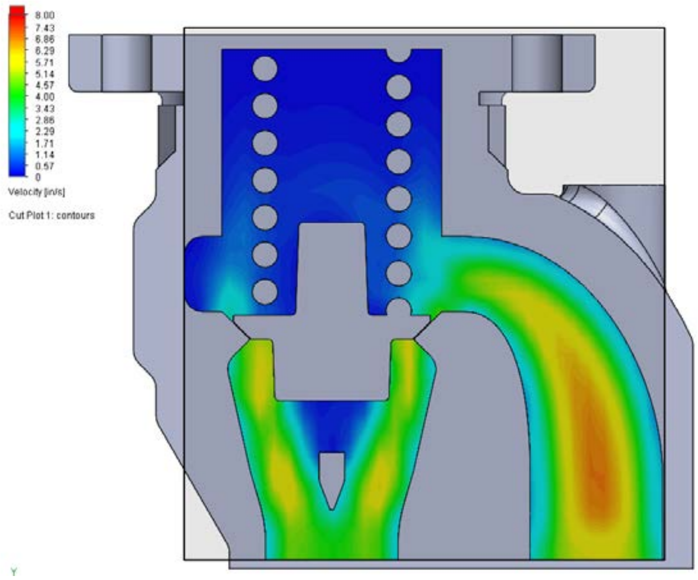

Figure 19: Revised Simulation Test Valve 'B'

The test valve did not improve the cracking to bypass differential pressure as expected. The simulation demonstrated an increase of the velocity to the fluid passing through the poppet, and a balanced flow relative to the axis of the poppet; however the device used to transition the flow from erratic to smooth flow required refinement. The surface area of the flow divider was reduced, with the goal of improving the test valve performance. Test valve 'A' was refined based on the data to increase the area of fluid flow in front of the poppet. Both test valve designs feature geometry to orient the poppet and prevent axial rotation. Test valve 'B' increases the fluid volume at the thinnest cross section of the poppet. By producing the valve component with additive manufacturing, geometric conditions not possible with traditional production methods were developed.

CHAPTER 5

PERFORMANCE TEST RESULTS

Pressure Test

The 3D printed relief valve components were assembled, see Figure 20, and installed without modifying pump head to valve interface of the 'standard product' positive displacement pump, see Figure 21.

Figure 20: Assembly of Prototype Valves

Figure 21: Relief Valve Mounting

The Reference Valve Extended is shown installed on the head of the positive displacement pump prior to pressure testing as shown in Figure 22: Reference Valve Extended Installed. The pump uses standard commodity hardware and a gasket to install. A possible improvement to the current prototype design would be the integration of a static O-ring seal to replace the current gasket. This improvement would demonstrate an advantage of the additive manufacturing process, additional machined features of a component could be added without increased cost. The development of the O-ring seal installation of the valve could be pursued in future research.

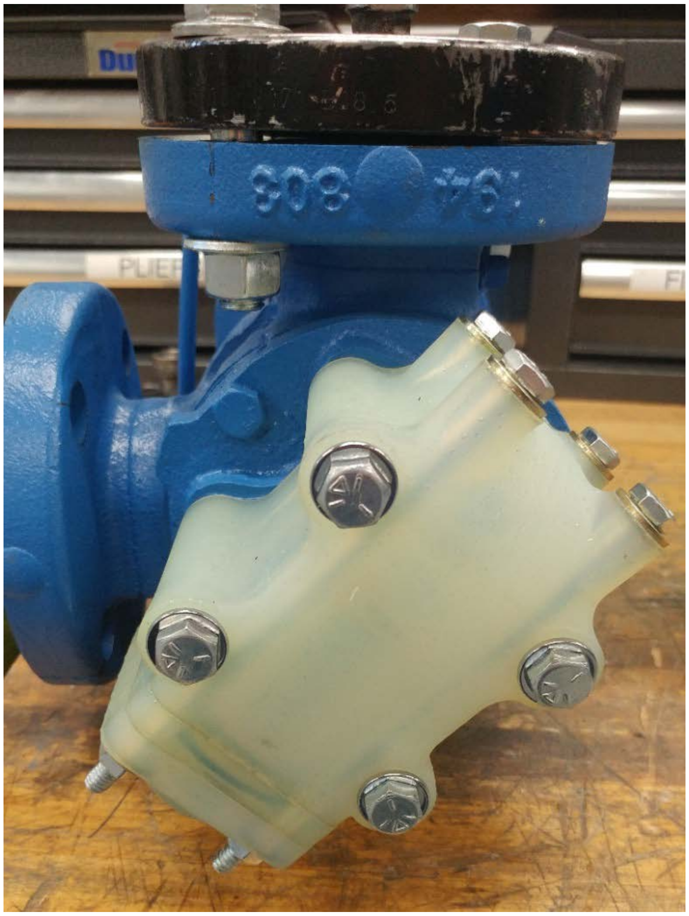

Figure 22: Reference Valve Extended Installed

Inlet and outlet hydraulic fittings were installed on the pump ports. The test pump was filled with a high viscosity solvent and pressure tested to 300 psi, see Figure 23. The primary goal of the pressure test was to determine if the static and dynamic O-ring seals of the 3D printed components would show signs of leaking.

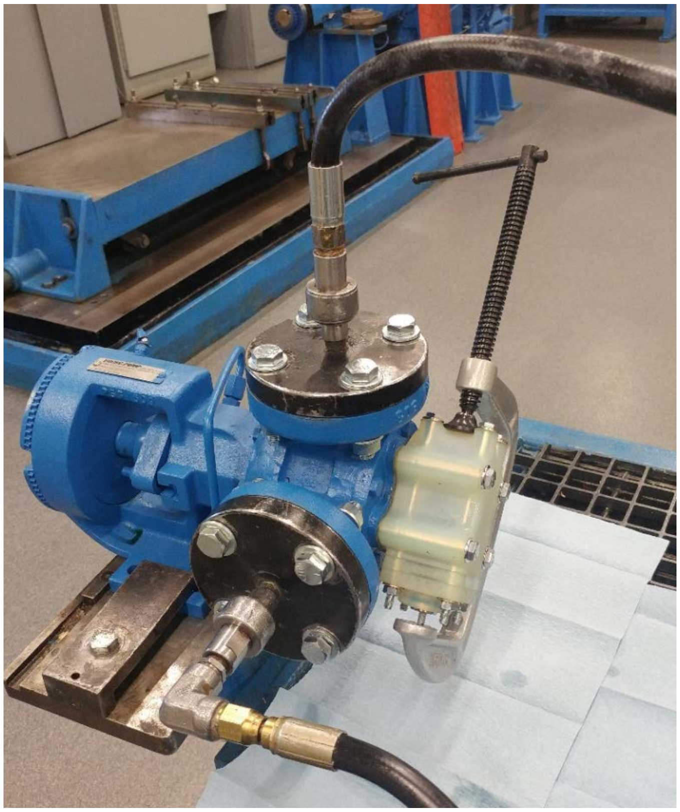

Figure 23: Pressure Testing the Valve

A mechanical clamp was added to the poppet movement rod to prevent a range of motion from over pressurization that could have caused the valve to leak. The additive manufactured produced components with O-ring seals performed very well with no signs of leaking. Each prototype assembly was pressure tested prior to operation.

Poppet Movement

A LVDT sensor was calibrated and tested in the data acquisition system, Figure 24. The sensor rod was connected to a cylindrical coupling nut that served as the dynamic O-ring sealing surface on the exterior of the prototypes. The coupling nut was attached to the poppet with a threaded stud. Mounting brackets to attach the LVDT sensor to the prototype valves were FDM 3D printed. The LVDT sensor was used to measure the poppet movement during the testing. The poppet movement data, with flow and pressure readings from the initial testing were used to improve the simulation boundary conditions.

Figure 24: LVDT Sensor with FDM 3D Printed Mounting Bracket

Initial Testing

The test pumps were installed on a 75 HP dynamometer, as shown Figure 25.

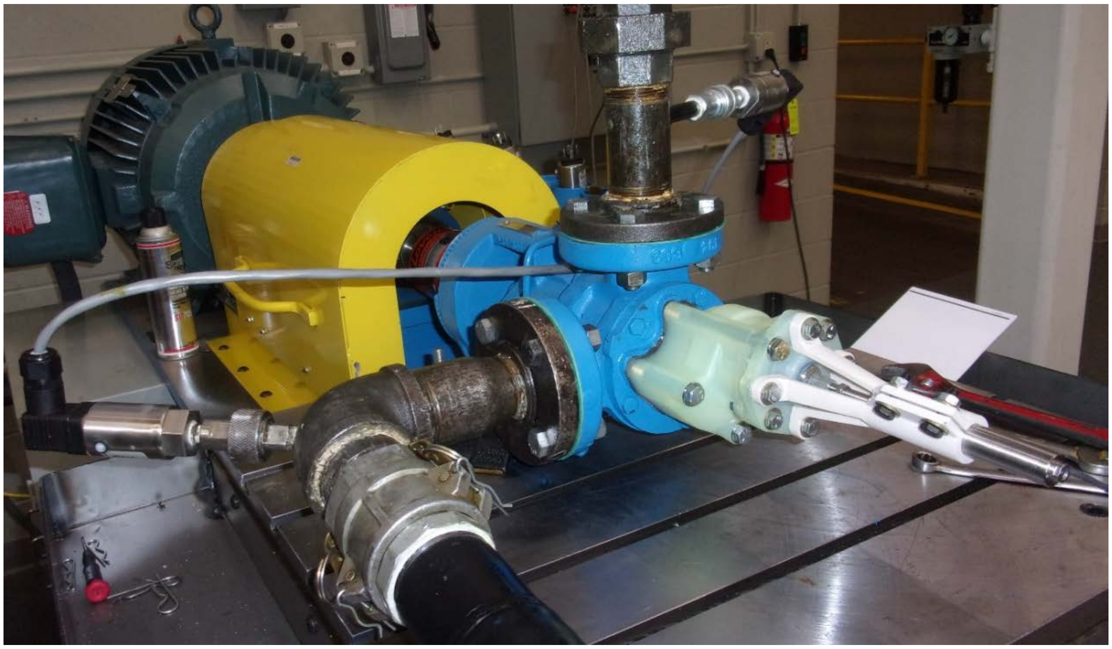

Figure 25: Test Setup Discharge Port at 90°

The performance test consist of the pump starting from zero flow increasing to full flow with an open inlet and discharge condition with the prototype valve installed. Data points were collected by restricting the discharge flow with a manually operated external valve, increasing the pressure of the prototype valve.

The performance data for the prototype valve is shown in Figure 26. The data is similar to the example performance data for a relief valve.

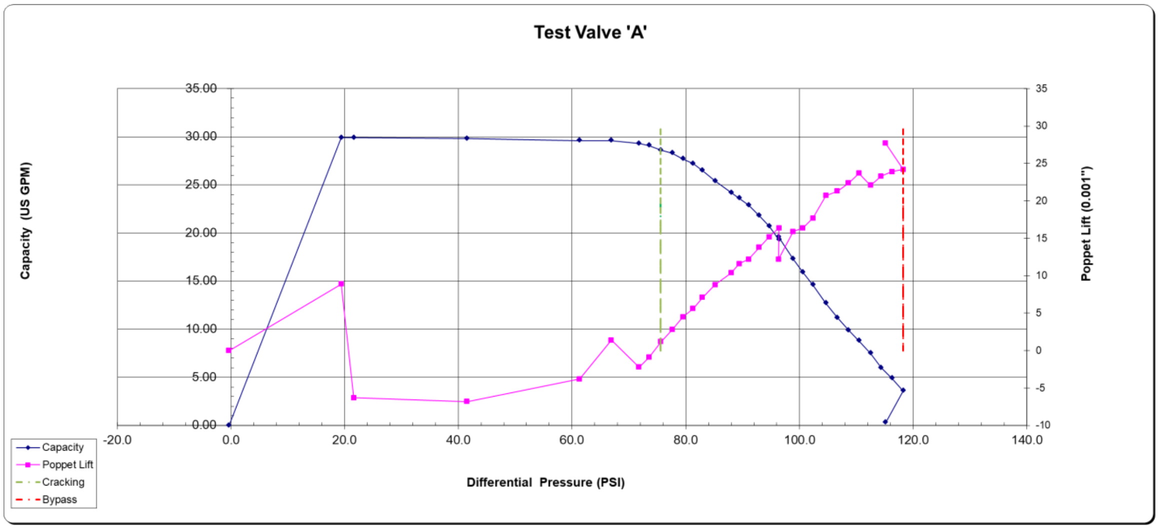

Figure 26: Prototype 'A' Test Results

The test data shows the prototype relief valve performed very well. Due to the test pump drive equipment, the LVDT linear position sensor was not able to measure poppet movement during the initial testing. Performance results for the Reference Valve Extended test are shown in Figure 27. The valve was re-tested with the inlet and outlet ports rotated to allow the use of the LVDT sensor.

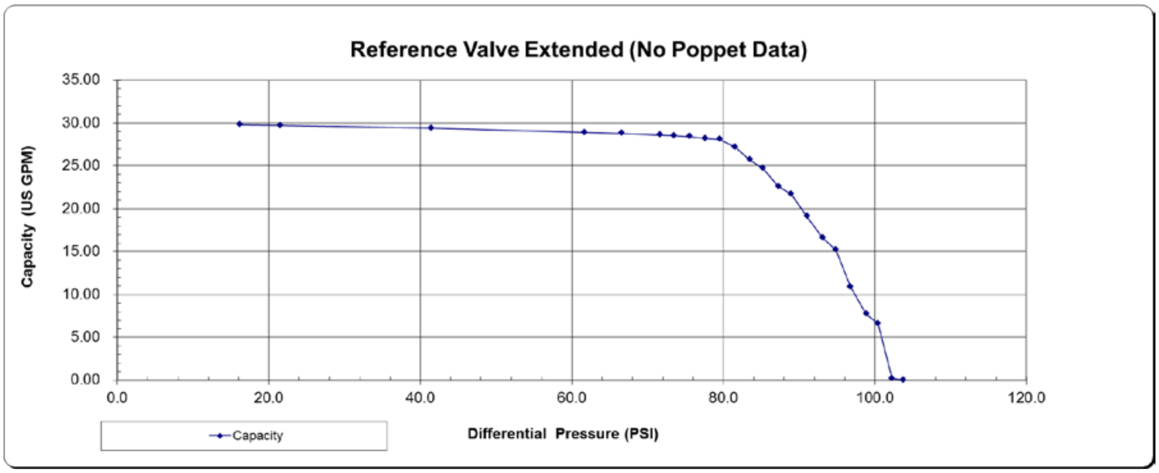

Figure 27: Reference Valve Extended (No Poppet Data)

The initial test data shows that the reference valve extended prototype decreased the cracking to bypass pressure differential, improving the performance of the valve.

Revised Testing

The performance results for Test Valve ‘B’ are shown in Figure 28. The results do not show an improvement in the cracking to bypass pressure differential. The test prototype valves produced higher full by pass pressures than the reference valves.

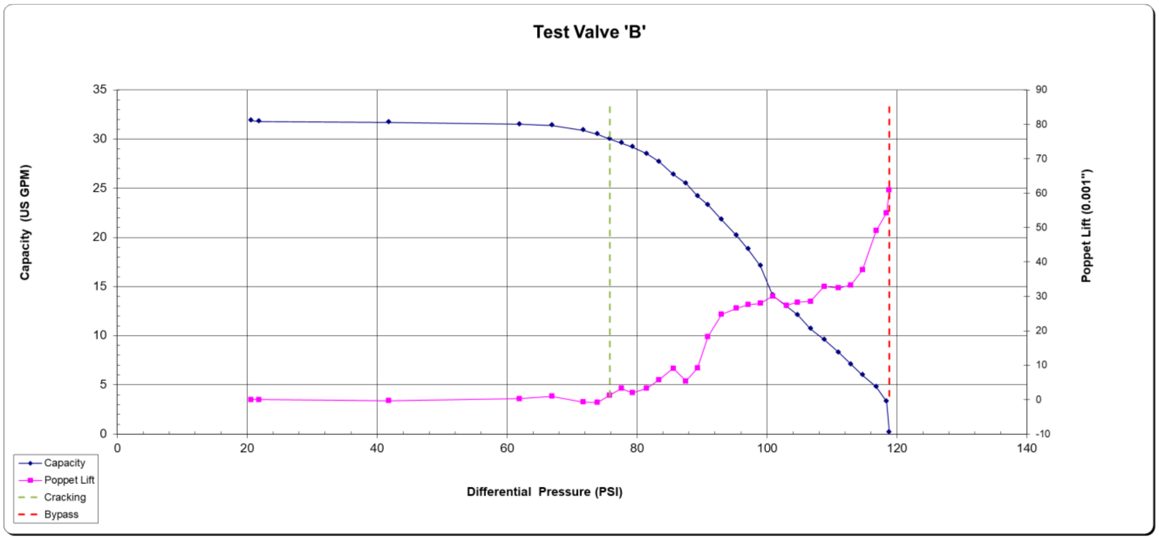

Figure 28: Prototype 'B' Test Results

Test results for Reference Valve are shown in Figure 29. The data shows performance similar to production valve results.

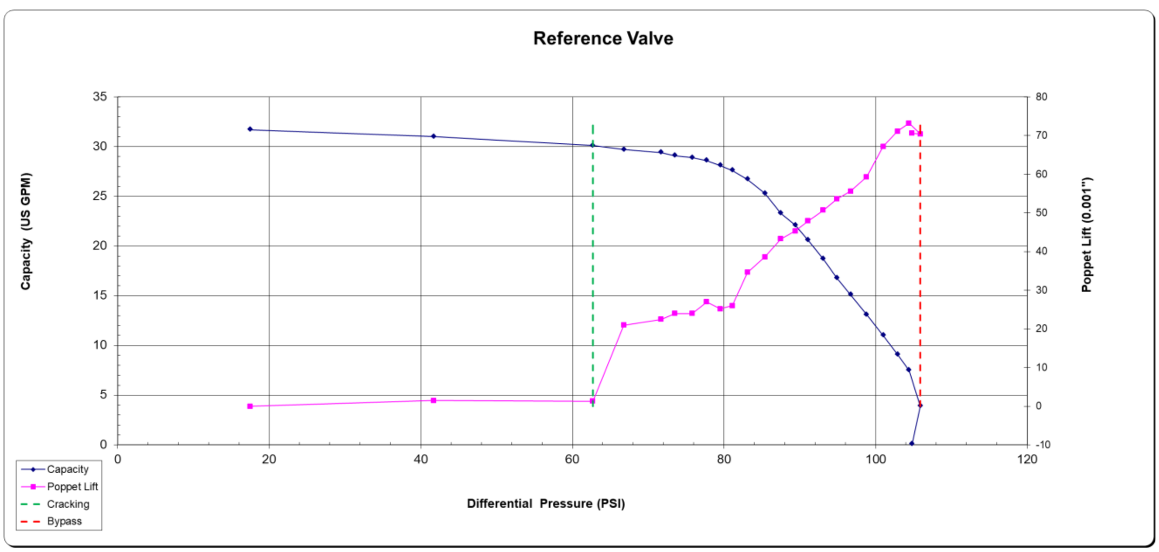

Figure 29: Reference Valve Test Results

The data shows that the reference valve extended performed better than the other prototypes tested, see Figure 30. The cracking to bypass pressure difference of the reference valve extended was reduced to 22.8 psi. The performance test results are similar to the test results obtained without the poppet movement data. A summary of the test data is shown in Table 3.

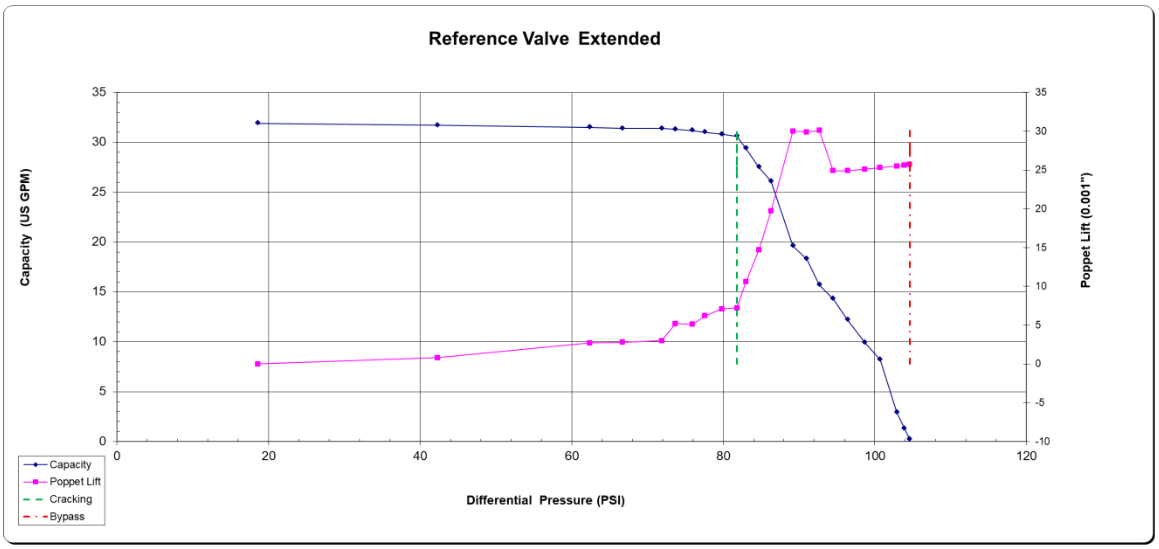

Figure 30: Reference Valve Extended Test Results

Table 3

Summary of Results

	Test Valve 'A'	Test Valve 'B'	Reference Valve	Reference Valve Extended
Cracking Pressure	75.6 psi	75.8 psi	62.7 psi	81.8 psi
Flow at Cracking	28.6 GPM (96%)	30 GPM (94%)	30.1 GPM (94%)	30.6 GPM (96%)
Poppet Lift at Cracking	0.0012"	0.0013"	0.0013"	0.0072"
Full Bypass Pressure	118.2 psi	118.8 psi	105.9 psi	104.6 psi
Differential Pressure	42.6 psi	43 psi	43.2 psi	22.8 psi

CHAPTER 6

CONCLUSIONS

This research has demonstrated the SLA 3D printing's ability to reproduce existing machined metal components. While extended performance testing was not the intent of this research, the 3D printed pressure vessel valve components performed very well in performance testing. The development of the design variations in timely manor would not have been possible without Additive Manufacturing. Testing has shown an improvement in the valve performance by reducing the cracking to full bypass pressure from 52.0 psi to 22.8 psi. The successful performance test to improve an existing product demonstrated the validity of the SLA 3D printed prototype assemblies.

The 3D printed prototypes allowed multiple design concepts to be developed in tandem, without the barriers of traditional manufacturing. The 3D printed prototypes were developed to reduce cost and delivery lead time for prototype testing. The ability of the SLA 3D printer to produce parts with the dimensional tolerances of machined components has allowed for faster development of prototypes for testing than traditional methods. The flexibility in design permutations that additive manufacturing allows with customization provides the opportunity to validate multiple product designs in parallel.

The simulation results provided insight into the flow conditions of the valve. The valve was studied in a static state, with a single operating condition. The simulation was performed in the design software used to create the prototype geometry allowing for reduced setup time among the design simulations. In this research, the prototype designs were developed prior to the simulation, however recent advances in design and simulation software allow the task to be developed in parallel, utilizing cloud based computing to create geometry optimized for 3D printing.

As the application conditions for positive displacement pumps expand into demanding service conditions, the supporting components of the pump system will need to increase performance. The performance increase can occur by customizing components of the system for an application condition. An example of customization to increase performance could be viscosity specific geometry. This research has shown that additive manufactured produced prototypes can support an improvement to the performance of an existing product.

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APPENDIX A

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Email correspondence requesting permission to use Viking Pump images:

Tony,

You are good to use these in your thesis.

Thanks,

Mike Strei – Engineering Director

Viking Pump / Wright Flow – A Unit of IDEX Corporation

406 State Street, Cedar Falls, Iowa 50613 USA

Web: www.vikingpump.com

From: Dutcher, Tony

Sent: Tuesday, December 12, 2017 1:47 PM

To: Strei, Mike; Thompson, Joe

Subject: Request for Permission to use images and test data results in Thesis

Hello All,

I would like to request the use of the attached images and test data for my thesis. No proprietary information is requested, and the only dimensional data presented is the movement of the poppet of the tested relief valves.

For test results, I am presenting pressure, flow and poppet movement results. The power data from the testing has been removed.

Please let me know if you have any questions, thanks.

Please note, this correspondence will be part of the thesis appendix.

Tony Dutcher - *Engineering Technology Specialist*
Viking Pump – A Unit of IDEX Corporation
406 State Street, Cedar Falls, Iowa 50613 USA
Web: www.vikingpump.com

APPENDIX B

PROTOTYPE TEST VALVE ‘A’ DATA

Pressure (PSI)	Flow (GPM)	Poppet Movement (0.001")
-0.4	0.0	0.0
19.4	29.9	8.9
21.6	29.9	-6.3
41.5	29.8	-6.8
61.3	29.6	-3.8
66.9	29.6	1.4
71.8	29.3	-2.2
73.6	29.1	-0.9
75.6	28.6	1.2
77.6	28.3	2.8
79.5	27.7	4.5
81.3	27.2	5.6
82.9	26.5	7.1
85.2	25.4	8.8
88.0	24.2	10.4
89.4	23.6	11.6
91.1	22.9	12.2
92.9	21.8	13.8
94.7	20.7	15.2
96.4	19.3	16.4
96.3	19.6	12.2
98.9	17.3	15.9
100.6	15.9	16.4
102.4	14.6	17.7
104.7	12.7	20.7
106.7	11.2	21.3
108.6	9.9	22.4
110.5	8.8	23.7
112.5	7.5	22.1
114.4	6.0	23.3
116.3	4.9	23.9

118.2	3.6	24.2
115.1	0.3	27.7

APPENDIX C

PROTOTYPE TEST VALVE ‘B’ DATA

Pressure (PSI)	Flow (GPM)	Poppet Movement (0.001")
20.6	31.9	0.0
21.8	31.8	0.0
41.8	31.7	-0.3
61.9	31.5	0.3
66.9	31.4	1.0
71.7	30.9	-0.7
73.9	30.5	-0.8
75.8	30.0	1.3
77.6	29.6	3.3
79.3	29.2	2.0
81.5	28.5	3.3
83.4	27.7	5.8
85.6	26.4	9.1
87.5	25.5	5.4
89.3	24.2	9.2
90.9	23.3	18.3
93.0	21.8	24.8
95.3	20.2	26.6
97.1	18.8	27.6
99.0	17.1	28.0
100.9	14.1	30.1
103.0	13.0	27.4
104.7	12.1	28.3
106.7	10.7	28.6
108.8	9.6	32.9
111.0	8.3	32.5
112.9	7.1	33.3
114.7	6.0	37.7
116.8	4.8	49.1
118.4	3.3	54.3

118.8	0.2	60.9

APPENDIX D

PROTOTYPE REFERENCE VALVE DATA

Pressure (PSI)	Flow (GPM)	Poppet Movement (0.001")
17.5	31.7	0.0
41.7	31.0	1.5
62.7	30.1	1.3
66.8	29.7	21.0
71.7	29.4	22.5
73.5	29.1	24.0
75.8	28.9	24.0
77.7	28.6	27.0
79.5	28.1	25.2
81.1	27.6	26.0
83.1	26.7	34.6
85.4	25.3	38.6
87.5	23.3	43.3
89.4	22.1	45.3
91.1	20.6	47.9
93.1	18.7	50.7
94.9	16.8	53.6
96.7	15.1	55.6
98.8	13.1	59.3
101.0	11.0	67.2
102.9	9.1	71.1
104.4	7.5	73.2
105.9	3.9	70.4
104.8	0.1	70.6

APPENDIX E

PROTOTYPE REFERENCE EXTENDED VALVE DATA

Pressure (PSI)	Flow (GPM)	Poppet Movement (0.001")
18.6	31.9	0.0
42.3	31.7	0.8
62.4	31.5	2.7
66.7	31.4	2.8
71.9	31.4	3.0
73.7	31.3	5.2
75.9	31.2	5.1
77.6	31.0	6.2
79.8	30.8	7.1
81.8	30.6	7.2
83.0	29.4	10.6
84.7	27.5	14.7
86.3	26.1	19.7
89.2	19.6	30.0
91.0	18.3	29.9
92.7	15.7	30.1
94.5	14.3	24.9
96.4	12.2	24.9

98.7	9.9	25.1
100.7	8.2	25.3
102.9	2.9	25.5
103.9	1.3	25.6
104.6	0.2	25.7

APPENDIX F

PROTOTYPE REFERENCE VALVE CFD REPORT

Flow Simulation Report

Reference Valve

1 General Information

Objective of the simulation:

To determine the velocity of 40# lube fuel oil moving through the poppet.

1.1 Analysis Environment

N/A

1.2 Model Information

Model Name: Ref Valve Sim.SLDPRT

Project Name: Project(1)

1.3 Project Comments:

Unit System: IPS (in-lb-s)

Analysis Type: Internal

1.4 Size of Computational Domain

Size

X min	-3.07 in
X max	-6.36e-003 in
Y min	-1.32 in
Y max	0.73 in
Z min	-0.75 in
Z max	0.74 in

1.5 Simulation Parameters

1.5.1 Mesh Settings

1.5.1.1 Basic Mesh

Basic Mesh Dimensions

Number of cells in X	14
Number of cells in Y	10
Number of cells in Z	8

1.5.1.2 Analysis Mesh

Total Cell count: 5950

Fluid Cells: 5950

Solid Cells: 5877

Partial Cells: 4026

Trimmed Cells:0

1.5.1.3 Additional Physical Calculation Options

Heat Transfer Analysis: Heat conduction in solids: Off

Flow Type: Laminar only

Time-Dependent Analysis: Off

Gravity: Off

Default Wall Roughness: 0 microinch

1.5.2 Material Settings

Material Settings

Fluids

40 Lube Oil

1.5.3 Initial Conditions

Initial Conditions

Thermodynamic parameters	Static Pressure: 14.70 lbf/in^2 Temperature: 68.09 °F
Velocity parameters	Velocity vector Velocity in X direction: 0 in/s Velocity in Y direction: 0 in/s Velocity in Z direction: 0 in/s

1.5.4 Boundary Conditions

Boundary Conditions

Inlet Volume Flow 1

Type	Inlet Volume Flow
Faces	Face<1>@Boss-Extrude23
Coordinate system	Face Coordinate System
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face Volume flow rate: 2 in^3/s Inlet profile: 0
Thermodynamic parameters	Temperature: 68.09 °F

Outlet Volume Flow 1

Type	Outlet Volume Flow
Faces	Face<2>@Boss-Extrude23
Coordinate system	Face Coordinate System
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face
	Volume flow rate: 2 in^3/s

Total Pressure 1

Ty pe	Total pressure
Fac es	Face<4>@Reference Valve body spring and poppet Face<3>@Reference Valve body spring and poppet
Coordinate system	Global coordinate system
Reference axis	X
Thermodynamic parameters	Total Pressure: 71.80 lbf/in^2 Temperature: 68.09 °F

1.5.5 Volumetric Heat Sources

1.5.6 Engineering Goals

1.6 Analysis Time

Calculation Time: 12 s

Number of Iterations: 52

2 Results

2.1 Analysis Goals

N/A

2.2 Global Min-Max-Table

Min/Max Table

Name	Minimum	Maximum
Density (Fluid) [lb/in^3]	0.029630	0.029630
Pressure [lbf/in^2]	71.77	71.82
Temperature [°F]	68.09	68.09
Temperature (Fluid) [°F]	68.09	68.09
Velocity [in/s]	0	17.02
Velocity (X) [in/s]	-12.03	8.80
Velocity (Y) [in/s]	-9.00	9.20
Velocity (Z) [in/s]	-11.34	12.03
Shear Rate [1/s]	0.065	752.565
Velocity RRF [in/s]	0	17.02
Velocity RRF (X) [in/s]	-12.03	8.80
Velocity RRF (Y) [in/s]	-9.00	9.20
Velocity RRF (Z) [in/s]	-11.34	12.03
Vorticity [1/s]	0.04	143.29
Relative Pressure [lbf/in^2]	57.07	57.12
Shear Stress [lbf/in^2]	1.94e-007	0.02
Bottleneck Number [ ]	1.4128823e-007	1.0000000

Heat Transfer Coefficient [lbf/s/in/°F]	0	0
ShortCut Number [ ]	5.7149329e-007	1.0000000
Surface Heat Flux [lbf*in/(in^2*s)]	0	0
Surface Heat Flux (Convective) [lbf*in/(in^2*s)]	-601161.91087	886348.16729

2.3 Results

The fluid flow velocity results are consistent with previous simulation on similar style geometry by Y. Hennery

2.4 Conclusion

There is an opportunity to improve this valve.

3 Appendix

3.1 Material Data

Engineering Database

Non-Newtonian/Compressible liquids

40 Lube Oil

Path: Non-Newtonian Liquids User Defined\40 Lube Oil.xml

Density: 0.029630 lb/in^3

Specific heat: 4397.8 lbf*in/(lb*°F)

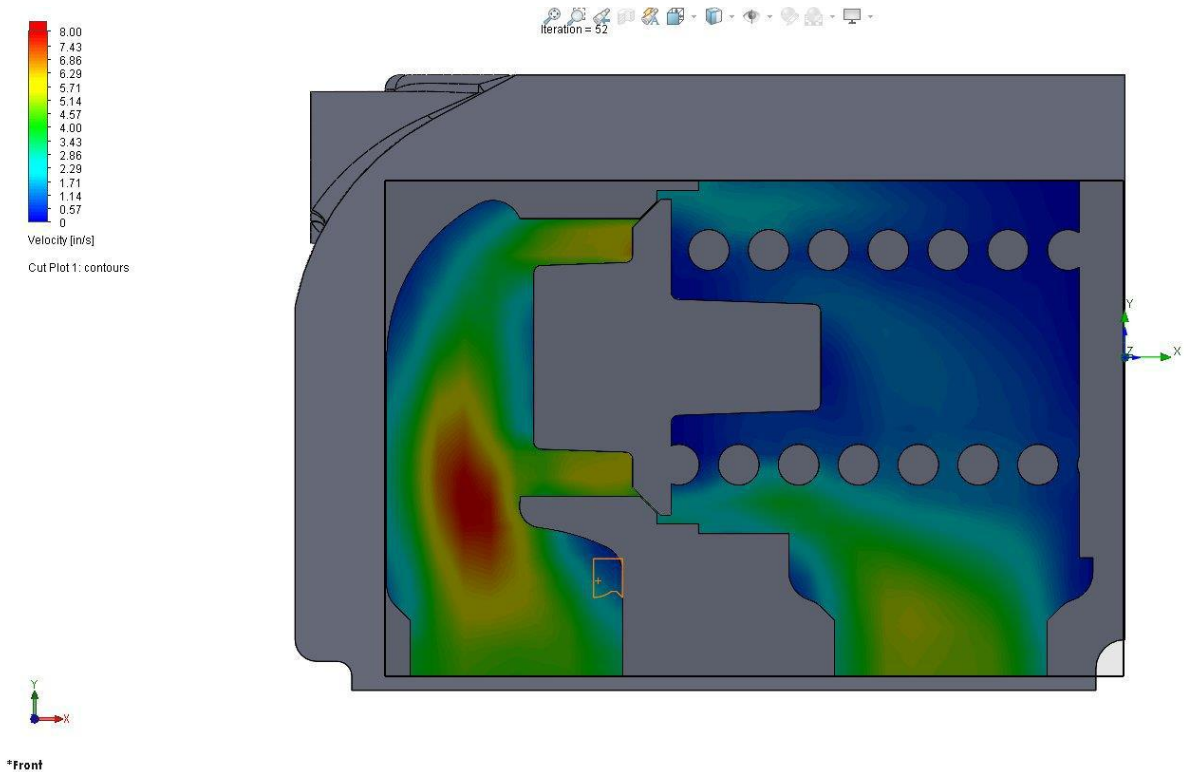
Thermal conductivity: 2.27369902e-006 Btu/(in*s*°F)

Viscosity: Power-law model

Set up maximum viscosity: No

Set up minimum viscosity: No

Power-law index: 1.0000000



APPENDIX G

TEST FLUID MSDS: NO. 40 LUBE OIL

Northland Rodaka 700

Safety Data Sheet

according to the federal final rule of hazard communication revised on 2012 (HazCom 2012)

Date of issue: 11/21/2013 Version: 1.0

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Product form	:	Substance
Trade name	:	Rodaka 700
Product code	:	40R9
Other means of identification	:	Lubricant

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture	:	Lubricant

1.3. Details of the supplier of the safety data sheet

MANUFACTURER:
Northland Products
1000 Rainbow Drive
Waterloo, IA 50704

Tel: +1-319-234-5585
+1-800-772-1724

1.4. Emergency telephone number

Emergency number	:	Chemtrec 1-800-424-9300 Chemtrec (Outside USA) +1 703-527-3887 (24 hours)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

GHS-US classification

Not classified

2.2. Label elements

GHS-US labelling

No labelling applicable

2.3. Other hazards

other hazards which do not result in classification	:	This product contains a petroleum-based mineral oil. Prolonged or repeated skin contact can cause mild irritation and inflammation characterized by drying, cracking, (dermatitis) or oil acne. Repeated or prolonged inhalation of petroleum-based mineral oil mists at concentrations above applicable workplace exposure levels can cause respiratory irritation or other pulmonary effects.

2.4. Unknown acute toxicity (GHS-US)

No data available

SECTION 3: Composition/information on ingredients

3.1. Substance

Name	:	Northland Rodaka 700

Full text of H-phrases: see section 16

3.2. Mixture

This product does not contain any substance presented in above cut-off concentration limits that classified as hazardous in accordance with paragraph (d) of §1910.1200.

SECTION 4: First aid measures

4.1. Description of first aid measures

First-aid measures general	:	Never give anything by mouth to an unconscious person. If you feel unwell, seek medical advice (show the label where possible).
First-aid measures after inhalation	:	Assure fresh air breathing. Allow the victim to rest. In case of breathing difficulties administer oxygen. In all cases of doubt, or when symptoms persist, seek medical advice.
First-aid measures after skin contact	:	Remove affected clothing and wash all exposed skin area with mild soap and water, followed by warm water rinse. Wash with plenty of soap and water. Wash contaminated clothing before reuse. If skin irritation occurs: Get medical advice/attention.
First-aid measures after eye contact	:	In case of contact with eyes, rinse immediately with plenty of flowing water for 10 to 15 minutes holding eyelids apart. Subsequently consult an ophthalmologist. If redness, burning, blurred vision or swelling occur, transport to nearest medical facility for additional treatment.

First-aid measures after ingestion	:	Rinse mouth. Do NOT induce vomiting. If vomiting occurs naturally, have victim lean forward to reduce risk of aspiration. Immediately call a POISON CENTER or doctor/physician.

4.2. Most important symptoms and effects, both acute and delayed

Symptoms/injuries	:	This product contains a petroleum-based mineral oil. Prolonged or repeated skin contact can cause mild irritation and inflammation characterized by drying, cracking, (dermatitis) or oil acne. Repeated or prolonged inhalation of petroleum-based mineral oil mists at concentrations above applicable workplace exposure levels can cause respiratory irritation or other pulmonary effects.
Symptoms/injuries after inhalation	:	In the event of insufficient ventilation: May produce an allergic reaction.
Symptoms/injuries after skin contact	:	Frequent or prolonged contact with skin may cause dermal irritation.
Symptoms/injuries after eye contact	:	Oil Mist. May cause eye irritation.

4.3. Indication of any immediate medical attention and special treatment needed

No additional information available

SECTION 5: Firefighting measures

5.1. Extinguishing media

Suitable extinguishing media	:	Foam. Dry powder. Carbon dioxide. Water spray. Sand.
Unsuitable extinguishing media	:	Do not use a heavy water stream.

5.2. Special hazards arising from the substance or mixture

Fire hazard	:	When heated above the flash point, releases flammable vapours.

5.3. Advice for firefighters

Precautionary measures fire	:	Stop and contain spill/release if it can be done safely. If this cannot be done, allow fire to burn under control. Gases/vapours, toxic.
Firefighting instructions	:	Use water spray or fog for cooling exposed containers. Exercise caution when fighting any chemical fire. Prevent fire-fighting water from entering environment.
Protective equipment for firefighters	:	Do not enter fire area without proper protective equipment, including respiratory protection. Wear self-contained respiratory apparatus during longer or intensive exposition or spraying processing.
Other information	:	Special danger of slipping by leaking/spilling product.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

General measures	:	Use personal protective equipment as required. Special danger of slipping by leaking/spilling product. Stop leak if safe to do so. Relevant water authorities should be notified of any large spillage to water course or drain.

6.1.1. For non-emergency personnel

Emergency procedures	:	Evacuate unnecessary personnel.

6.1.2. For emergency responders

Protective equipment	:	Equip cleanup crew with proper protection.
Emergency procedures	:	The low volatility of this product does not require ventilation. However depending on the condition an adequate ventalation might be required.

6.2. Environmental precautions

Prevent entry to sewers and public waters. An environmental fate analysis is not available for this specific product. Plants and animals may experience harmful or fatal effects when coated with petroleum products. Petroleum-based (mineral) lubricating oils normally will float on water. In stagnant or slow-flowing waterways, an oil layer can cover a large surface area. As a result, this oil layer might limit or eliminate natural atmospheric oxygen transport into the water. With time, if not removed, oxygen depletion in the waterway may be sufficient to cause a fish kill or create an anaerobic environment. Notify authorities if liquid enters sewers or public waters.

6.3. Methods and material for containment and cleaning up

Methods for cleaning up	:	Soak up spills with inert solids, such as fabric absorbents, clay or diatomaceous earth as soon as possible. Collect spillage. Store away from other materials. Consult the appropriate authorities about waste disposal. For large liquid spills (> 1 drum), transfer by mechanical means such as vacuum truck to a salvage tank for recovery or safe disposal.

6.4. Reference to other sections

See Heading 8. Exposure controls and personal protection.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Additional hazards when processed	:	Special danger of slipping by leaking/spilling product.

Precautions for safe handling	: Avoid contact with skin, eyes and clothes. Personal protective equipment should be selected based upon the conditions under which this product is handled or used. Provide good ventilation in process area to prevent formation of vapour. Avoid breathing dust/fume/gas/mist/vapours/spray. Empty container retains product residue. Wash hands and other exposed areas with mild soap and water before eating, drinking or smoking and when leaving work. Proper grounding procedures to avoid static electricity should be followed.
Hygiene measures	: Contaminated work clothing should not be allowed out of the workplace. Wash contaminated clothing before reuse. Separate working clothes from town clothes. Launder separately. Do not eat, drink or smoke when using this product. Discard contaminated leather articles.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions	: Keep container closed when not in use. Keep only in the original container in a cool, well-ventilated place away from highly flammable substances. Keep away from open flames, hot surfaces and sources of ignition. Keep container tightly closed.
Incompatible materials	: Strong acid. Base. Oxidizing agents.
Storage temperature	: Store at ambient temperature
Heat and ignition sources	: Remove all sources of ignition.
Storage area	: Protect against direct sunlight.
Special rules on packaging	: Correctly labelled.

7.3. Specific end use(s)

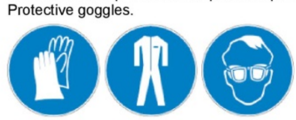
No additional information available

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

8.2. Exposure controls

Appropriate engineering controls	: A washing facility/water for eye and skin cleaning purposes should be present. Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of mists and/or vapors below the recommended exposure limits.
Personal protective equipment	: Personal protective equipment should be selected based upon the conditions under which this product is handled or used. Avoid all unnecessary exposure. The following pictograms represent the minimum requirements for personal protective equipment. Gloves. Protective clothing. Protective goggles.



Hand protection	: Wear protective gloves, rubber gloves.
Eye protection	: Chemical goggles or safety glasses. with side-shields.
Skin and body protection	: Chemical resistant suit. Wear rubber boots.
Respiratory protection	: Work in well-ventilated zones or use proper respiratory protection.
Thermal hazard protection	: In case of insufficient ventilation, wear suitable respiratory equipment. Wear a self-contained breathing apparatus and appropriate personal protective equipment (PPE). Wear heat resistant boots and protective clothing when handling material at elevated temperatures.
Environmental exposure controls	: Do not allow run-off from fire-fighting to enter drains or water courses. Ensure waste is collected and contained. Notify authorities if product enters sewers or public waters.
Other information	: Do not eat, drink or smoke during use.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state	: Liquid
Colour	: Clear to light amber.
odour	: Petroleum. characteristic.
Odour threshold	: No data available
pH	: No data available
Relative evaporation rate (butylacetate=1)	: No data available
Melting point	: No data available
Freezing point	: No data available
Boiling point	: > 325 °C (617 ºF)
Flash point	: 263 °C (505 ºF)
Self ignition temperature	: No data available
Decomposition temperature	: No data available
Flammability (solid, gas)	: No data available

Vapour pressure	:	< 0,01 mm Hg Maximum @ 37.8 °C (100 °F)
Relative vapour density at 20 °C	:	> 1
Relative density	:	0.888 g/cm³ at 15.6 °C / 60 °F
Solubility	:	Water: insoluble Organic solvent:completely soluble
Log Pow	:	Base oil hydrocarbons: log Kow > 4 (estimate)
Log Kow	:	Base oil hydrocarbons: log Kow > 4 (estimate)
Viscosity, kinematic	:	150 cSt (40 °C/104 °F)
Viscosity, dynamic	:	No data available
Explosive properties	:	No data available
Oxidising properties	:	No data available
Explosive limits	:	No data available

9.2. Other information

No additional information available

SECTION 10: Stability and reactivity

10.1. Reactivity

No additional information available

10.2. Chemical stability

Stable at normal conditions.

10.3. Possibility of hazardous reactions

Hazardous polymerization will not occur.

10.4. Conditions to avoid

Do not pressurize, cut, weld, braze, solder, drill, grind, or expose containers to flames, sparks, heat, or other potential ignition sources.

10.5. Incompatible materials

Strong acid. Strong bases. Oxidizing agents.

10.6. Hazardous decomposition products

fume. Carbon monoxide. Carbon dioxide.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity	:	Not classified
Skin corrosion/irritation	:	Not classified
Serious eye damage/irritation	:	Not classified
Respiratory or skin sensitisation	:	Not classified
Germ cell mutagenicity	:	Not classifiedBased on available data, the classification criteria are not met
Carcinogenicity	:	Not classified
Reproductive toxicity	:	Not classifiedBased on available data, the classification criteria are not met
Specific target organ toxicity (single exposure)	:	Not classified
Specific target organ toxicity (repeated exposure)	:	Not classifiedBased on available data, the classification criteria are not met
Aspiration hazard	:	Not classifiedMay be fatal if swallowed and enters airways
Potential Adverse human health effects and symptoms	:	Based on available data, the classification criteria are not met.
Symptoms/injuries after inhalation	:	In the event of insufficient ventilation: May produce an allergic reaction.
Symptoms/injuries after skin contact	:	Frequent or prolonged contact with skin may cause dermal irritation.
Symptoms/injuries after eye contact	:	Oil Mist. May cause eye irritation.

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general	:	An environmental fate analysis is not available for this specific product. Plants and animals may experience harmful or fatal effects when coated with petroleum products. Petroleum-based (mineral) lubricating oils normally will float on water. In stagnant or slow-flowing waterways, an oil layer can cover a large surface area. As a result, this oil layer might limit or eliminate natural atmospheric oxygen transport into the water. With time, if not removed, oxygen depletion in the waterway may be sufficient to cause a fish kill or create an anaerobic environment.

12.2. Persistence and degradability

Northland Rodaka 700	
Persistence and degradability	Not established.

12.3. Bioaccumulative potential

Northland Rodaka 700	
Log Pow	Base oil hydrocarbons: log Kow > 4 (estimate)
Log Kow	Base oil hydrocarbons: log Kow > 4 (estimate)
Bioaccumulative potential	Not established.

12.4. Mobility in soil

No additional information available

12.5. Other adverse effects

Other information : Avoid release to the environment.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Waste disposal recommendations : Dispose in a safe manner in accordance with local/national regulations. Liquid product may not be disposed of with household waste or landfilled. Do not allow to enter into drains/waters or in the soil.

Additional information : Used oil, may contain harmful impurities. It is the responsibility of the user to determine if disposal material is hazardous according to federal, state and local regulations.

Ecology - waste materials : Avoid release to the environment.

SECTION 14: Transport information

In accordance with ADR / RID / IMDG / IATA / ADN

14.1. UN number

Not applicable

14.2. UN proper shipping name

Not applicable

14.3. Additional information

Other information : No supplementary information available.

Overland transport

No additional information available

Transport by sea

No additional information available

Air transport

No additional information available

SECTION 15: Regulatory information

15.1. US Federal regulations

No additional information available

15.2. International regulations

CANADA

No additional information available

EU-Regulations

No additional information available

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Not classified

Classification according to Directive 67/548/EEC or 1999/45/EC

Not classified

15.2.2. National regulations

No additional information available

15.3. US State regulations

No additional information available

SECTION 16: Other information

Other information : None.

SDS US (GHS HazCom 2012)

The information presented herein has been compiled from sources considered to be dependable and is accurate to the best of Northland Products Company's knowledge; however, Northland Products Company makes no warranty whatsoever, expressed or implied, of merchantability or fitness for the particular purpose, regarding the accuracy of such data or the results to be obtained from the use thereof. Northland Products Company assumes no responsibility for the injury to the recipient or to third party persons or for any damage to any property and recipient assumes all such risks

APPENDIX H

TEST FLUID MSDS: CHEM FINISH EDM 3033

SAFETY DATA SHEET

1. IDENTIFICATION

Product Identifier
Product Name: Chem Finish EDM 3033

Additional Identification
Product Code: 20051
Synonyms: none

Recommended use of the chemical and restrictions on use
Recommended use: Metalworking Fluid
Restrictions on use: Not determined

Details of the supplier of the safety data sheet
Manufacturer
Company Name: CLC Lubricants
Address: 0N902 Old Kirk Road
Geneva, IL 60134
Telephone: 630-232-7900

Emergency Telephone number
Infotrac: 800-535-5053

2. HAZARDS IDENTIFICATION

Classification
Health Hazards:
Aspiration Hazard Category 1

Label Elements
Hazard Symbols:

Signal Word: DANGER

Hazard Statements:
H304 May be fatal if swallowed and enters airways

SAFETY DATA SHEET

Precautionary Statements:

Prevention:	Wear protective gloves/protective clothing/eye protection/face protection. Wash thoroughly after handling. Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Avoid breathing dust/fume/gas/mist/vapours/spray. Wash thoroughly after handling. Use only outdoors or in a well-ventilated area.
Response:	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. IF ON SKIN: Take off immediately all contaminated clothing. Rinse skin with water [or shower]. IF SWALLOWED: Rinse mouth. DO NOT induce vomiting.
Storage:	Store in a dry place. Store in a closed container. Store in a well-ventilated place. Keep cool.
Disposal:	Dispose of contents/container in accordance with local/regional/national/international regulations.

Hazards not otherwise classified (HNOC): None Identified

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	CAS number	Percentage
Normal Paraffins	90622-46-1	80 – 90
Straight run middle distillates	64742-79-7	5 – 15
Mineral Oil	8042-47-5	1 – 5

4. FIRST-AID MEASURES

Eye Contact: In case of contact with eyes, rinse immediately with copious amounts of water. Get medical attention if irritation occurs. Remove contact lenses, if present and easy to do.

Skin Contact: Immediately wash exposed skin with soap and water. Remove contaminated clothing and shoes. Wash clothing before reuse. Clean shoes thoroughly before reuse. Obtain medical attention if irritation occurs.

Inhalation: If inhaled, remove to fresh air. Get medical attention if symptoms appear.

Ingestion: If swallowed, DO NOT induce vomiting. Drink plenty of water. Never give anything by mouth to an unconscious person. Get medical attention.

Most important symptoms and effects, both acute and delayed

Symptoms: no information available

Indication of any immediate medical attention and special treatment needed

Note to physicians: Treat symptomatically

SAFETY DATA SHEET

5. FIRE-FIGHTING MEASURES

Suitable Extinguishing Media: Use water spray, Foam, Dry Chemical, Carbon Dioxide (CO2).

Inappropriate Extinguishing Media: Straight streams of water.

Fire-fighting instructions:
Evacuate area. Prevent runoff from fire control or dilution from entering streams, sewer, or drinking water supply. Firefighters should use standard protective equipment and in enclosed spaces, self-contained breathing apparatus (SCBA). Use water spray to cool fire exposed surfaces and to protect personnel.

Unusual Fire Hazards:
None known

Hazardous Combustion Products:
Smoke, Fume, oxides of carbon

6. ACCIDENTAL RELEASE MEASURES

Personal Precautions: Ensure adequate ventilation, especially in confined areas. Eliminate all ignition sources (no smoking, flares, sparks or flames in immediate area).

Environmental Precautions: Large spills, dike far ahead of liquid spill for later recovery and disposal. Prevent entry into waterways, sewers, basements or confined areas. Prevent further leakage or spillage if safe to do so.

Methods and material for containment and cleaning up: Pick up and transfer to properly labeled containers for disposal. Residual liquid can be absorbed on inert material and dispose of according to local regulations.

7. HANDLING AND STORAGE

Precautions for safe handling: Keep containers closed. Avoid contact with skin, eyes or clothing. Wash hands after handling. Empty container may retain residue which may exhibit hazards of product. Do not attempt to clean empty containers since residue is difficult to remove.

Conditions for safe storage, including any complications: protect against physical damage. Store in cool, dry well ventilated location. Store away from incompatible materials.

Incompatible materials: Strong Oxidizing Agents.

8. EXPOSURE CONTROLS/ PERSONAL PROTECTION

Ingredients with occupational Exposure Limits

SAFETY DATA SHEET

Chemical Name	TLV-TWA
Normal paraffins	5 mg/m3
Straight run middle distillate	10 mg/m3
Mineral Oil	10 mg/m3

Appropriate engineering controls

Engineering Controls	Showers; Eye wash stations; Ventilation system

Individual protection measures, such as personal protective equipment

Eye/face Protection: Wear safety glasses with side shields (or goggles) and a face shield.

Respiratory Protection: If exposure limits are exceeded or irritation is experienced, wear a NIOSH/MSHA approved (or equivalent) full-face piece airline respirator in the positive pressure mode with emergency escape provisions.

Skin and Body Protection: Wear impervious gloves to prevent contact with the skin. Wear long sleeves when contact is likely to occur. Wear protective gear as needed – apron, suit, boots.

Other Protective Equipment: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

Hygenic Practices: Do not eat, drink, or smoke in areas where this material is used. Avoid breathing vapors. Remove contaminated clothing and wash before reuse. Wash thoroughly after handling. Wash hands before eating.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Clear water white	Physical State:	liquid
Odor:	Typical	Odor Threshold:	Not Determined
Specific Gravity:	0.78	Solubility in Water:	Insoluble
Flash Point °F (°C):	248(120) PMCC	Explosive limits, vol%:	0.5 – 4.7
Viscosity 40°C	35 SUS		
Vapor Pressure:	<0.1 mm Hg @ 20°C	Vapor Density:	7.1 (air=1)
Boiling Range:	500°F (260°C)	Auto Ignition Temperature:	400°F (204°C)

10. STABILITY AND REACTIVITY

Reactivity: No data available.

Chemical stability: Material is stable under normal conditions.

Possibility of hazardous Reactions: Hazardous polymerization will not occur.

Conditions to avoid: Avoid heat, sparks, open flames and other ignition sources.

Incompatible materials: Strong oxidizers

SAFETY DATA SHEET

Hazardous decomposition: Material does not decompose at ambient temperatures. During combustion carbon monoxide may be formed.

11. TOXICOLOGICAL INFORMATION

Information on Toxicological Effects:

Acute Toxicity – dermal	LD50 rabbit: > 2,000 mg/kg
Acute Toxicity – inhalation	LC50 rat (4 hours): > 5.8mg/l
Acute Toxicity – oral	LD50 rat: > 2,000 mg/kg

12. ECOLOGICAL INFORMATION

No Information Available

13. DISPOSAL CONSIDERATIONS

Disposal of Wastes: Disposal should be in accordance with applicable regional, national, and local laws and regulations.

Contaminated Packaging: Do not reuse container.

14. TRANSPORTATION INFORMATION

DOT
Not Regulated

15. REGULATORY INFORMATION

OSHA Hazard Communication Standard:
Non-hazardous substance.

US Federal Regulations:
TSCA:
This product and/or its components are listed on the Toxic Substances Control Act (TSCA) inventory.

SARA 311/312 Hazard Categories:
Immediate (acute) Health

SARA 313 Toxic Release Inventory:
This material contains no chemicals subject to the supplier notification requirements of the SARA 313 Toxic Release Program.

CWA (Clean Water Act):

SAFETY DATA SHEET

This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42).

CERCLA:

This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355).

16. OTHER INFORMATION

	HEALTH	FLAMMABILITY	PHYSICAL
HMIS	1	1	0
NFPA	1	1	0

Date Prepared: October 14, 2015
Revision Date: October 14, 2015
Version: 1

Disclaimer

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

END OF SAFETY DATA SHEET

APPENDIX I

PHOTOREACTIVE RESIN: FORM 2 DURABLE RESIN

formlabs

Durable

Photoreactive Resin for Form 2

SAFETY DATA SHEET

Prepared: 01/26/2017

GHS-Labelling
Hazard pictograms:

Signal word: Warning

1. Chemical Product and Company Identification

Product Identification: Photoreactive Resin
Product Class: Mixture of methacrylic acid esters, photoinitiators, proprietary pigment and additive package
Product Use: For use in Formlabs printer Form 2
Company: Formlabs, Inc.
35 Medford Street, Suite #201
Somerville, MA
Date of Preparation: 01/26/2017
For Emergencies: North America call +1 800 255 3924
Worldwide Intl. call +01 813 248 0585
Reference Contract Number MIS4707563

2. Hazards Identification in Accordance with EC 1272/2008

EMERGENCY OVERVIEW
COLOR: TRANSPARENT LIGHT YELLOW
PHYSICAL STATE: LIQUID
ODOR: STRONG ACRYLIC

***Classification of the substance or mixture:**
Skin irritation, Category 2
Respiratory or skin sensitization, Category 1
Eye irritation, Category 2B
Target Organ Systemic Toxicity: Single Exposure Category 3
Harmful to aquatic life with long lasting effects, Category 3

GHS LABELLING
Hazard pictograms:

SIGNAL WORD: WARNING

HAZARD STATEMENTS
H315 Causes skin irritation
H317 May cause an allergic skin reaction
H319 Causes serious eye irritation
H335 May cause respiratory irritation
H412 Harmful to aquatic life with long lasting effects

PRECAUTIONARY STATEMENT(S)
Prevention:
P261 Avoid breathing gas/mist/vapors/spray
P264 Wash skin thoroughly after handling
P272 Contaminated work clothing should not be allowed out of the workplace
P273 Avoid release into the environment
P280 Wear protective gloves/protective clothing/eye protection/face protection

Response:
P302 + P352: IF ON SKIN (or hair) : Wash with plenty of soap and water
P305 + P351 + P338: IF IN EYES : Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310: IF SWALLOWED : Immediately call a POISON CENTER or doctor/physician
P333 + P313 : If skin irritation or rash occurs: Get medical advice/attention
P362 : Take off contaminated clothing and wash before reuse
P391 : Collect spillage

SUPPLEMENTAL HEALTH INFORMATION

Potential Health Effects:

Effects due to processing releases:
Irritating to eyes, respiratory system and skin. Prolonged or repeated exposure may cause: headache, drowsiness, nausea, weakness (severity of effects depends on extent of exposure).

Other:
This product may release fume and/or vapor of variable composition depending on processing time and temperature. Possible cross sensitization with other acrylates and methacrylates.

3. Composition/Information on Ingredient

Components	Approximate % by weight	C.A.S. No. & EINECS No.	Hazard Statements in accordance with EC 1272/2008	UK/EU Classification according to Directive 67/548/EEC
A. Acrylated oligomers	Proprietary	Proprietary or not assigned	H315, H317, H319, H335	Xi; Irritant, R36/37/38, R43 S3, S7/9, S20, S26, S29, S37/39
B. Methacrylated oligomers	Proprietary	Proprietary or not assigned	H19, H335	Xi; Irritant, R36/37/38, R43 S3, S7/9, S20, S26, S29, S37/39
C. Acrylated monomers	Proprietary	Proprietary	H315, H319	Xi; Irritant, R36/37/38, R43 S3, S7/9, S20, S26, S29, S37/39
D. Methacrylated monomers	Proprietary	Proprietary	H315, H317, H319, H412	Xi; Irritant, R36/37/38, R43 S3, S7/9, S20, S26, S29, S37/39
E. Photoinitiators	Proprietary	Proprietary	H317, H411	

4. First-Aid Measures

Emergency Overview: This product is a light yellow colored liquid with a characteristic odor. This product may cause skin and eye irritation. The inhalation of high vapor concentration may cause a headache and nausea.

Inhalation: In case of exposure to a high concentration of vapor or mist, remove person to fresh air. If breathing has stopped, administer artificial respiration and seek medical attention.

Eye Contact: Immediately flush with plenty of clean water (under eye lids) for at least 20 minutes. Hold eyelids apart to ensure flushing. Washing within one minute of contact is essential to achieve maximum effectiveness. Seek medical attention immediately. Do not apply oil or oily ointments unless ordered by a physician.

Skin Contact: Remove contaminated clothing and rinse contact area thoroughly with soap and water. Particular attention should be paid to hair, nose, and ears, and other areas not easily cleaned. Wash clothing before reuse. If irritation develops, consult a physician.

Ingestion: If ingested, dilute with water by giving glasses of water or milk to the victim. Do not give anything by mouth if the victim is rapidly losing consciousness, is unconscious, or convulsing. **Do not induce vomiting.** If vomiting occurs naturally, keep airways clear. Get medical attention. Provide an estimate of the time at which the material was ingested and the amount of the substance that was swallowed.

5. Fire-Fighting Measures

Flash Point: > 130 °C / 266 °F

Method: ASTM-D93

Ignition Temperature: No data

Lower Explosion Limit: No data

Upper Explosion Limit: No data

Extinguishing Media: Use carbon dioxide or dry chemical for small fires; aqueous foam or water spray for large fires.

Special Firefighting Procedures: Firefighters should wear full protection clothing and self-contained breathing apparatus (SCBA). Thoroughly decontaminate firefighting equipment including all firefighting apparel after the incident.

Unusual Fire & Explosion: Emits irritating vapors. High temperatures, accidental impurities, or exposure to radiation or oxidizers may cause spontaneous polymerization generating heat/pressure and rupture/explosion of closed containers.

Exposure Hazard(s): Material — Irritant

6. Accidental Release Measures

Procedures of Personal Precautions: Wear adequate personal protective clothing and equipment, as outlined in Section 8.

Environmental Precautions: Contain spill to prevent spread into drains, sewers, water supplies, or soil. Avoid release into the environment. Dispose of in accordance with all applicable federal, state and local regulations.

Methods of Cleaning Up: In the event of a spill, immediately remove all sources of ignition. Cover the liquid with inert absorbent. Using appropriate personal protective equipment and non-sparking tools, contain spilled material.

Waste Disposal Method: Do not dispose of in sewers, lakes, rivers or streams. Scoop all contaminated material into compatible bottles or drums for proper disposal. Dispose of in accordance with all applicable federal, state and local regulations. National or regional provisions may also be in force.

7. Handling and Storage

Handling Precautions: User Exposure — This product should be used in well-ventilated areas. Product may cause irritation. Avoid contact with eyes. Avoid prolonged or repeated contact with skin. Wash hands with soap and water before eating, drinking, smoking, applying cosmetics, or using toilet facilities. Launder contaminated clothing before reuse. Contaminated leather articles, including shoes, cannot be decontaminated and should be destroyed to prevent reuse. Solvents should never be used to clean hands or skin because they increase the penetration of the material into skin.

Storage Precautions: Suitable — Store in a cool, dry place out of direct sun light, in opaque or amber containers. Store the containers at 10-35°C (50-95°F). Do not exceed 60°C (140°F) when in storage. Keep containers closed. Avoid ignition sources.

Special Requirements: Do not heat containers with steam or electrical equipment. Heating this product above 150 °C (300 °F) in the presence of air may cause slow oxidative decomposition; above 260 °C (500 °F) polymerization may occur. Fumes and vapors from this thermal decomposition may be dangerous (nitrous vapors, carbon monoxide, carbon dioxide). Do not breathe fumes.

8. Exposure Controls & Personal Protection

EXPOSURE LIMITS

Component	HSIS Australia	IOELVs (UK)	ACGIH TLV	OSHA PEL	WEEL
1. Acrylated oligomers	None	None	None	None	None
2. Methacrylated oligomers					
3. Acrylated monomers	None	None	None	None	None
4. Methacrylated monomers					
5. Photoinitiator(s)	None	None	None	None	None

No occupational exposure limit values exist for the materials contained in this product.

NOTATIONS

IOELVs — Indicative Occupational Exposure Limit Values
TWA — Time Weighted Average
OEL — Occupational Exposure Limits
PEL — Permissible Exposure Limit
TLV — Threshold Limit Value
STEL — Short Term Exposure Limit
WEEL — Workplace Environmental Exposure Level by the American Industrial Hygiene Association

EXPOSURE CONTROLS

Ventilation Controls: Ensure adequate ventilation.

Respiratory Protection: Respirators are generally not needed under normal conditions of use. If this material is handled at elevated temperature, under mist forming conditions or in case of accidental release of large quantities of product use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Protective Gloves: Wear impervious gloves (nitrile or neoprene) for routine handling.

Eye and Face Protection: Chemical splash goggles or a face shield is recommended during operations where splashing could occur.

Skin Protection: Avoid all skin contact. Depending on the conditions of use, cover as much of the exposed skin area as possible by wearing gloves, aprons, long pants, and long sleeved shirts.

Other Controls: For operations where contact can occur a safety shower and eye wash facility should be available. Always use good personal hygiene and housekeeping practices. Wash hands thoroughly after handling.

Environmental Exposure Controls: Keep product from waterways and watersheds. This substance is not readily biodegradable and is dangerous for the environment. Avoid release into the environment.

9. Physical & Chemical Properties

Appearance: Transparent Yellow Color
Odor: Strong/Characteristic/Acrylate

	Value	Unit	Method
Specific Gravity	1.04	g/cm^3	
Boiling Point	> 100	°C	
Flash Point	> 100	°C	
Ignition Temperature	no data		
Lower Explosion Limit	no data		
Upper Explosion Limit	no data		
Viscosity	2480	cps	@ 25 °C (77 °F)

Vapour Pressure: Not established
Solubility in Water: Only very slightly soluble
Solubility in Organic Solvents: Soluble in organic solvents
Volatile Characteristics: Negligible
Electrostatic Discharge: Safe
Electric Conductivity: Dielectric

10. Stability and Reactivity

Stability: Stable when stored in original container designed for use with light sensitive materials under 35 °C (95 °F) in dark, cool place.

Conditions to Avoid: Storage > 38 °C (100 °F), exposure to light, loss of dissolved air, and contamination with incompatible materials.

Incompatible Materials to Avoid: Polymerization initiators, including peroxides, strong oxidizing agents, alcohols, copper, copper alloys, carbon steel, iron, rust, and strong bases.

Hazardous Decomposition Products: Hazardous decomposition products may include oxides of carbon, nitrogen and various hydrocarbon fragments.

Hazardous Polymerization: Hazardous polymerization may occur. Uncontrolled polymerization may cause rapid evolution of heat and increase in pressure that could result in violent rupture of sealed storage vessels or containers.

11. Toxicological Information

A. Acrylated oligomers	Not tested
B. Methacrylated oligomers	Not tested
C. Acrylated monomers	Acute Oral toxicity (rat) LD50 > 2000 mg/kg body weight (vendor literature)
D. Methacrylated monomers	Acute Oral toxicity (rat) LD50 > 2000 mg/kg body weight (vendor literature) Acute Dermal toxicity (rabbit) LD50 > 5000 mg/kg body weight (vendor literature)
E. Photoinitiator(s)	Virtually nontoxic after a single ingestion. Virtually nontoxic after a single skin contact

Individual components of this product are not reported to produce mutagenic effects in humans. None of the components of this material are listed by IARC, NTP, OSHA or ACGIH as carcinogens.

12. Ecological Information

Keep product from waterways and watersheds. This substance is not readily biodegradable. Dispose of in accordance with all applicable federal, state and local regulations.

A. Acrylated oligomers	No data available
B. Methacrylated oligomers	No data available
C. Acrylated monomers	No data available
D. Methacrylated monomers	No data available
E. Photoinitiator(s)	No data available

13. Disposal Considerations

Dispose of in accordance with governmental regulations (community, national or regional). Contact a licensed professional waste disposal service to dispose of this mixture. As with all foreign substances, do not allow to enter storm or sewer drainage systems. Avoid release into the environment.

Contaminated Packaging: Dispose of as unused product. Expose the open emptied container to light until material has solidifed, then dispose.

14. Transport Information

Department of transportation classification: Not hazardous by D.O.T. regulations
D.O.T. proper shipping name: Not regulated
International Maritime Dangerous Goods Code (IMDG): not regulated
International Air Transportation Association (IATA): not regulated
Other requirements: N/A
Australian HazChem Code: N/A

15. Regulatory Information

			EUROPEAN ECONOMIC COMMUNITY (EEC)				CANADA REGS	
Ingredient	**EPA* TSCA**	**CA Prop 65**	**EINECS**	**European Community Standards**	**Listed as dangerous chemicals per ESIS**	**EC 1272/2008**	**DSL**	**NDSL**
A. Acrylated oligomers	Yes	No	Yes	None	No	H315, H317, H319, H335	Yes	No
B. Methacrylated oligomers	Yes	No	Yes	None	No	H319, H335	Yes	No
C. Acrylated monomers	Yes	No	Yes	None	No	H315, H319	Yes	Yes
D. Methacrylated monomers	Yes	No	Yes	None	No	H315, H317, H319, H412	Yes	Yes
E. Photoinitiator(s)	Yes	No	Yes	None	No	H317, H411	Yes	No

All the components present in this product at concentrations equal to or greater than 0.1% are listed, or excluded from listing, on the United States Environmental Protection Agency Toxic Substances Control Act (TSCA) inventory.

Substance Preparation Classification:


Irritant

The following provides a summary of the legal requirements.

FULL TEXT OF ANY R-PHRASES AND S-PHRASES:

Risk Phrases:
R36/37/38 — Irritating to eyes, respiratory system and skin
R43 — May cause sensitization by skin contact

Safety Phrases:
S3 — Keep in a cool place
S7/9 — Keep container
S20 — When using do not eat or drink
S26 — In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
S29 — Do not empty into drains
S37/39 — Wear suitable gloves and eye/face protection

SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

Pursuant to Title III of the Superfund Amendments and Reauthorization Act of 1986, (SARA) and 40 CFR 372 Part 372, this product does not contain chemicals subject to the reporting requirements under Section 313.

California Proposition 65: This product does not contain chemicals which are known to the state of California to cause cancer.

Section 355 (extremely hazardous substances): None of the ingredients is listed.

Section 313 (specific toxic chemical listings): None of the ingredients is listed.

16. Other Information

HMIS (Hazardous Materials Information System) for secondary labelling:

HEALTH	2
FIRE HAZARD	1
REACTIVITY	1
PERSONAL PROTECTIVE EQUIPMENT	D

REFERENCES:

1. 2011 Threshold Limit Values and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists.
2. MSDS + Cheminfo CD-ROM, Canadian Centre for Occupational Health and Safety
3. SAX'S Dangerous Properties of Industrial Materials, Tenth Edition
4. TSCA & SARA Title III, U.S. Environmental Protection Agency and the National Technical Information Services
5. Raw Material Manufacturers Material Safety Data Sheets
6. US National Institute of Medicines Toxnet current edition
7. ESIS: European Chemical Substance Information System, http://ecb.jrc.it/esis
8. NOHSC Hazardous Information Substances Information System, Department of Employment and Workplace Relations, Australian Government, 2005

To the best of our knowledge the information contained herein is accurate. However, Formlabs, Inc. makes no warranty, expressed or implied, regarding the accuracy of these results to be obtained from the use thereof. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist. Formlabs, Inc. assumes no responsibility for injury from the use of the product described herein.