Development of a One-way Silicone Valve for a No-Spill Droplet Generator

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Abstract

Biofuels (e.g., those derived from algae and other biofeedstocks) have the potential to reduce emissions and allow for an environmentally friendly alternative to fossil fuels while keeping a similar or improved efficiency. When used for combustion testing, the biofuel alternative requires distinct machinery to generate a controllable amount of liquid for combustion. This research aims to develop a specific one-way valve that can restrict the liquid flow after the usage of a no-spill droplet generator system while operating under the required conditions for biofuels. Furthermore, this paper assesses the development of supporting pieces and the theoretical simulation of their operations in the system. An assessment covering the different alternatives to this system and the supporting pieces is conducted. The results demonstrate that the system and the shape, material, and sizes of the one-way valve were selected as the most well-structured design. Possible approaches to real-life testing are also discussed in the paper.

Introduction

Algae-derived biofuels are new types of fuels that use algae as a pathway to generate combustible liquids[1]. These biofuels have the potential to become alternatives to fossil fuels by having a natural and efficient option available with a material that is prevalent in the world[1]. Algae-derived biofuels also remove most of the risks that come with fuel sources, by reducing the harmful emissions during combustion[1]. As an alternative fuel source, algae-based biofuels have proven to be very effective as not only an alternative but also as a higher quality than fossil fuels in terms of emissions. When used for droplet combustion testing, the fuel does require an effective mechanism for generating droplets which are later ignited[2]. This mechanism is very intricate, which in turn requires multiple parts for it to function properly. One of these parts is a droplet generator. A droplet generator can produce liquid droplets to the precise size needed for the mechanism[2]. The specific generator used for this design is based on a previous model of the droplet generator, with the difference being based on the orientation of the generator. In earlier designs, the droplet generator used a piezoelectric transducer to generate pressure and shoot the droplet upwards, generating a parabolic path for the droplet to reach the desired location for combustion[2]. With the new model in this work, the design has changed where the requirement needs it to face downward, which requires a new design for this generator[3]. This project now required the new system to be a leak-proof system to combat the forces of gravity after the usage of the generator and for such a system to be actioned remotely. Many types of valves and solutions were proposed to combat this, yet none were found could provide the size requirement for droplet generation. This paper aims to bridge this gap by designing an effective droplet generator involving a silicone valve.

Methods

Silicone valves are commonly seen in soaps, ketchup bottles, and other viscous liquid containers. They are made of a synthetic material using polystyrene. This flexible yet durable solid offers flexibility, allowing for softer valves that can hold viscous liquids in place until pressure is applied. They specialize in allowing for a calculated amount of liquid to flow out of the nozzle with the application of pressure through any method, the most common being that of squeezing a bottle. The droplet generator system uses a similar mechanic that could theoretically function the same. However, the new objective is to create a no-spill system on the droplet system.

There were two options for manufacturing the silicone valve needed for the system. The first was to have an official manufacturer with experience shape the valve to our design. The difficulties with this option were not the development but the quantity of production and delivery. Manufacturing such a valve with a company would require the order to be a minimum of 10,000 pieces, from which we only required a maximum of 5. In other companies, the design of the valve would not be able to be customized to our parameter, meaning that it could not be able to reproduce the desired droplet sizes. The second option involved manufacturing the valve using 3D-printed molds. This would allow for easy development of the valve as well as access to control over the materials the valve is made of. This option required much attention as, at any point in the making, the valve could be deemed unusable if not made to the right quality needed.

When it comes to the construction of the droplet generator system, the prototype model was suggested to be 3D-printed in a resin printer. 3D printing would allow for an affordable model of the system to be tested, and it could be used as a trial phase to test the theory behind the design. Resin printing would be most beneficial for trials as well as generating very detailed and smooth surfaces for the system. This method would be used for the housing portion of the design, as liquid flow must be very smooth through the housing and tubing. A similar method was suggested for the manufacturing of the silicone valve.

Results

The housing was based on a cylindrical tube that would narrow towards the end, having a holder for the valve at the narrowed portion. The housing would also set the valve before the final opening to allow the liquid to have contact with the tube, forming the spherical shape required for the combustion. The housing contained a smaller area for the piezoelectric transducer above the allotted space for the liquid to be held in, allowing for little intervention between the plate and the outlet of the generator. This plate, as seen in Figure 1, is used to generate enough pressure for the liquid to be ejected from the generator, while also controlling the output of liquid the generator disposes of. Figure 2 shows the sectional view of the tubing with the valve.

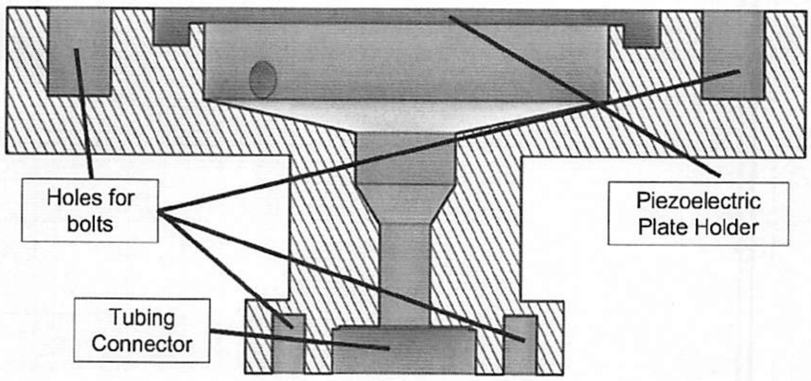


Figure 1: Sectional view of the piezoelectric plate and tubing housing.

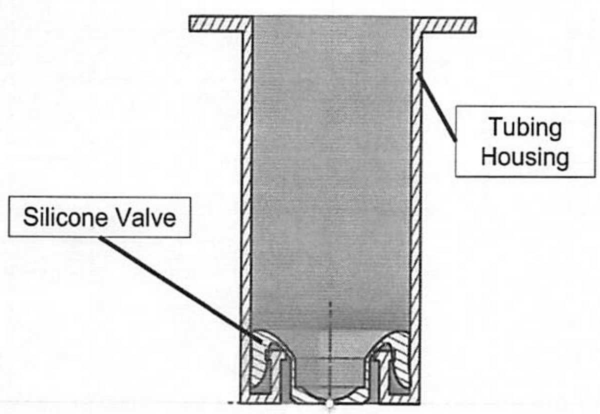


Figure 2: Tubing connected to the housing with a silicone valve inside.

The valve is a cylindrical silicone valve with a diameter of 5 mm and a height of 2.3 mm[4]. The valve is composed of a cross cutout at the bottom to allow movement when pressure is applied while also restricting liquid flow in the absence of said pressure. The valve shape has a peculiar formation, as it allows for the valve and the housing to be intertwined with each other to hold the valve in place. When assembling with the housing, this design can be attached without an outside adhesive for additional attachment to the housing. Under pressure, the valve will open to the distance required to allow the fuel to flow. This valve can control liquid flow further by applying different amounts of pressure, allowing for a flux of fuel flowing through the valve into the ignition system.

The design process required the valve to be systematic with the rest of the system. There were multiple requirements the valve needed to accomplish to be considered a successful prototype, which was to generate the size and spherical shape of the droplet, so as not to allow any extra material to drop after usage and to work with the current design that was being developed alongside it. The diameter of the nozzle must be 0.323 mm whenever it exits the system to be able to obtain the 0.5-mm range required for the combustion chamber.[4] The pressure can be varied and controlled by the piezoelectric transducer, and the liquid viscosity and density can be compared to that of petroleum-based liquid fuels.

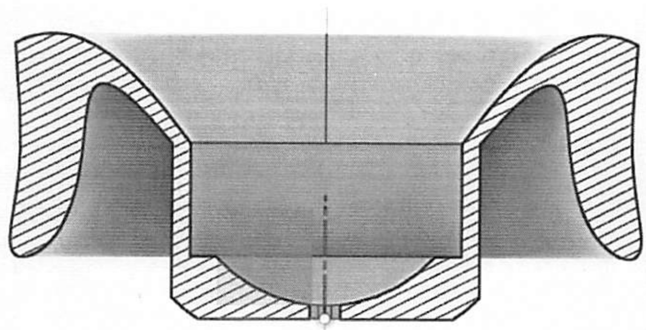
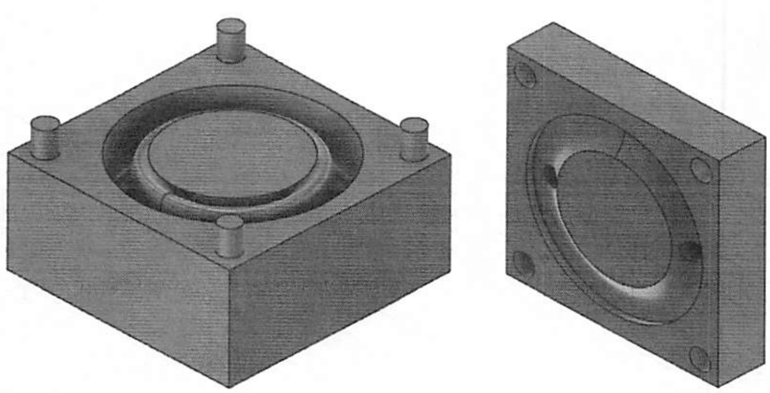


Figure 3: Sectional View of the silicone valve.

The molds would be modeled and completed as a 3D design, based on the design of the silicone valve in Figure 3. It would have four pins, as shown in Figure 4(a), to hold the mold in place for easy setting and removal of the mold. The top of the mold, as seen in Figure 4(b), also has two holes that allow for easy pouring of a silicone mix inside, allowing for easy displacement of the silicone as well as easy removal of the mold. The mold can be printed using either resin or threaded printing, however, the use of resin allows for higher design precision.



(a) (b)

Figure 4: Silicone mold: (a) Bottom portion and (b) Top portion.

Conclusions

Throughout this research, a prevalent event that kept occurring was the specifications of the design being too specific for market products to fit the role. The indicated event was a common occurrence, as encountering a specific description for an item that has never been used in this work is difficult. Using tools at our disposal, solutions were always suggested to accommodate those missing pieces. The solutions all had logical explanations, and theoretically, each could allow the system to function. The only dilemma was the time in this case, as whenever the production of the mold began, the research program time had ended. The team did suggest that work could continue if allowed.

This research has much potential for future development. There is still a demand for a system that requires droplet generation for the algae biofuel. The prototype can still use much work, such as storage for the liquid before reaching the piezoelectric plate. Perhaps there are more applications to some of the concepts that were used which could be investigated further. Continuing this research and design has much potential to benefit the future of droplet generation for fuel systems.

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References

1. Xu, Y., Brunson, J.D., Avedisian, C.T., Shen, Y., Keresztes, I., Condo Jr, A.M., Phillips, D., 2020, "Burning of algae-derived biofuel droplets and their mixtures with jet fuel," Energy & Fuels, Vol. 34, Issue 1, pp. 929-935.
2. Avedisian, C.T., Yang, J.C., Wang, C.H., 1988, "On low-gravity droplet combustion," Proceedings of the Royal Society of London A, Vol. 420, pp. 183-200.
3. Fan, K-C., Chen, J.-Y., Wang, C.-H., Pan, W.-C., 2008, "Development of a drop-on-demand droplet generator for one-drop-fill technology," Sensors and Actuators A: Physical, Vol. 147, Issue 2, pp. 649-655.
4. Muelasa, Á., Remacha, P., Ballester, J., 2019, "Droplet combustion and sooting characteristics of UCO biodiesel, heating oil and their mixtures under realistic conditions," Combustion and Flame, Vol. 203, pp. 190-203.

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