**California State Polytechnic University, Pomona**

**Mechanical Engineering Department**

**MEMORANDUM**

**To:** Professor McNamara **Date:** May 19, 2025

**From:** Shruthika Ilavarasu

**Subject**: Insulin Pump Design

**Introduction**

This assignment develops the design and simulation of the positive displacement of an insulin syringe system. The model integrates mechanical actuation, fluid transport through a representative syringe and tubing setup using pipes, and a battery power system capable of supporting a week’s worth of operation without need to recharge. The goal of this assignment is to analyze the performance under realistic operating conditions and ensure the system can run autonomously for at least 7 days.

In order to achieve this, the insulin syringe delivery system comprises of three major subsystems:

* The insulin pump system models the piston motion driven by a mechanical actuation converter using a damping force to give us the force input of the system.
* The fluid network subsystem models the way the pipes transport the insulin in the packet. It accounts for the flow losses from the syringe and pipe.
* The battery pack models how much power it takes for the pump to displace the right administration of insulin.

A translational mechanical converter is used to simulate the piston motion under external damping force. The pison is modeled as a damped system using a viscous damper. The relationship is shown through equation 1.

(1)

Where F(t) is the input force, c is the damping coefficient, and v(t) is the piston velocity. Displacement is then obtained by integrating the velocity from the force, then the insulin volume displaced is calculated by using equation 2.

(2)

The area of the piston is calculated by using the volume of the units needed to be administered. “1 unit of rapid-acting insulin will process anywhere from 12 to 15 grams of carbohydrates… A bolus dose may also be used to correct high blood sugar. In general, 1 unit of insulin lowers your blood sugar by about 50 milligrams per deciliter (mg/dL).”[1] Using the bolus administration, I decided to go with U-100 insulin, which has a volume of 0.01 mL per unit.[2] To define the liquid properties of insulin, I assumed it to be the same as water. The total simulation time is 24 hours, meaning the simulation time is set to be 86400 seconds, and to perform the integrations and derivatives, a time step of 0.5 is used. I am assuming that the patient is situated in a room temperature hospital room at 25 degrees Celsius.

The units I need to administer per day is 68 total, for the constant base value, as well as the peaks during breakfast, lunch, dinner, and bedtime, so the chamber volume I used was 0.68 mL.

For the fluid network model, I used the tubing diameter of 1.5 mm and at a length of 23 inches.[3] Since there is typically a 30-degree insertion angle, I used a pipe bend at that point of 30 degrees. I approximated the bend radius to be small in comparison to the length because the material used for this tubing is typically soft and flexible, called flexible soft cannula. I used the same surface roughness as a smooth plastic pipe of 0.0015 mm [4]. The syringe needle chosen was a 28 guage needle [5].

A screenshot of a cell phone

AI-generated content may be incorrect.

Figure 1. Recommended needle length and gauge needed to administer set amount of insulin units.

I chose the 28 gauge needle because the amount of insulin deposited at a time is always less than 30 units. The needle length is 5mm and gauge is 28 meaning outer diameter is 0.362 mm and inner diameter of 0.184 mm [5].

Finally, to model the power system, the mechanical energy required was converted to the electrical energy the system demanded using equation 3.

(3)

This accounts for the losses of the pump efficiency being 70%, the battery efficiency being 10%, and the battery load is modeled as a constant power drain. The total energy is integrated over time using a discrete integrator to output the energy consumed in joules.After the simulation ran for 86400 seconds or 1 day, it was concluded that the total energy consumed is 5000 J according to the power consumption scope.

To convert the consumption to a week, we multiply this by 7 days. This is 35,000 J total for the week. When converting to mAh, we use a typical 3.7 volt lithium ion battery.

(4)

In order to last a week, this system needs a battery pack of 2,627 mAh.

This system modeled the real-world behavior of an insulin syringe pump system. The model considers mechanical dynamics of the pump, fluid network losses, and the energy consumption from the battery pack.

Works Cited

[1]

M. Ghoshal, “Does the Size of an Insulin Syringe Matter?,” *Healthline*, Mar. 24, 2021. https://www.healthline.com/health/diabetes/insulin-syringes-sizes#sizes-and-lengths (accessed May 20, 2025).

[2]

“How to Convert Insulin Units to mL?,” *4AllFamily*, Dec. 16, 2022. https://4allfamily.com/blogs/diabetes/how-to-convert-insulin-units-to-ml (accessed May 20, 2025).

[3]

“Tandem,” *Tandem Diabetes*, 2023. https://www.tandemdiabetes.com/support-center/pumps-and-supplies/infusion-sets/article/infusion-set-overview

[4]

Pipe Flow Software, “Pipe Roughness,” *Pipeflow.com*, 2019. https://www.pipeflow.com/pipe-pressure-drop-calculations/pipe-roughness

[5]

“Needle Gauge Chart | Syringe Needle Gauge Chart | Hamilton,” *www.hamiltoncompany.com*. https://www.hamiltoncompany.com/laboratory-products/needles-knowledge/needle-gauge-chart