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Analysis of Ink Droplet Formation in Manufacturing of Automotive Bio-Sensors using Flow- 3D

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ABSTRACT

Additive manufacturing is used to create a three dimensional object by successive coating of material. In inkjet printer the chamber ejects small drops of ink through a nozzle on to the substrate. This paper studies about the droplet formation of ink with fluid properties like density, viscosity and surface tension with respect to two different nozzle diameters using Flow 3D software. This paper shows effect of fluid properties and diameters in the droplet formation and also the droplets ejects per second. Simulations of the objects or prototypes are used to reduce the cost of the prototype manufacturing and design, time consuming is also reduced using Flow 3D.
Keywords: Inkjet Printer, Flow 3D, Droplet Formation, Biosensor, Nozzle Diameter.

I. INTRODUCTION

Additive manufacturing is used to create an object by using layer by layer deposition of the material. It is also known as rapid prototyping or additive manufacturing. Rapid prototyping is mechanized method of 3D printing whereby 3D objects are created on a reasonably sized machine. The machine is connected to a computer containing blueprints for the object.

Additive manufacturing systems are the latest improved machines for the 3D printing that produce physical 3D models from digital data by printing layer by layer.3D printing technology has four types it is listed below. (1) Stereo lithography, (2) Selective laser sintering, (3) Multi-jet modeling, (4) Ink-jet 3D printing. Physical models of objects are obtained as a CAD document or scanning the physical model using a 3D scanner. Additive manufacturing used in designing of architecture, industrial component, automotive industry and engineering industries and etc.

Additive manufacturing systems has many more capabilities some of the capabilities are listed. (1)3D printers are used to examine the ideas of the engineers and designers with 3 dimensional products. (2) 3D printers have easiest way to test the 3D object with less cost before producing too expensive tooling and manufacturing processes. (3) 3D printing enables designers and engineers to create their objects easily but in conventional process it will be difficult, requires more cost and time consuming process.

II. METHODS AND MATERIAL

1. Inkjet Printing Technology

A. Inkjet Printing

Ink-jet printing technology is used to eject a small amount of droplet from the nozzle ejects the droplet layer by layer ejection. Inkjet technology offers an advantage to a wide range of applications. Inkjet printing technology has two types they are listed below. (1) Continuous ink-jet technology ejects drops constantly on a substrate or to a collector for a re-circulation and reuse. (2) Drop on Demand ink-jet technology ejects drops according to the requirements.

B. Drop on Demand

Drop on Demand methods based on the requirements of the object to be printed. Drop on Demand method has four types it is listed below. (1) Electrostatic Ink-jet Printer, (2) Thermal Ink-jet Printer, (3) Piezoelectric Ink jet Printer, and (4) MEMS.

Thermal ink-jet technology utilizes bubble jet or solid jet system to eject the drops from the nozzle. In piezoelectric ink-jet technology Piezo crystal undergoes distortion when an electric field is applied on the crystal and this distortion creates a pressure pulse that causes a drop to be ejected from the nozzle. In this we use a push mode piezoelectric inkjet technology.

C. Piezo Inkjet Printing

A Piezo crystal pushes against an ink chamber wall when an electric field is applied on the piezo crystal and this creates a pressure pulse that utilized to create drops from the nozzle. Piezo ink jet printer has the many variations in their creation of pressure like tube, edge, face, moving wall, and piston. It allows maximum ink or fluid development freedom and has more head life.

D. Fluid Dynamics

Fluid dynamics is a branch of physical science which deals with the analysis static and dynamic behavior of the fluid. The analysis is based on the fundamental laws of fluid dynamics. The laws are follows. (1) Conservation of mass, (2) Conservation of energy, (3) Conservation of momentum.

F. Computational Fluid Dynamics

Computational Fluid Dynamics is a branch of physical science which deals dynamic behavior of the fluid. It uses the numerical methods and algorithms to solve response of the fluid flow and analysis of their behavior.

E. Computational Fluid Dynamics Simulation

For the simulation purpose we use FLOW-3D software. For the analyses of the fluid flow it is suitable. Flow-3D is used to examine various design of the nozzle with respect to the diameter and the height of the chamber and the pressure force acting on the chamber. For testing the prototypes and identifying the design flaws it can be utilized. Simulations are used to reduce the physical model. FLOW 3D is accurate for the free surface simulations with true form of the volume of fluid technique. It has easy meshing with multiple structured blocks and having powerful physical modeling capabilities.

FLOW-3D enables highly-accurate simulations from the two methods. One is True Volume of Fluid Technique and other Volume of Fluid Techniques. The True Volume of Fluid Technique maintains a sharp interface for the free-surface problems and it does the faster computation than other methods using a single-fluid Volume of Fluid Technique. Other VOF methods have an interface that diffuses and it desirable for free surface problems using a two-fluid Volume of Fluid Technique.

General Moving Object (GMO) and Fluid Structure Interaction (FSI) Models. Flow-3D’s GMO model is a fully coupled, six degree of freedom, fluid or structure interaction model with an extensive number of features including: (1) The applied forces and torques, (2) Tethering with springs and ropes, (3) Fixed axis translation, (4) Rotation and fixed points, (5) Heat transfer (convection and conduction) and (6) collision.

F. Biosensors

Biosensor is an analytical device which converts biological response into an electrical signal. Electrical signal controls Electronic control unit to responds to the requirement. Biosensor has two components it is listed below. (1) Transducer, (2) Receptor. Receptor is a biomolecule that recognizes the target molecule. Transducer is a device for converting the recognition event into a measurable signal. Receptor materials are cells, nucleic acids, enzymes, antibodies and Transducer materials are FET devices, nanoparticals and electrodes.

G. Biosensor Applications

(1) A biosensor-enhanced steering wheel wraps(Alfred) and driver alert system. Biosensors can identify driver heart rate, hand position and the number of hands on the steering wheel. The system is easy for anyone to install in an existing car.
(2) Alfred is designed to detect the warning signs of sleepy or distracted driving and to alert drivers with vibration alerts when they are not paying attention. Even the most experienced drivers can have lapses when they are not concentrating on the road or other vehicles around them, but by keeping drivers focused biosensors can help avert preventable accidents.

(3) Alfred can also be paired with your smart phone or an existing telematics solution to send alerts to fleet managers or other third party monitors.

2. INK Preparation and Properties

For the preparation of the required ink for the manufacturing of automotive biosensors we selected the Borine Serrum Allumin as the main source and for increasing and decreasing properties of the ink required to add the Carboxy Methyl and Tritronic X 100.

Table 1 : Types of inks

Liquid Name	Main Solution	Added Solution
BSA 1	BSA	0.1 Molar PBS

To find out the properties of the ink some of the methods are used. For the density of the ink it will be weighted on weighing scale and volume of the ink is calculated with the help of the extracted ink volume.

For the viscosity viscometer is used to find out the viscosities of four inks. U-tube viscometer is used in these.For the surface tension of the ink capillary rise method is used to find the values.

Fluid Properties Calculation:

Density(ρ) = VolumeMass kg/m_3.

Surface Tension(σ) = $\frac{1}{2} \rho g r(h+\frac{r}{3})$ N/m.

Dynamic Viscosity(μ) = $\mu_{w*} t_s * \rho_s / t_w * \rho_w$ N-s/m^2.

Density(ρ) = 5.07e-3/5e-6

=1014 kg/m^3.

Surface Tension(σ)=0.5*1014*9.81*0.0335e-2(0.00146+0.0335e-2/3)

=0.025N/m.

Dynamic Viscosity(μ)=1000*(288*1014/289*1000)

=0.001N-s/m^2.

Table 2 : Fluid Properties

Fluid Property/Ink	Density(kg/m^3)	Viscosity(N-s/m^2)	Surface Tension (N/m)
Ink	1014	0.001	0.025

3. Nozzle Deign and Dimensions

Nozzle design (Fig. 1) shows the frequency is used to obtain pressure. When the frequency is increased or decreased the input value it reacts in the pressure value. Pressure value is based on the required drop to be ejected. Drops ejection is based on the object and pressure required is also affected by the fluid properties and nozzle diameter.

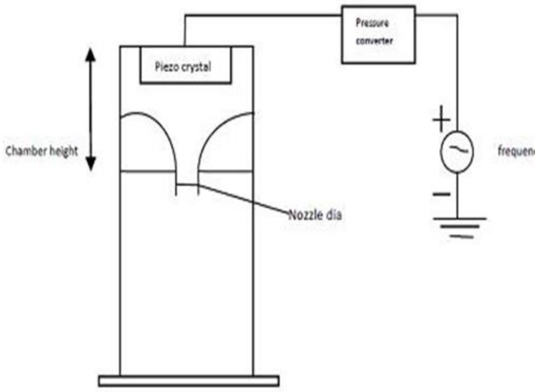


Figure 1. Nozzle Design

A. Nozzle

Ink Chamber:

Height = 0.015cm
Cylinder inner radius = 0.0105cm

Move the subcomponent into the position by translating from 0 cm to 0.1 cm in the positive z-direction.

B. Nozzle Tip

Cylinder outer radius = 0.0105cm Minor torus radius = 0.0085cm Major torus radius = 0.0105cm

Move the subcomponent into the position by translating from 0 cm to 0.1 cm in the positive z-direction.

C. Piezo Electric Crystal

Height = 0.002cm
Cylinder outer radius = 0.0105cm

Move the subcomponent into the position by translating the crystal from 0 cm to 0.1 cm in the positive z-direction.

D. Fluid Region

Fluid will be contained in the 0 to 0.013cm in the ink chamber.

III. RESULTS AND DISCUSSION

Droplet formation of the above mentioned(Table 1) inks will be showing in the below listed tables. It shows the droplet formation of the 20 and 30 micrometer diameters. It also the droplets ejected per second based on the ink properties and the nozzle diameter.

To check the printability of the ink we need to find the ohenosorge number. It is the ratio between the Reynolds and Weber number. Printable fluid should have the z value will be 1 to 10.

Table 3 : *BSA 1 Nozzle diameter 30micrometer*

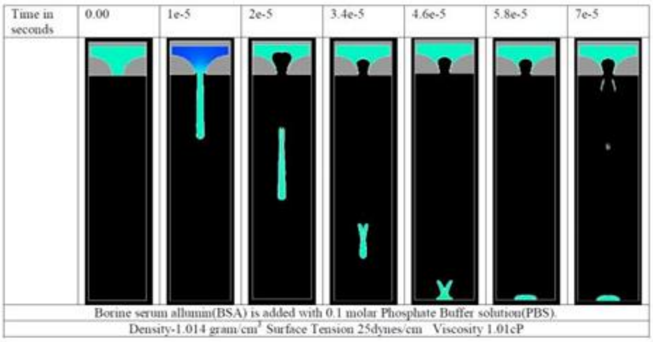
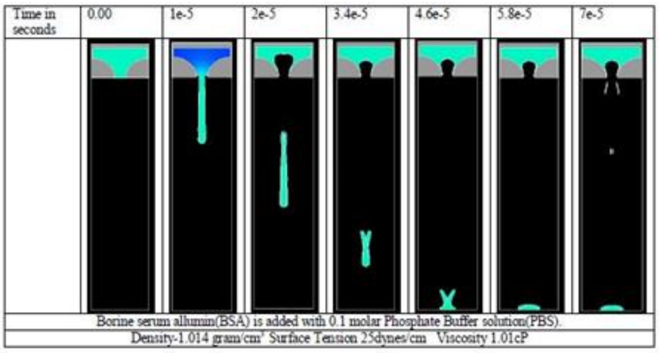


Table 4 : *BSA 1 Nozzle diameter 20micrometer*



Droplets ejection per second

For the Nozzle diameter 30 micrometer

BSA 1-14287 Droplets will be ejected per second

For the Nozzle diameter 20 micrometer

BSA 1: 27000 Drops will be ejected per second.

A. Drop Volume

It is based on the application and the performance required achieving the target. Drop Volume size will be varying from 2 to 32 picoliter. Drop volume will be controlled by the applied voltage.

B. Drop Speed

It is the ratio between the positions of the drop to the delay time. Unit is m/s. Drop speed is based on the density, viscosity and surface tension of the ink.

A drop ejected is based on the fluid properties of the ink like density, viscosity and surface tension. From the above table shows that drop ejection will be reduced when the viscosity value increases. Tail length of the drop will be high when the viscosity is less and vice versa.

Drop Speed = Position of the Drop in m/ Delay Time in Seconds.

For 30 micrometer nozzle diameter,

BSA 1:

$$\text{Drop Speed} = 0.05e\text{-}2/2.399e\text{-}5 = 20.84 \text{ m/s.}$$

For 20 micrometer nozzle diameter,

BSA 1:

$$\text{Drop Speed} = 0.06e\text{-}2/2.399e\text{-}5 = 25.01 \text{ m/s.}$$

When comparing the results of the 20 micrometer and 30 micrometer nozzle diameter with the same chamber dimensions drop speed of the 20 micrometer is higher than the nozzle diameter 30 micrometer. Comparing the same nozzle diameter with ink it shows that it is based on the ink properties. When the Viscosity of the ink is high than the drop speed will be less if it is less than the drop speed is more. Results show that Drop ejection per second is affected marginally by the Viscosity of the ink and the nozzle diameter.

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