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Design and development of pump based chocolate 3D printer

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***Abstract* - The use of 3-Dimensional (3D) printing, known as Digital fabrication (DF) or additive manufacturing (AM), technology in the food sector has countless potential to fabricate 3D constructs with complex geometries, customization, and on-demand production. For this reason, 3D technology is driving major innovations in the food industry. This paper presents the construction of a chocolate 3D printer by applying the pressure pump technique using chocolate as a printing material. Here the conventional 3D printer's design was developed as a chocolate 3D printer. As an improvement, a new extruder mechanism was introduced. The extruder was developed to print the chocolate materials. In the working mechanism, the 3D printer reads the design instruction and chocolate material is extruding accordingly, through the nozzle of the pump to the bed of the 3D printer followed by the design (layer by layer). The special part of this chocolate 3D printer is the pressure pump in the extruder part. That pressure pump provides pressure on melted chocolate from the chocolate container to the nozzle point. The usability and efficiency of the 3D printer were tested with sample designs. The obtained results were presented and discussed. Together with these advances this 3D printer can be used to produce complex food models and design unique patterns in chocolate-based sweets by satisfying customers.**

Keywords - 3D printing, additive manufacturing, food printing, hot melt extruder, pressure pump

I. INTRODUCTION

3D Printing, also known as the additive manufacturing technique, refers to processes used to synthesize a three-dimensional object in which successive layers of material are formed under computer control to create an object. Referring to the present used to synthesize a 3D object layer by layer materials are formed under a complete control system, to create an object. Currently, this technique is applied to make proofs of concept, prototypes, or end-products. Companies are implementing 3D printing at different stages of their manufacturing processes. The modern world has lots of applications of 3D printing technology. Now 3D printers have become more affordable for ordinary consumers.

Food printing manufacturers have realized the potential of 3D food printers in promoting culinary creativity, nutrition, and ingredient optimization, and food sustainability [1]. 3D printing has a process to manufacture 3D objects, this process can divide into steps such as (i) Create a model using software and convert it to STL (Standard Triangle Language) format. (ii) Fill the storage tank choose to model. (iii) Input STL format to the system. (iv) Operate the 3D printer to extrude the material. (v) Final object using with XYZ movement [1].

This project mainly focuses on chocolate 3D printing. Most chocolate 3D printers can process CAD files, just like normal 3D printers. Currently, chocolate 3D printers use a syringe instead of a filament, load it, and then hold it at a temperature at the time of printing [2]. The extruder head moves and deposits the melted chocolate in the desired shape. The chocolate eventually cools and solidifies. The syringe loading system is safe, clean, efficient, and keeps the chocolate fresh. If the operating temperature is followed, the chocolate will not dry at all in the syringe [3]. In a conventional 3D printing machine, the mechanical parts of the 3D printer have four stepper motors used to drive the XYZ axis. The movement of the Y-axis is independent and is performed mainly by a pair of ball screws with sliding supports that move the platform back and forth. The movements of the X and Z axes are interconnected and are performed mainly by a spherical screw supporting the optical axis. The X-axis is responsible for horizontal movement and the Z-axis is responsible for vertical movement [4]. Fig. 1 shows the conceptual design of the 3D printer XYZ axis.

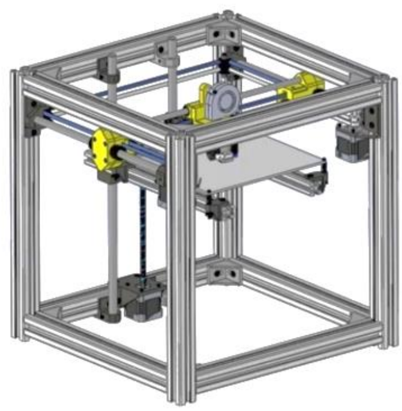

Fig. 1. Conceptual design of 3D printer XYZ axis

II. MATERIALS AND METHOD

The following techniques were applied when developing the chocolate 3D printer. It is the development of a chocolate 3D printer that uses chocolate as ink with a novel pump mechanism.

A. *Mechanical platform and controls*

Food structure can be deposited/sintered effectively point by point and layer by layer according to a computerized design modeling and route planning. This system uses layer-by-layer extruding.

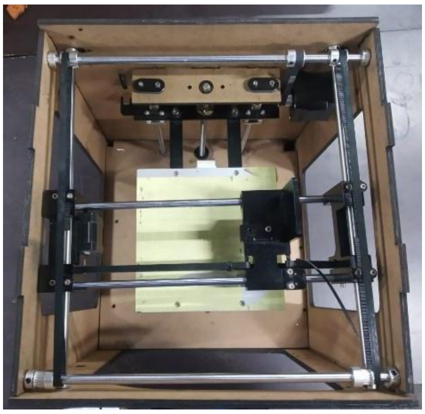

Fig 2. Mechanical platform of the chocolate 3D printer

Fig. 2 shows the mechanical mechanism part without the extruder of the chocolate 3D printer. As above mentioned, the pulleys, rods, and belts were used for the mechanical movement with the stepper motors. The rotational movement provided by the motor is activated by the pulleys, rods, and belts.

3D printer makes products by various kinds of layer-by-layer deposition on the plane surface. 3D printing has different types of layer deposition methods. The extrusion head usually pushes food through the nozzle through compressed air. Typically, the smaller the nozzle, the longer it takes to print the food [6]. In this research, the normal 3D printer was designed like a chocolate 3D printer by introducing a pump base chocolate pressure system. Especially, it is considered extruder mechanism. This proposed system will be focused on chocolate base food products using paste-type ingredients.

Following modifications were done when developing the proposed system. In the extrusion-based printing technique, the pump usually pushes the materials to the nozzle through compressed air [2]. The compressed air means the air inside of the food syringe, but the proposed system has extra pressure on extruding chocolate. Therefore, the storage tank can be larger than the syringe. In the storage tank of the chocolate 3D printer, the food container should provide the chocolate continuously and not need to pause the 3D printing process to refills. Fig 3 shows the complete chocolate 3D printer.

The movements of the 3D printer are using the belt mechanism. The rotational movement provided by the NEMA 17 stepper motor was activated by the pulleys and belts. Four NEMA 17 stepper motors were used for the mechanical part. XYZ axis was powered by three NEMA 17 stepper motors. Another one is used for power to a pump of the extruder system.

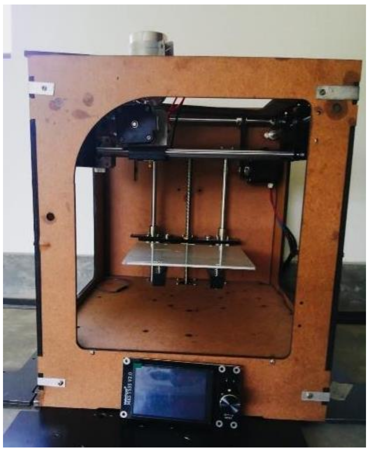

Fig. 3. Chocolate 3D printer

B. *Extruder design*

The design of the extruder part has three main components, such as chocolate containers, chocolate pumps, and nozzle sets. The chocolate container has a cylindrical shape, and the pieces of chocolate are put into this container. Then melted chocolate goes through the chocolate pump to the nozzle set with pressure. That chocolate pump has two gear wheels, and it has the same mechanism as an oil gear pump. All parts of the extruder set were prepared using stainless steel because all components are in contact with the chocolate. Further extruder set has a temperature system.

A too-small nozzle will lead to too slow extrusion speed, and a too-large nozzle will lead to a rough food surface [7]. Three nozzle diameters such as 1 mm, 1.25 mm, and 1.5 mm were investigated by varying the extrusion rates and nozzle moving speed the best nozzle diameter was found as 1.25 mm in terms of the property of the deposited product.

Stainless steel is a commonly used material in the food industry and is generally resistant to corrosion. [5]. Food Grade Stainless Steel 316 turned into used for the layout of an extruder, the grade 316 SS, can experience severe pitting corrosion when exposed to chocolate, which is often present in food product machines. 316 SS makes for great food-grade stainless steel parts for nearly any food application.

Extreme care must be taken when making the extruder part of the 3D printers which are used for food. Stainless steel has proven itself, time and time again to be a food-safe material. It does not corrode, rust, or provide livable conditions for harmful pathogens. In terms of hygiene and durability, stainless steel was used in the design.

C. *Feature-based software*

The chocolate 3D printer has used firmware to control all activities called “Marlin”. Marlin is an open-source firmware that controls all real-time activities of the machine such as adjust heaters, steppers, sensors, lights, LCD screens, buttons, and everything related to the 3D printing process.

D. Chocolate (as the material intended to be printed)

Normal 3D printers are used plastic materials for printing purposes however chocolate 3D printers use paste-type melted chocolate [2]. This proposed system is based on cooking chocolate. Cooking chocolate is a type of chocolate and uses for decorating foods. Cooking chocolates contain sugar, vegetable fat, and cocoa powder [4]. The main distinction between cooking chocolate and ‘normal' eating chocolate is how sweetened it is. Baking chocolate has a higher percentage of cocoa solids and usually contains less or no sugar than regular eating chocolate. Cooking chocolate for tempering or coverture may have more cocoa butter to ensure that it melts evenly and easily. The melting temperature of cooking chocolate is between 38˚C and 42˚C. The solidifying temperature of cooking chocolate is between 26 ˚C and 28 ˚C [4]. The melting temperature is important for the temperature unit of the chocolate 3D printer to melt the chocolate pieces. The temperature is important for solidifying the printing object. When the temperature is at the low 26 ˚C, chocolate begins to melt. When chocolate is crystallized or tempered, it is liquid and usable between 30 ˚C and 32 ˚C (lower for white and milk chocolate, higher for dark), and solidifies quickly at room temperature. Your chocolate melted but didn't get tempered/re-crystallized when it cooled, therefore it stayed liquid due to its lack of crystalline structure.

III. Results and Discussion

A. *Printing technology*

A chocolate 3D printer is a machine that can be used to produce prototype products rapidly. This 3D printer used chocolate as a process material. Further, this 3D printer applied a pump-based 3D printing technique using the pressure pump. In normal, 3D food printers use several 3D printing technologies such as Selective Sintering, Hot melt extrusion, Binder jetting, and Inkjet printing [3].

This chocolate 3D printer used hot-melt extrusion technology to extrude the chocolate. In this hot-melt extrusion, the chocolate material was heated up to its melting point. After this melted chocolate is deposited on the bed to builds the required object layer-by-layer from the bottom to the top by heating and extruding the filament. This food printer was designed based on the efficient size of the hot-melt extrusion with low maintenance cost. The disadvantages such as the time take to connect the layers, long production time, and delamination caused by temperature variation, need to be further investigated.

In this chocolate 3D printer was used Hot melt extrusion technology with a pressure pump. It is a special feature of this 3D printer. That pressure pump is made up of an external gear pump with two gear wheels. An external gear pump contains two equals, interconnecting gears supported by separate shafts. Generally, one gear is driven by a stepper motor, and this drives the other gear. Fig 4 shows the cross-sectional area of the pressure pump. This chocolate 3D printer compares with syringe-type 3D food printers. This syringe-type 3D printer used a pressure syringe to extrude the printing materials and this chocolate 3D printer uses a pressure pump to extrude the printing materials. That pressure pump provided extra pressure on extruding materials (chocolate) than normal syringe-type food 3D printers. The pressure of the pump can be change depend on the amount of the chocolate container. Fig. 5 shows the top side is of the extruder with melted chocolate.

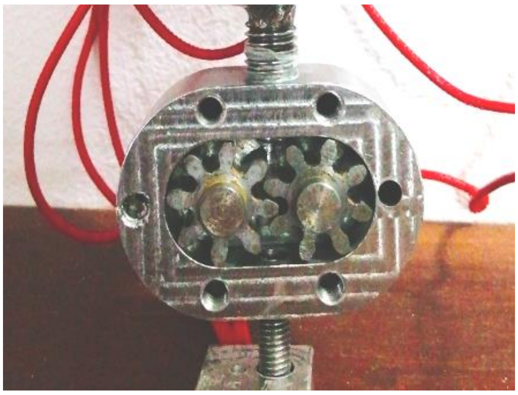

Fig. 4. Cross sectional area of pressure pump

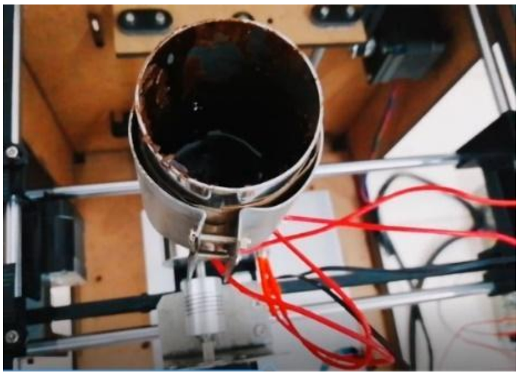

Fig. 5. Melted chocolate in chocolate container

Another advantage of this design is the continuation of the printing process. In syringe-type 3D printers, the printing process will stop when finished the materials' contents from the syringe. The syringe plunger wants to remove to refill the syringe. However, that problem can be overcome using this extruder. The extruder is powered by a pressure pump by a stepper motor. The upside of the chocolate container is free; therefore, it can be refilled as soon as it is printing. Fig 6 shows a chocolate extruder with its features.

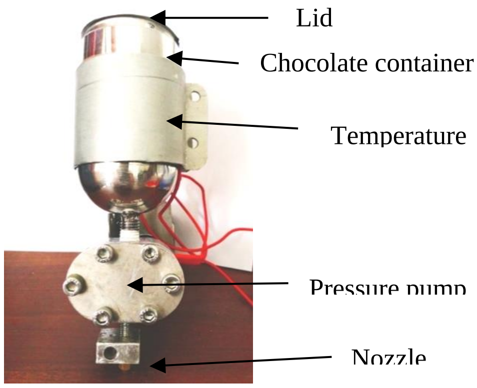

Fig. 6. Chocolate extruder

B. *The efficiency of the chocolate 3D printer*

The printing rate was calculated by dividing the weight of the printed object overprinting time [7].

$$Printing\ rate\ (g/min) = \frac{Total\ weight\ of\ the\ printed\ object\ (g)}{Printing\ time\ (min)} \qquad (1)$$

The melting and crystallization behaviors of fat present in chocolate will be important to understand from the point of view of deposition temperature and change occurring in deposited chocolate. The physical properties and mouth feel of the 3D printed chocolate product will be dependent on the time and temperature history after deposition. Fig 7 shows the slicing software detail of a printing object.

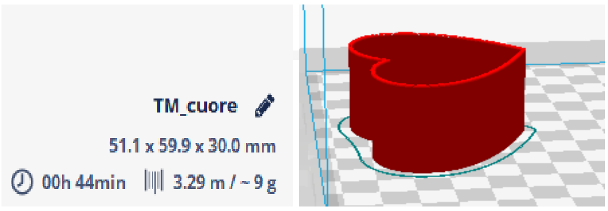

Fig. 7. Slicing software details of print object

TABLE I. CALCULATION DETAIL OF PRINTING RATE OF PRINTER

Printing time	***Total weight of the object***	***Printing rate of printer***
44 min	9 g	0.20 g/min

Differential Scanning Calorimetry analysis (DCS) is a thermo-analytical technique in which the difference in the amount of heat is required to increase the temperature of the sample. This analysis is used to study the behavior of the material of the function of temperature or time. Ex: Melting point, Crystallization behavior, Chemical reaction. DCS analysis of the deposited chocolate product, indicating that the viscosities of the chocolates can be relatively constant when the temperature is between 32^{0}C and 40 Celsius and the pressure between 3.5Pa and 7Pa [2].

Some research papers about DCS analysis were studied and get an idea about the temperature behavior of the chocolates. The quality of the print object is depending on printing materials and nozzle type. In this chocolate 3D printer, the quality of the print was compared with nozzle type only. Normal chocolate 3D printers have used the adapter of syringe (endpoint of the normal syringe) but this chocolate 3D printer was used the normal nozzles of normal 3D printers. Therefore, the quality of the print objects can increase.

Further, this chocolate 3D printer can use different size nozzles such as 0.8 mm, 1.0 mm, 1.25 mm, and 1.50 mm. The quality of the print was changed depending on nozzle size. The 1.25 mm nozzle is the best nozzle size for this chocolate 3D printer, and it was selected based on several experiments. Fig. 8 shows printed chocolate objects.

Fig. 8. Printed objects

C. *Three-axis mechanism*

The structure of the chocolate 3D printer was prepared by using MDF (Medium-density fiberboard). And pully, rods, and belts were used for constructing the movement of the three-axis. It provides smooth rotation and reduces vibrations. The bed of the 3D printer moves to the Y-axis, the set of the extruder move to the Z-axis, and the extruder move to the x-axis. This system has four stepper motors, three for the XYZ axis and another one is to rotate the pressure pump.

IV. CONCLUSIONS

The developed, chocolate 3D printer has a maximum printing size is 150 mm*150 mm*150 mm. The chocolate 3D printer was developed using a pressure pump. The pressure pump provides the extrusion of the materials with the support of the stepper motor and driving commands. Comparing to other food printing techniques in the market, most of the printing methods have syringe-type extruders. Using this syringe-type extruders, have several limitations. Mainly that continuation of the printing process. The printing process will stop the contains of materials is finish at the syringe. However, that problem can be overcome using this extruder. The advantage of this 3D printer is the ability to get beautiful and creative designs, and it can be used very effectively in the hotel industry. Also, another limitation of this chocolate 3D printer is the lack of an advanced cooling system which is required to printing the bed. The chocolate printer contains a normal cooling system with the cooling fan was attached to the frame, to help the solidification of the printing object. Additionally, in future work, the bed cooling system will be introduced.

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