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Influence of Water-jet Nozzle Geometry on Cutting Ability of Soft Material

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Abstract

Hygiene is main reason for food processor to use waterjet cutting system. Traditionally food cutting process is low-quality, unsafe products, procedures and direct contact between product and labor. This paper introduced a low cost waterjet system for cutting soft material as identic food material. The low cost waterjet system has been developed by using a commercial pressure pump for cleaning purposes and modified nozzle. In order to enhance waterjet pressure for cutting products, a modified waterjet nozzle was designed. Paramater design of waterjet system was setup on nozzle orifice diameter 0.5 mm, standoff distance 15 mm, length of nozzle cylindrical tube 2.5 mm. Polycarbonate, polysterene, and polyethelene materials are used as sample product with thickness 2 mm, to represent similar properties with agriculture products. The experimental results indicate good possibilities of waterjet system to cut material in appropriate profile surface. The waterjet also can be used to improve cutting finished surface of food products. Therefore, utilizing a low cost commercial pump and modified nozzle for waterjet system reduces equipment price, operational cost and environmental hazards. It indicates viable technology applied to substitute traditional cutting technology in post harvest agriculture products.

Keywords: cutting ability, modified nozzle, polymer material, water-jet system

1. Introduction

In food industry, high quality and safe products are the major issues that have to be considered. There are four criteria to measure quality and safety products, physical apperarance, flavor, texture and nutritional properties (René Carreño-Olejua *et al*, 2010). Poor quality of agriculture products are caused by direct contact between the product and labor at the peeling and cutting process. The cutting procedure has significant influenced to quality and safety of the product. Using continuously the same cutting tools, without cleaning, will reduces the quality of the product through microbiologic contamination. This method significantly decreases both quality of cut and product's shelf life. Maintaining cutting process will increase shelf life of products.

Recently, many researchers have conducted experiments to minimize the effect of process that have a strong influence on the quality of the products. Utilization waterjet cutting by food processors is mainly for hygiene reasons. During the cutting process, the food is only contacted with pure water. There is no risk of contamination as can occur with knives. The food is not heated during cutting and not exposed to any chemicals. González-Aguilar *et al.* (2010), present using of more emerging cutting technologies to preserve the quality of freshly cut fruits. KMT waterjet as a leading company in developing waterjet technology presented wide areas of waterjet including food production industry. Most common food products use waterjet in the cutting process such as cutting of pizzas, cakes, meat, fish, chocolate bars, potato chips and frozen food (KMT Waterjets, 2012). Alitavoli and McGeough (1998), describe development of water-jet system for cutting soft materials and determine important procedural variables such as cutting pressure, cutting speed, and nozzle diameter for applied in sheep, beef, and chicken meat processing. Becker and Gray (1992), exploring feasibility of water jet for potatoes cutting process. Recent study, water-jet method was applied to the peeling process of tropical fruits.

Polymer material is used as representative of food due to their properties. The cutting parameters of waterjet systems are tranverse velocity, standoff distance, nozzle diameter, water pressure, and water flow rate. Those were investegated to get good quality surface and variation of afected color agriculture products. In this paper, a low cost waterjet system was proposed as an alternative food cutting process. It expected technically able to subsititude food traditional

cutting tools and their associated drawbacks for preserving hygiene foods.

Water Jet Cutting

The strengthening of water as primary power was firstly used in mining industry. It is used to wash out desired materials from rocks since 1850's. In a few years later, higher pressure and flow rate were developed for breaking the harder rocks and containing more coal and metals effectively. In period of 1950's, Dr. Norman Franz introduced high pressure water method which was used in various kinds of application. His study used the ultrahigh-pressure (UHP) water as a cutting tool for slicing thick trees into lumber (Flow International Corporation, 2002). Franz proved that a focused beam of water at very high velocity has enormous cutting power. In principle, waterjet system is a tool that is able to slice metal or other materials by using a jet of water at high velocity and pressure, or a mixture of water with an abrasive substance. The process is essentially the same as water erosion found in nature but greatly accelerated and concentrated. It is often used either during fabrication or manufacturing for machinery parts and other devices. It is preferred method for cutting materials which are sensitive to high temperatures.

Waterjet Technology

In waterjet cutting, water is directed at high pressure through an orifice ranging in diameter from 0.003 inches to 0.090 inches. Until recently, the speed of the stream was limited by pumping equipment which could provide only about 15,000 psi, which is inadequate for many applications. Today, with the availability of intensifier-type pumps, pressures as high as 60,000 psi result in an ultra-high-pressure stream. This stream, unlike a saw or a knife, can cut in any direction and is applied to a material in much the same way as a laser beam might. There are many advantages to this method of cutting, cleaner, more precise cut, no airborne dust, minimal material waste, easy shape cutting, no blade to require sharpening, easier cutting of soft or sticky material, no heat build-up,and no toxic fumes. There will be more to be said here about the advantages in food preparation and confectionery applications. In general, the cutting ability of the jet is directly proportional to the energy expended per unit length cut (Tangwarodomnukun, 2008). Thus, increasing the pressure and orifice diameter or lowering the feed velocity would increase the effective cutting thickness.

Waterjet system equipment

There are six major components in a waterjet system: the nozzle, the pump, the tubing, the catcher, the nozzle manipulator, and the cutting fluid. Figure 1 shows scheme of waterjet cutting system.

Nozzle (cutting head)
Basic principle of nozzle is that high pressure water enters the upper portion of the nozzle assembly and passes through a small-diameter jewel orifice to form a narrow jet. Mixing tubes are approximately three inches long, about 0.25" diameter with inside diameters that can vary from about 0.020" to 0.060". The normal standoff distance between the nozzle and the workpiece is usually between 0.01" and 0.1".

Pressure Pump
Generally, there are three types of pumps that can be used in waterjet cutting equipment, an intensifier type pump, a crankshaft type pump, and a direct drive type pump. One of them showing appropiate cost is a direct drive type pump. This pump is the 'low pressure' type sprayer that is commercially available in market for cleaning purpose. These types of pumps are simple and reliable and operate at 20-55,000 psi. The second one is intensifier pumps operating in the range of 40-87,000 psi. The third type of pump is a crankshaft type pump providing pressures to 55,000 psi.

Tubing (hoses)
Special hoses are capable to handle operation pressures up to 55,000 psi. These hoses are multi-walled and have burst pressure ratings in excess of 110,000 psi, making them especially suitable for hand tools and other slow moving applications.

Catcher
Catcher unit is a simple structure attached on the table acting like a dam for collecting the water in process. A draining hole was made on the table to drain water out through direcly to the catcher.

Nozzle manipulator
Nozzle manipulator unit based on three axis, in X, Y and Z direction. The manipulator is coupled to a support frame and configured to the position of nozzle. It allows nozzle to create complicated shape.

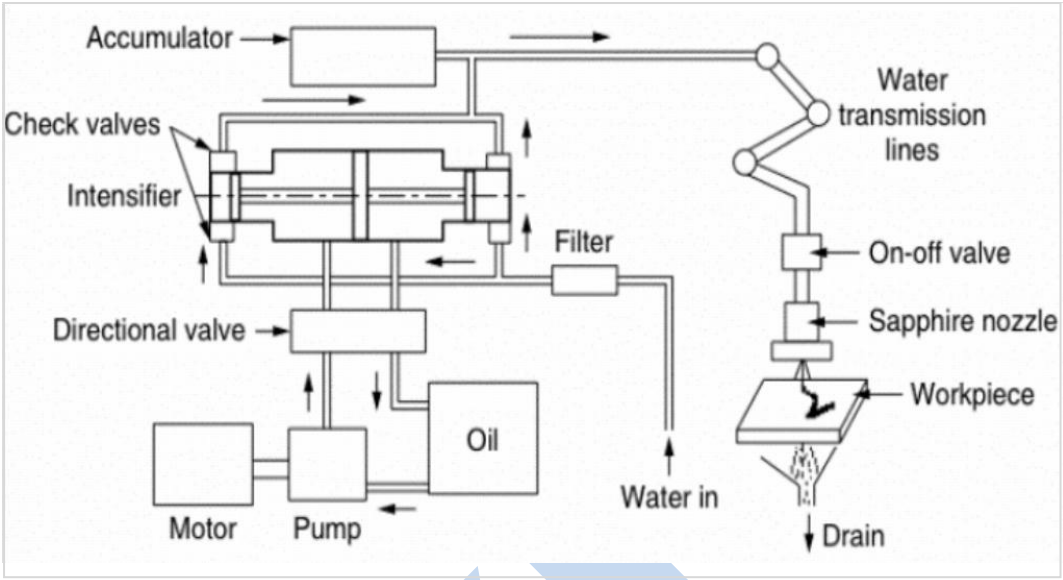

Figure 1. Schematic diagram of waterjet system (El-Hofy, H, 2005).

Cutting fluid
Most waterjet cutting theories explain waterjet cutting as a form of micro erosion. It means, pure water is used as cutting media. The water should be demineralized and purified to prevent stuck in nozzle.

2. Methods

The waterjet technology system is an alternative technology proposed in this study. In order to get a low cost waterjet system, a low pressure pump commonly used for household cleaning purpose with the maximum pressure of 110 bar is employed.

Polymer materials used in this experimental study as representative of agricultural products includes polycarbonate (PC), polystyrene (PS) and polyethylene (PE). In order to increase water beam cutting to agriculture products, some of waterjet system parameters were modified. The cutting parameters are stated at condition; manually tranverse with constant velocity, stand-off distance 15 mm, maximum water pressure 110 bar, and water flow rate. Result study of experiment was observed by evaluating ability of waterjet system to cut sample material, provide good surface profile quality, and not change natural color of products. The main components of waterjet system used in this investigation are shown as follow as:

1. Design of waterjet nozzle
Shavlovskii. (1972), stated that the adequate conical angle of nozzle used for cutting is 13°. In this study material of nozzle is made of brass having ability anti-corrosion and working presssure under 690 bar. Geometry of nozel was design in 0.5 mm orifice nozzle diameter and three various of nozzle tube lengths 1, 1.75 and 2.5 mm as shown in figure 2.

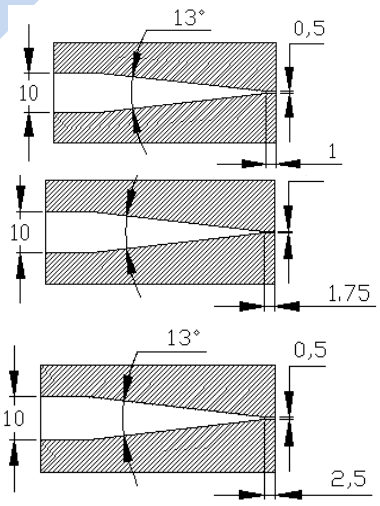

Figure 2. Design of waterjet cutting nozzle

2. Reciprocating pump
To increase water pressure, a reciprocating pump produced by Danish company nilsifk C 110.3 was used. Pump specification is:

Power : 1. 4 kW
Electrical current : 6A
Max. Capacity : 440 litre/h
Pump pressure : 110 bar
Pipe Length : 5 m

3. Pressure gauge
Pressure gauge is used to measure factual pressure during testing. By knowing initial pressure at nozzle prevents the pressure back. It takes into account due to the pump is completed by automatic stop. If the pressure increased rapidly to 110 bar, the pump will turn off. This pressure gage has ability to measure up to 3500 psi.

4. Connecting tube
The shape of connecting tube is a hollow pipe made of aluminium (Al) as shown in Figure 3. It delivers the water to the cutting head. For transporting high-pressure water, the connecting tube provides freedom of movement to the cutting head. It maintains the pressure flowing through a nozzle. Diameter of inlet pipe was designed according to orifice diameter of nozzle 10 mm and length 260 mm, working at high pressure more than 110 bar.

5. Flexible hose
The flexible host should be able to flow water from source site to nozzle with maximum pressure 35 MPa. The diameter is 8 mm and length 2 m. There are several steps of experiments preparation including purifying water to avoid stuck of nozzle, setting up equipment, and assembling all of component waterjet system as shown in Figure 4.

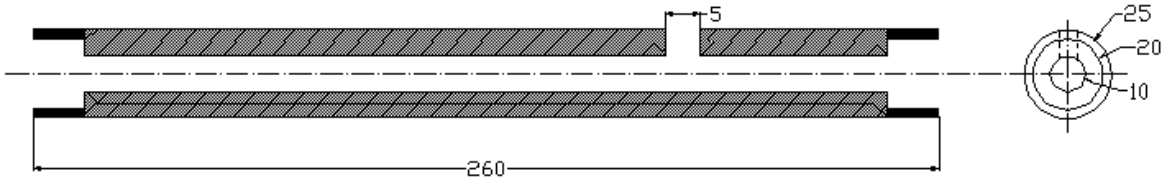

Figure 3. Connecting tube

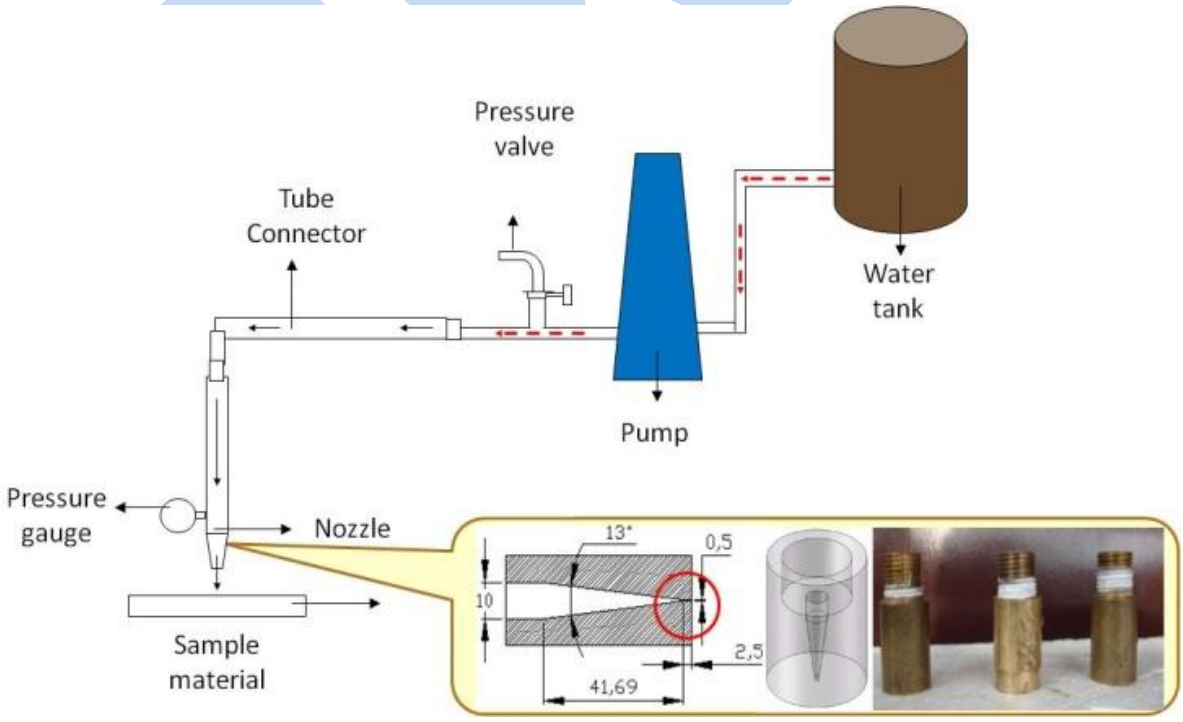

Figure 4. Apparatus scheme of waterjet system

3. Results and Discussion

According to experiment results, designed and manufactured waterjet systems are sufficient enough to use for cuttting agriculture product. Before going to consider on the waterjet possibilities, the structure of waterjet beam should be addressed to investigate, as shown in Figure 5. In waterjet system, modified nozzle is used to increase pressure impact on material. High pressure water is out from nozzle called beam. Waterjet beam produced by nozzle is classified into three main regions, initial, transitional and main regions. In the initial region, uniform distribution of waterjet velocity appears as waterjet core. It provides maximum velocity rather than any region. In the transitional region, a bell-shape of waterjet beam indicating the maximum velocity is in the middle of the short beam. Shortening the distance of beam will increase jet velocity and continuous flow still appears.

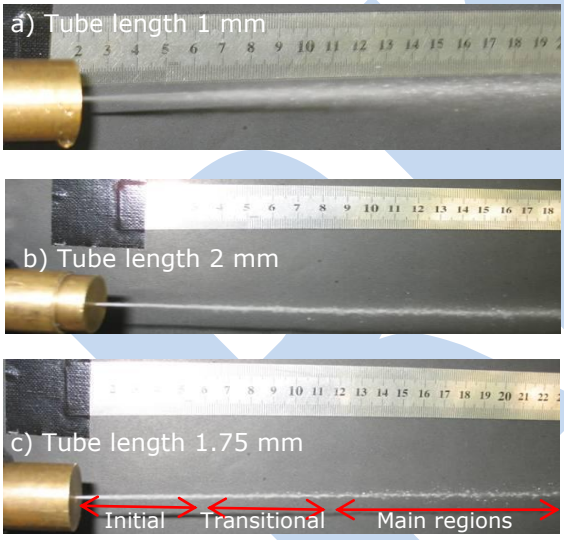

Figure 5. Structure profile of waterjet beam

In Figure 5a, nozzle with conical angle 13° to 1 mm tube length presents short and random spread water beam. However, water beam is still formed in the core of waterflow. This type of flow is not good used to cut because it results in low impact to material. A better result is presented by nozzle with tube length 2 mm, as shown in Figure 5b.

It provides straight line water beam at initial region coming out from nozzle. The length of water beam formed is quite long before waterjet speed reduced. In Figure 5c, waterjet beam formed presents more length compare to the previous nozzle. This nozzle has tube length 1.75 mm. So the appropriate tube length for this water jet system is 1.75 mm. Once the tube length increased, the waterjet beam formed are shortened and dispersed.

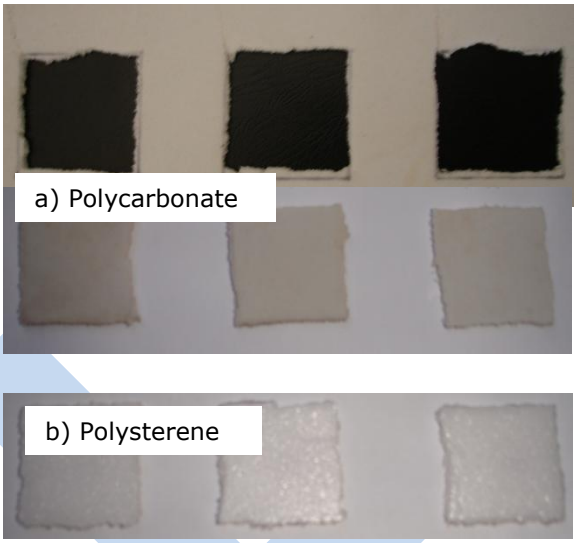

Figure 6. Profile of waterjet beam cutting

Ideally in waterjet cutting process, the waterjet flow should form a water beam with appropriate length at intial region. It is due to around this region, water flow present the maximum speed that creates high momentum impact compare to that at transition and main region.

In contrast, waterjet spread dispersed at both regions. Based on calculation used referring to primary equation, Continuity law stated that mass at inlet equal to mass at outlet. Bernoulli's equation stated total pressure is constant. Flow rate (Q) is $2.26 \times 10\text{-}5$ m^3/s and cross-section area of nozzle is 0.2 mm^2. Hence, waterjet velocity (v) is found around 115.16 m/s. In term of relationships between waterjet velocity and pressure (P), it is stated that calculated pressure is 66.3 Pa and used energy is PWRwaterjet = 2446.7 watt. Then, waterjet force presented (Fbt) is 0.0425 N. Experimental study shows that waterjet system is able to cut polymer material with thickness 2 mm. It works for polycarbonate and polysterene, but is not sufficient enough for polyethelene materials, as shown in Figure 6.

4. Conclusion

A low cost waterjet system has been developed and has been briefly described because its performance shows sufficient promising. Main power of water pressure is

provided by a commercial pressure pump which is available in the market for cleaning purposes. To increase water pressure that came out from pump, the modified nozzles were introduced. Pressured water, orifice nozzle diameter, stand-off distance between nozzle and materials have been set at certain level. Experimental result shows waterjet cutting system able to cut three various polymer materials as representative of food. The water jets can be used to improve cutting finished surface of agricultural products. Therefore, utilizing a low cost commercial pump and modified nozzle for waterjet system reduces equipment price, operational cost and environmental hazards. It shows viable technology applied to substitute traditional cutting technology in post harvest agriculture products.

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