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Design and experimental verification of a small sized machine for making Vietnamese fresh *Bun* rice noodle

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Abstract Fresh *Bun* is the quintessence of Vietnamese cuisine. Nowadays in Vietnamese, fresh *Bun* has been produced by specialized production lines in factories. In other Asian countries, *Bun* is mostly imported from Vietnam and Thailand in a dried form. Customers prefer fresh *Bun* over dried one due to its different taste and combination with other cooking ingredients. In order to produce fresh *Bun* directly in restaurants and hotels, the *Bun* making machine must be small enough and have suitable power consumption to be installed and operated in these environments, while having the same quality as *Bun* produced by the industry. The proposed design therefore has the following technical specifications: Length: 1000 mm, Width: 500 mm, Height: 1350 mm, main materials: Stainless steel 316 (SUS 316), *Bun*'s diameter: 1.5 mm; 2.0 mm; 2.5 mm**,** Elasticity: 5000 - 5500 Pa**,** Color: White, Capacity: 20 Kg/hour. The machine has been built and experimentally verified, and the fresh *Bun* produced by the machine has the same quality with the industrially produced *Bun*.

Keywords: *Bun*, swelling factor, screw extruder

Introduction

Fresh *Bun* is a type of Vietnamese rice noodle used to make soup with sprouts, dill, split water spinach, cilantro, onion and broth and either beef or pork. It is convenient, easy to cook, delicious and nutritionally rich product and is now gaining great appraisal outside Vietnam. Fresh *Bun* is different from other Vietnamese rice noodle due to its production technology and the rice type used to make it. Currently, fresh *Bun* is produced in industrial environment with available high-power machines. Small sized machines that can be placed in restaurants to produce fresh rice *Bun* noodle directly to serve customers is still a challenge. The developed small sized machines were found suitable to address the needs for restaurants and hotels in the world.

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Vietnamese fresh rice noodle has many types as *Pho*, *Bun*, *Banh hoi*, *Hu tieu*, which are categorized according to making processes. The process of making Bun is illustrated in Figure 1.

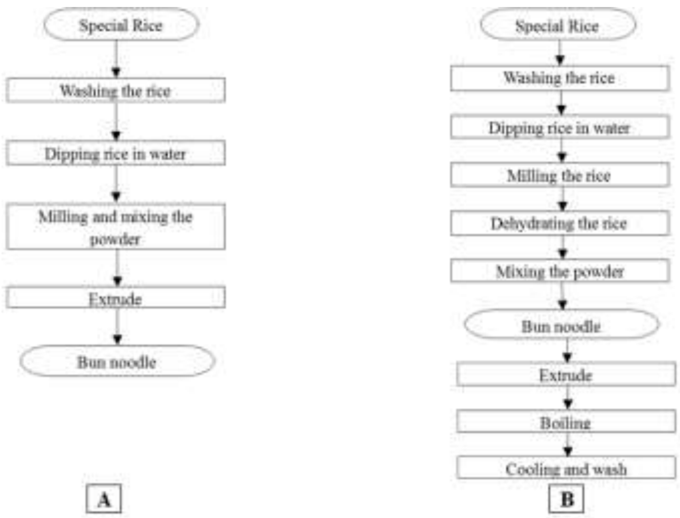


Figure 1. Making Processes of Fresh Bun Rice Noodle A-in proposed machine, B-in conventional industry

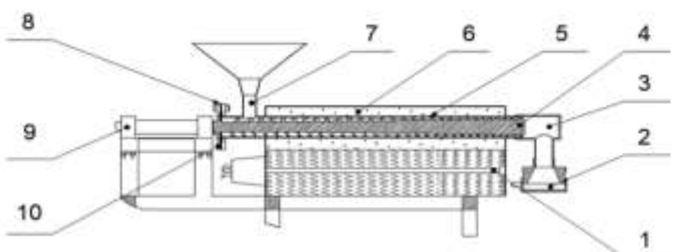


Figure 2. Equipment used in industrial production 1-Electrical resistor, 2-Extrusion mold, 3-Cylinder's cover, 4-Rice powder,5-Screw extruder, 6-Water, 7-Liquid powder feeder, 8-Seal housing, 9-Bearing, 10-Seal

Figure 2 showed the structure of the conventional industrial machine. When heating, the temperature of the screw extruder is the same along its longitudinal direction, it is usually from 75^0 C to 80^0 C. The *Bun*'s surface in contact with the inner surface of the cylinder can reach up to 95^0 C. The 75^0 C – 95^0 C range can complete only about 50% of *Bun* cooking, so the extruded *Bun* must go through further boiling. If heating is over 100^0 C, the powder is instantly solidified and burnt, and it gets stuck in the cylinder and making the process of detaching from the screw extruder difficult.

The proposed machine is not a miniaturized version of its industrial counterpart but an entirely new design with an optimized heat transfer process suitable for swelling the rice (Bhesh *et al.*, 2013), and also is capable of changing key parameters like heat and pressure while maintaining product's quality. With this design, fresh Bun produced with the proposed machine does not need further boiling as in industrial production process.

Rice grain is the base ingredient for making *Bun*, which has a long round appearance and is highly expansive after cooking. The type of used rice is not sticky but dried rice.

The South Vietnamese market has many brands of rice, such as *504* and *Long Dinh*, while northern markets usually provides *DT10, CR203, 13/2, Moc Tuyen, VN10* and *Khang Dan* brands. In the United States there are many types of long grain rice imported from Mexico, Thailand and India that can be used to make *Bun* like *Basmati* (India), *Sarita* (Mexico). In Japan there is *Yume Toiro*, and so on.

The starch content in rice is around 60%, protein is from 7,57% to 10,84% and amylose is higher than 25% (Hoang and Ngo, 2006), (Juliano, 2004).

Materials and methods

Parameters requirement

Fresh *Bun* produced with the proposed machine should satisfy the technical and microbiological requirements is given in Table 1.

Table 1. Specifications for a small sized machine and produced *Bun*

Specifications for small sized machine		**Required Specifications for Bun**	
Length of a Machine (mm)	1000	***Bun*'s diameter (mm)**	1.5; 2.0; 2.5
Width of machine (mm)	500	**Elasticity (Pa)**	5000 – 5500
Height of machine (mm)	1350	**Color**	white
Production capacity (kg/hour)	20	**Microbiological indicators**	46/2007/QĐ-BYT

Conceptual design

Principles

In industrial production line, in addition to extrusion process performed by the screw extruder, there was pressing process performed by a piston-cylinder structure as illustrated in Figure 3.

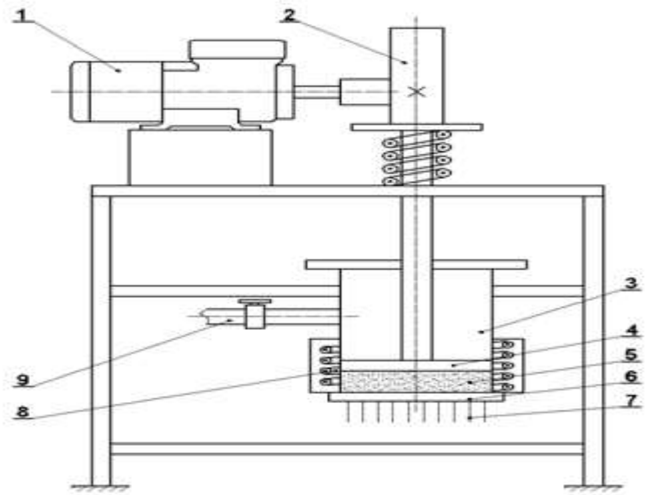


Figure 3. Fresh *Bun* pressing process by a piston – cylinder 1-Electric Motor, 2-Cam mechanism, 3-Cylinder, 4- Piston, 5-Rice Powder, 6-Mold, 7-Fresh Bun, 8-Electrical resistor, 9-Rice powder feeder

This process was simple in principle but difficult to design the mechanism and optimize the heat transfer process. Furthermore, it is complicated and time-consuming to clean the machine after shifts, and therefore unsuitable for restaurants and hotels environment.

In order to satisfy the specifications in Table 1, in the proposed design illustrated in Figure 4, the milled rice powder is poured into the feeder (5), and the extrusion screw (7) is heated by water boiled by the electrical resistor (3). When the temperature of water reaches 90^0 C, a valve on the feeder is opened and liquid rice powder flows into the cylinder. The motor (1) is turned on to actuate the screw driven by belt mechanism (2). Initially, the frequency converter is set to 20 Hz and the screw rotates slowly to convert the liquid rice powder to a solid form. After a few minutes, the frequency converter is set to 30-32 Hz. The cooked powder is forced through the hole in the mold (13). Fresh *Bun* falls into the sink and is ready for use. If fresh *Bun* elasticity was not satisfactory, the cover (12) can be tightened or loosened manually to increase or decrease the extrusion pressure.

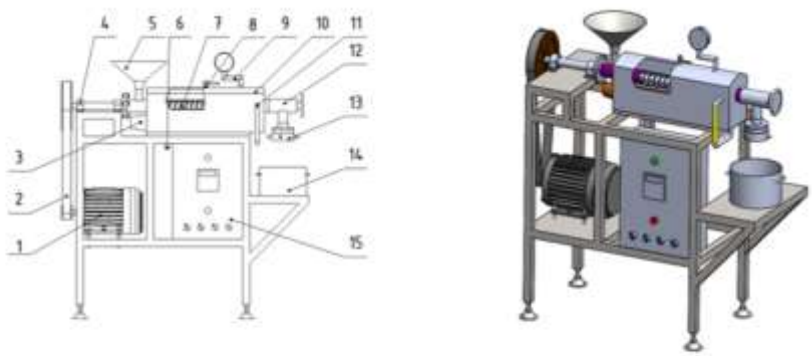


Figure 4. Schematic diagram of the proposed machine 1-Electric motor, 2-Belt drive, 3-Heating resistor , 4-Bearing housing, 5-Rice powder feeder, 6-Water outlet, 7-Screw shaft, 8-Water inlet, 9-Temperature gauge, 10-Water tank, 11-Water level indicator, 12-Cylinder's cover, 13-Mold, 14-Production tank , 15-Electric box.

Specific design

Cylinder Design

The cylinder encloses the extrusion screw, so that the rice powder can be compressed and moved from the feeder to the mold. In addition, the cylinder's wall acts as a medium for heat transfer from the boiled water to the extrusion screw. The structure and size of the cylinder corresponds to the change in the structures of the rice powder under the effect of heat illustrated in Figure 5.

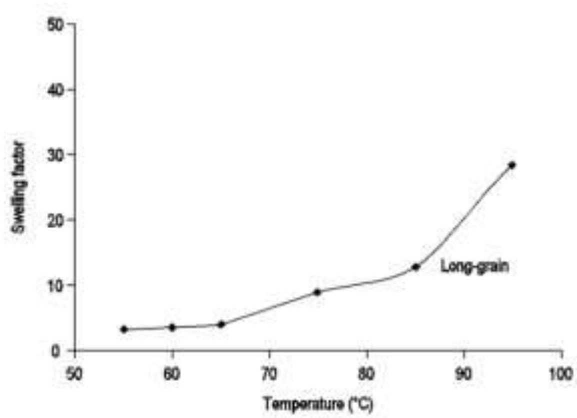


Figure 5. Swelling factor of rice type long grain (Bhesh *et al.*, 2013)

The long - grain curve in Figure 5 described the change in expansion of the powder by temperature. By considering that the temperature of steam is unchanged, the thickness of the cylinder's wall must change in order to provide different temperature range that corresponds with the temperature range shown in Figure 5.

The cylinder made of SUS 316 has a shape in Figure 6; inside radius r_1, outside radius r_2, mean radius r, thermal conductivity λ constant, temperature at walls t_{w1} and t_{w2}. Differential equation for heat conduction is given by (Mohr and Mallouk, 1959):

$$\frac{\partial t}{\partial \tau} = a \times \left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r} \times \frac{\partial t}{\partial r} + \frac{1}{r^2} \times \frac{\partial^2 t}{\partial \varphi^2} + \frac{\partial^2 t}{\partial z^2}\right) \quad (1)$$

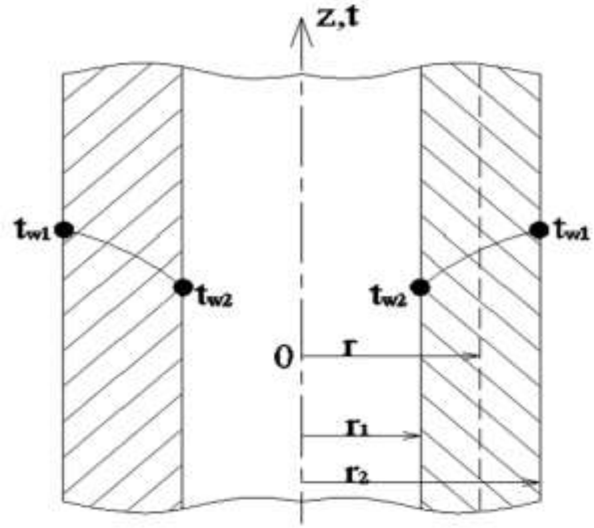


Figure 6. Structure of the cylinder used in calculation

The heat in the steamer should follow the long-grain line in Figure 5 to gradually swell and achieve good texture and elasticity after cooking. From this long – grain line, it can be seen that the expansion of flour during the ripening process did not change much between 55^0 C and 65^0 C, and began to vary gradually in the range 65-85^0 C, then changed rapidly in the range 85 -100^0 C. Therefore, during the ripening process, the amount of heat that the powder receives to increase its temperature should be appropriated to maintain the quality of *Bun*.

The slurry is boiled and cooked by steam during the process through the screw extruder. At the end of the process, *Bun* was ready to use and re-boiling or cooking are not required.

By assuming that the heat transfer through a cylinder radially in a steady state, the unidirectional condition is given by:

$$\frac{1}{r} \times \frac{dt}{dr} + \frac{d^2t}{dr^2} = 0 \qquad (2)$$

Conditions $t_{r=r1} = t_{w2}$ and $t_{r=r2} = t_{w1}$ lead to:

$$t = t_{w1} - \frac{t_{w1} - t_{w2}}{ln\frac{r_2}{r_1}}\ ln\frac{r}{r_1} \qquad (3)$$

Table 2 showed the parametric values for the cylinder design, where the thickness of cylinder's wall is $\delta = r_2 - r_1$.

Table 2. Outside radius design of the cylinder following Figure 5

t_{w1} (°C)	**100**	**100**	**100**	**100**	**100**	**100**	**100**
t_{w2} (°C)	55	60	65	70	75	80	85
t (°C)	60	65	70	75	80	85	90
r_1 (mm)	21	21	21	21	21	21	21
r_2 (mm)	26	25,39	24,79	24,2	23,63	23,07	22,53
r (mm)	25,39	24,79	24,21	23,63	23,07	22,53	22,01
δ (mm)	4,39	3,79	3,21	2,63	2,07	1,53	1,01

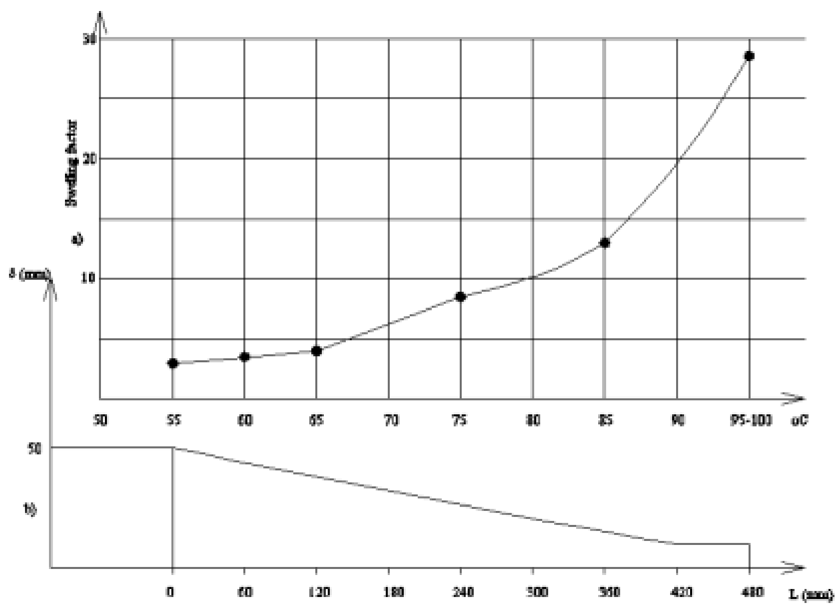


Figure 7. Cylinder's thickness satisfying Figure 5

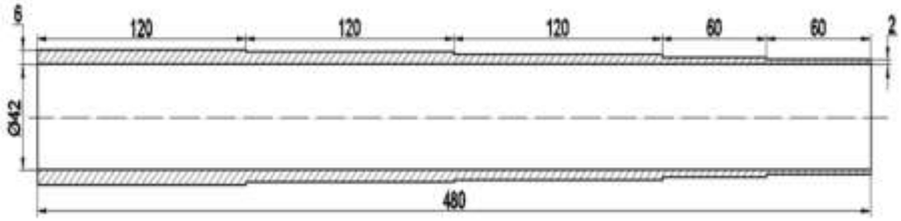


Figure 8. Cylinder structure corresponding to Figure 7

The cylinder shown in Figure 8, its diameter varied along its length to simplify the manufacturing process, although there were only 5 temperature regions in the real cylinder as opposed to 6 regions given in Figure 7. The resulting effect was acceptable. In addition to changing the outside dimension of cylinder, it was able to change the temperature that acts on the cylinder along its longitudinal direction.

Design of screw extruder

Extrusion is carried out by a single-screw extruder illustrated in Figure 9, which has the following parameter values:

Compression ratio of the screw: 2.58

Barrel diameter: D = 41.5 mm

Input core diameter: D_a = 21 mm

Output core diameter: D_b = 35 mm

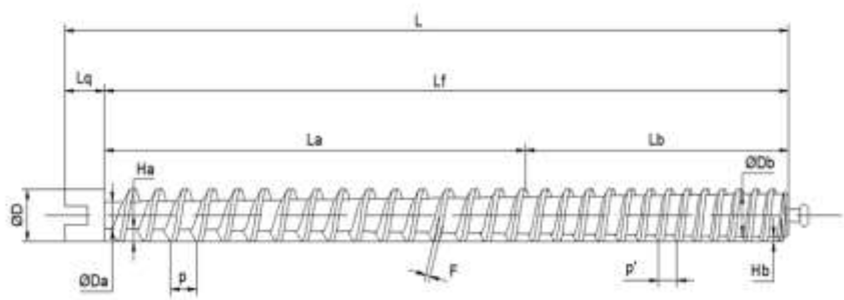


Figure 9. Screw Shaft

Design of enclosed steam chamber

The input parameters used to calculate heat and heat loss of the machine given in Table 3. Table 4 showed the results for heat and heat loss calculation.

Table 3. Parameters values used for design of steam chamber

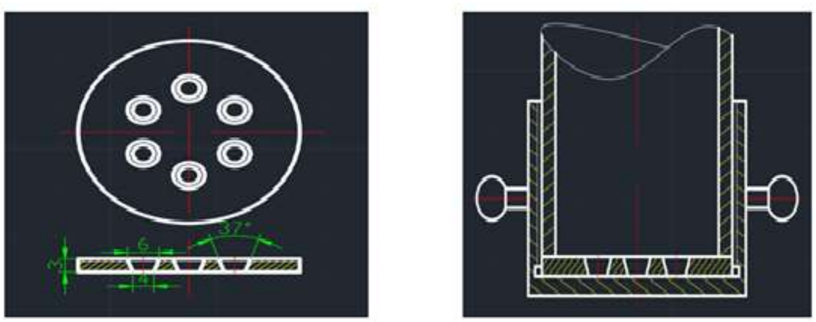
Number	Parameter for calculation	Symbol	Value	Unit
1	Dimension of steam chamber	L x W x H	420 x 140 x 150	mm
2	The height of water in the chamber	H_{nc}	100	mm
3	Temperature of environment	t_{mt}	25	^oC
4	Elevated temperature of water	$t_s = t_{w1}$	110	^oC
5	Saturated pressure of water at 110 ^oC	p_{bh}	1.4326	bar
6	Specific heat of water	C_{pnc}	4.18	kJ/kg.K
8	Density of water	ρ_{nc}	1000	kg/m^3
9	Specific heat of steel SUV 304	c_{ptv}	0.46	kJ/kg.K
10	Specific volume of steel SUV 304	ρ_{tv}	7850	kg/m^3
11	Specific heat of steel used to make the chamber	c_{pb}	0.5	kJ/kg.K
12	Specific volume of steel used to make the chamber	ρ_b	7980	kg/m^3
13	The coefficient of convection of air	α_2	10	W/m^2 K
14	Thermal conductivity coefficient of SUV 304	$\lambda_1 = \lambda_3$	16.3	W/m. K
15	Thermal conductivity coefficient of insulator	λ_2	0.0425	W/m. K
16	Time to boil water to 110^{o}C	τ_1	8	minute
17	Specific heat of flour mixture	c_{pbot}	2.76	kJ/kg.K
18	Density of powder mixture	ρ_{bot}	1020	kg/m^3
19	Machine productivity	G_{bot}	20	kg/h
20	Temperature on the outside surfaces of the chamber	t_{w4}	40	^oC
21	Shell thickness of chamber	δ_1	3	mm
22	Thickness of stainless steel layer wrapped outside the chamber	δ_3	1	mm

Design of noodles mold

The quality of the *Bun* depends on the size, roughness and delivery ducts of the mold, which can be achieved by machining the mold with either High-Speed Machining or Electrical Discharge Machining (López De Lacalle *et al.*, 2002). The design of the mold must ensure that the *Bun* has good appearance and is smooth on the surface, and the fiber flows out of the mold quickly and easily. The design of the mold for 4 mm fresh *Bun* is given in Figure 10, which has hole-shape conical cylinder and the *Bun* is easy to pass through the holes.

Table 4. Design of noodles mold

Number	Values need to calulate	Symbol	Equation	Value	Unit
1	The mass of water in the chamber	G_{nc}	$V_{nc}.\ \rho_{nc}$	5.88	kg
2	Heat to boil the water	Q_{nc}	$G_{nc}.c_{pnc}.\Delta t$	2104.16	kJ
3	The amount of heat to heat the screw	Q_{tv}	$G_{tv}.c_{ptv}.\Delta t$	79.33	kJ
4	The amount of heat to heat the cylinder	Q_v	$G_v.c_{pv}.\Delta t$	49.72	kJ
5	The amount of heat to heat the chamber	Q_b	$G_b.c_{pb}.\Delta t$	282.2	kJ
6	Total heat to boil the water	Q_1	$Q_{nc} + Q_{tv} + Q_v + Q_b$	2515.41	kJ
7	Power consumption of resistors	P_{dt}	$\frac{Q_1}{\tau_1}$	5.24	kW
8	Thickness of wool insulator layer	δ_2	$q = \frac{t_{w1-}t_{w4}}{\frac{\delta_1}{\lambda_1}+\frac{\delta_2}{\lambda_2}+\frac{\delta_3}{\lambda_3}}$	22	mm
9	Heat loss in τ_2 = 1 hour	Q_{mt}	$q.F.\tau_2$	259.2	kJ
10	Total heat needed in τ_2 = 1 hour	Q_2	$G_{bot}.c_{pbot}.\Delta t$	4692	kJ
11	Total heat consumed in τ_2 = 1 hour	Q_t	$Q_{mt} + Q_2$	4951.2	kJ
12	Working time of resistors in τ_2 = 1 hour	τ_3	$\frac{Q_t}{P_{dt}}$	15.75	minute



C D

Figure 10. *Bun* mold C- The arrange the hole on the mold, D- Extruder assembly

Results

Special rice collected from markets is usually the 504 type of Vietnam and the long grain rice Sarita of Mexican and American Markets. Rice is dipped in the water for 6 hours and it is milled (Figure 11) by the wet method with 1:1 ratio (rice/water). The moisture content of the slurry is maintained within the range of 50–55%. After the proposed machine was fabricated (Figure 12), fresh *Bun* was produced (Figure 13) in order to evaluate the reliability of the machine and the quality of fresh *Bun*.

Quality analysis of fresh Bun

There are many factors that determine whether the fresh Bun satisfies the requirements in Table 1 or not. Ultimately, the fresh Bun must also satisfy the customers in term of taste and food safety. The following three factors that affected to the quality of Bun are considered in this study.

Material viscosity, too high viscosity of material causes damage to the machine and making it difficult to press. In contrast, if the viscosity is too low, the molecules are less flexible, so they are difficult to align with each other to make the bond tight, making Bun cracked.

The temperature of the gelatinization of the powder in the screw: High gelatinization temperature of the powder in the screw makes the water molecules more dynamic, and it easily diffuses into the powder mix to shorten the gelatinization time. However, if the gelatinization temperature is too high, it hydrolyzes the starch and affects the toughness of the vermicelli later. In contrast, low temperature slows down the gelatinization time. If the temperature is too low, it cannot gelatinize the powder. Rotational speed of the screw extruder: Together with the gelatinization temperature, it determines whether the slurry is completely gelatinized and cooked or not.

Figure 11. Rice milling machine

Figure 12. Proposed fresh *Bun* making machine prototype

Figure 13 E-Small sized machine in the process of making *Bun*, F-Produced fresh *Bun*

Sensory evaluation

Sensory evaluation is an important criterion for the final acceptance of food quality. After introducing new processing equipment, it is essential to check the consumer acceptability of the processed products, in terms of "color", "taste", "texture" "overall acceptability", and so on. For fresh Bun, four samples were produced using the same type of rice (504 brand), using the same milling equipment and with the same moistures for the powder. The machine temperature setting is different for each sample. Sample 1: $T = 90^0 C$, sample 2: $T = 95^0 C$, sample 3: $T = 100^0 C$, sample 4: $T = 105^0 C$. The evaluation team of four people judges the sample 2 to be the best, with similar qualities to sample 5 obtained from the market. The sample 2 is then used to analyze the quality of the products.

Microbiology of Bun

TỔNG CỤC TIÊU CHUẨN ĐO LƯỜNG CHẤT LƯỢNG
TRUNG TÂM KỸ THUẬT TIÊU CHUẨN ĐO LƯỜNG CHẤT LƯỢNG 3
QUALITY ASSURANCE & TESTING CENTER 3
QUATEST 3

KT3 – 03377AVS8 | PHIẾU KẾT QUẢ THỬ NGHIỆM / TEST REPORT | 24/09/2018 Page 01/01

1. Tên mẫu / *Name of sample* : BÚN
2. Mô tả mẫu / *Sample description* : Mẫu thử nghiệm do khách hàng lấy mẫu, tên mẫu và thông tin về mẫu do khách hàng cung cấp./ *Testing sample was sampled by customer, sample name and sample information were supplied by customer.* Mẫu dựng trong hộp nhựa./ *As received sample contained in plastic box.*
3. Số lượng mẫu / *Quantity* : 01 (500 g)
4. Ngày nhận mẫu / *Date of receiving* : 15/09/2018
5. Thời gian thử nghiệm / *Testing duration* : 17/09/2018 – 24/09/2018
6. Nơi gửi mẫu / *Customer* : **HO CHI MINH UNIVERSITY OF TECHNOLOGY 268 Ly Thuong Kiet, Ward 14, District 10, Ho Chi Minh City**
7. Kết quả thử nghiệm / *Test results* :

Tên chỉ tiêu / *Characteristic*		Phương pháp thử / *Test method*	Kết quả thử nghiệm / *Test result*
7.1. Tổng số vi sinh vật hiếu khí / *Total aerobic plate count*	CFU/g	ISO 4833 - 1 : 2013	$4,5 \times 10^2$
7.2. Coliforms,	CFU/g	ISO 4832 : 2006	< 10 (*)
7.3. *Escherichia coli*,	CFU/g	ISO 16649 – 2 : 2001	< 10 (*)
7.4. *Staphylococcus aureus*,	CFU/g	AOAC 2016 (975.55)	< 10 (*)
7.5. Tổng số nấm men, / *Total yeast,*	CFU/g	ISO 21527 – 1 : 2008	< 10 (*)
7.6. Tổng số nấm mốc, / *Total mould*	CFU/g	ISO 21527 – 1 : 2008	< 10 (*)

Ghi chú/*Notice*: (*) Theo phương pháp thử, kết quả được biểu thị nhỏ hơn 10 CFU/g khi không có khuẩn lạc mọc trên đĩa. / *According to the test method, the result is expressed as less than 10 CFU/g when the dish contains no colony.*

PHỤ TRÁCH PTN VI SINH - GMO / *HEAD OF MICROBIOLOGY - GMO TESTING LAB.*
Trần Thị Ánh Nguyệt

TL. GIÁM ĐỐC/ *PP. DIRECTOR*
TRƯỞNG PHÒNG THỬ NGHIỆM/ *HEAD OF TESTING LAB*
Ngô Quốc Việt

Figure 14. Test on microbiology content of *Bun*

Bun sample tested satisfied all requirement for microbiological content according to the standard set by Vietnamese Ministry of Health (Fig.14).

__Tensile stress of Bun__

The experimental setup for testing samples 2 and 5 is shown in Figure 15. The results were similar to each other so this paper only showed the testing result for sample 2 in Figure 16 and Table 4. Bun produced using the proposed machine has similar physical properties to Bun currently sold in the market, the machine enables to provide the satisfactory results.

Figure 15. Experimental set-up

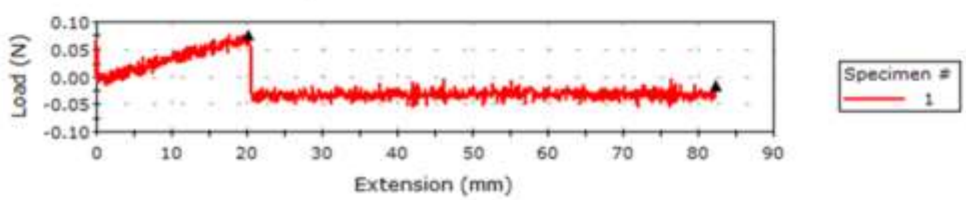


Figure 16. Tensile stress and extension of Bun samples 2 and 5

Table 5. Testing results for sample 2

	Specimen label	Load at Break (Standard) (N)	Maximum Load (N)	Tensile stress at break (Standard) (MPa)	Tensile extension at maximum load (mm)	Extension at break (Standard) (mm)	Tensile extension at break (Standard) (mm)	Tensile stress at maximum load (MPa)
Mean Value	Bun	-0.02	0.07757	-0.00533	20.1014	82.30218	82.32018	0.02469

Discussion

The developed small sized machines were found suitable to address the needs for restaurants and hotels in the world. The originality of study is that cylinder structure is calculated following the swelling of the long-grain rice (Bhesh *et al.*, 2013).This reaserch is not found in any reference cited and this study is different with industrial cylinder structure. Due to the thermal analysis and calculations performed in this article, quality of Bun is maintained with short heat exposure duration, and Bun produced does not need a following boiling operation. Other calculations performed in "Design of enclosed steam chamber" section are similar to other references (Yunus, 2003). The Bun noodle is produced with the proposed small sized machine satisfies sufficient textural and physical properties and safe microbiological content. The proposed small sized structure and the power source requirement ensure that most home, hotels and restaurants can afford to install and operate it. In addition, customers can enjoy seeing the process while eating.

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Number of topic: 09/2018/TN

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