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Research Article

Design the semi-automation shrimps tempura frying production line

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ABSTRACT

Currently, Tempura shrimp consumption is very high in most Japanese restaurants all over the world. There are many companies that produce Tempura shrimp to provide for many restaurants as well as to sell in many supermarkets in many countries. In fact, the benefits of this product are enormous for the seafood industry in Vietnam as well as in other countries. However, most of the companies that produce the Tempura shrimps manually by workers. There are a lot of workers who fry shrimp manually to keep the company productive. The quality of this product also bases on the skill of the workers. And, to satisfy the condition of mass production, the enterprise also needs the very large area to set up the workplace for the workers. Secondly, this situation leads to the practical results that the quality of Tempura shrimp is not identical, unstable and the amount of waste is very high. Therefor, the requirement for the application of automatic control system in this tempura field can help the company to solve these difficult problems. This issue is the primary focus of this document. It is the situation of the Tempura fried shrimp companies which lead them to implement automated systems to replace unskilled workers. This paper presents the design of the whole semi automation single-side Tempura shrimp frying production line to propose some innovation about the shrimp tempura frying process. The entire Tempura semi automation production line consists of 3 main modules. Each module can operate as an independent machine. The workers just put the coated shrimp in the molds and then the frying process will perform the remaining steps automatically. The first module (Module 1) is the shaping module or the first time frying module. The powder solution also installed with this module. The second module (Module 2) is the finished frying module. Finally, the oil drainning module (Module 3) using the technique of the hot heating airflow system to drain the excess oil inside the Tempura shrimps.

Key words: Shrimps tempura, mechanical design, automation, modules, frying, system

LITERATURE REVIEW AND INTRODUCTION

In Japanese cuisine, Tempura is one of the most popular dishes that is frequently mentioned. The production of tempura is quite simple. Fishes, prawns, and vegetables are cut to size for eating with chopsticks, then dipped in a bowl of Koromo (batter), a coating of eggs and flour mixed with cold water, then fried in hot vegetable oil [1]. The delicious results in tempura cooking are created by the fact that the coating preserves the natural tastes while absorbing the oil… One of the most popular Tempura is Shrimp Tempura. This is a dish where the shrimp are mixed with a mixture of tempura powder solution and then fried with hot vegetable oil.

Solahudin, M *et al.* [2] believes that manually counting for shrimp fry should be replaced by automatic systems because it still contains many drawbacks when the whole deep-frying process fully depends on human beings, such as subjectivity in counting, time payload, exhausted in counting and inadequate accuracy, especially in calculate large quantities of shrimp fry which is a common sense in the food industry where numbers of shrimps are processed during a day. Because of that, the main goal of the mechanical design of the deep-frying system is to ensure the quality of the products after being processed, which means that the outcomes should satisfy two standards: Taste and Texture. Especially for food manufacturing companies where the texture of the products is as important as its taste. On the other hand, the deformation of metals due to temperature is the other thing that should be concerned when designing the frying system since the temperature of frying oil usually stays at around 175^0C. Nowadays, there are many published suggestions on how the frying system should be designed in other to satisfy mentioned conditions. Banks, D *et al.* [3] indicates conveyor systems can be applied as a new approach to the deep-frying method, which concept is to convey products through hot frying oil. To be specific, product items are loaded onto

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a conveyor belt before being moved through the frying oil environment without contacting other product pieces. Furthermore, according to[3], in order to obtain the uniform color of the fried product, a perforated baffle plate under the product conveyor can be installed to ensure the bottom layer of the processing product is cooked evenly. Also, Rywotycki, R *et al.*[4] states that the conveyor velocity plays an important role in the outcome of the finalized product. The optimized traveling speed of the conveyor can not only bring the perfect taste to the tempura shrimps but also improve economic indices due to decreasing energy consumption during the frying process. However, there are also some drawbacks like the conveyor material can affect the quality of frying oil, leading to the inappropriate taste of the final product and even health risk. On the other hand, the type of conveyors that can be applied to fryer design is also not mentioned. It also states in material[3] that the finish frying area plays an important role in the frying system, regarding fryer control and changes those products may occur. The main purpose of this area is to prevent the product from being removed just as the finish fryer begins, so it can enhance not only the flavor, color but also the texture of the finished product. Another factor that needs to be included is that the movement of the product through this specific area should be carefully executed due to support the outcome texture.

It is common for the industrial fryer to work under high- temperature oil for hours, specifically, around 150^0C as mentioned above for oil used in the deep-frying techniques. As a result, the deformation of elements like metal beams in the frying system needs to be carried out. In addition to this problem, H, Conrad *et al.*[5] states that the plastic deformation of metals is not only dynamic but also time-dependent, which means that the dislocation of a metal beam behaves randomly under high temperatures. They also propose that using alternative mechanisms can benefit the rate-controlling deformation of other beams. However, this is just a theoretical approach to this specific problem since no field experiments have been carried out. Furthermore, the idea of using alternative mechanisms is not an optimized solution since there is a lack of experiments proving that the mentioned idea would be appropriate enough to be applied in real cases.

As mentioned above, the inappropriate material of system components could not only impact the final product quality but also the health problems of customers. Additionally, M.S.Jellesen *et al.*[6] states that consumer health could be endangered by metal release, which is caused by material degradation. They also suggest that stainless steel types AISI 304 and AISI 316, is the most utilized metallic material used in the food industry[7]. In addition, it has been demonstrated that corrosion problems of stainless steel can be avoided by applying appropriate design or strict cleaning protocols and also suitable materials. In most cases, stainless steel is always chosen as the most suitable material to manufacture the machinery or equipment used in the food industries. In practice, corrosion of stainless steel is based upon the quality of the stainless steel brand. If the ingredient of the AISI 304 or AISI 316 is fabricated in the correct amounts and method, the corrosion of the material can be avoided in such a harsh working environment of the seafood industries.

An example of a frying system can be shown by H.Wu *et al.*[8], which is a two-dimensional frying model used for processing potato slices. The concept of this system can be separated into three sections, the combustor at first, followed by the oil heat exchanger and the fryer, respectively. In the combustor section, natural gas with fresh air and foul gas is burned by the gas burners before flowing through a heat exchanger to heat up the frying oil which is re-circulated through the fryer. After being fried, potato crisps are being left alone allowing the cooling process to take place naturally. There are still some improvements that should be considered. Complex equipment used for heating the frying oil can be replaced by thermistors which are more convenient to install and control the oil heat. On the other hand, for some specific products, the natural cooling process allows the oil uptake to decrease the crispy, crunchy behavior of finalizing products, especially for those that are being cooked by the deep-frying method. Furthermore, frozen food packaging is widely applied nowadays, meaning that after being processed, the products are usually moved to a freezer room which reduces the crispy texture of finalizing food. As a result, a forced air cooling system should be designed to tackle this problem.

Another factor that must be included when designing the frying system is the safety aspect. According to S.P.Kochhar *et al.*[9], a filtration system should be installed for the removal of debris which can cause smoking, charring, darkening, and lowering the quality of frying oil, leading to the adverse effects of the finished product. Apart from that, D. G. f. F.e *et al.*[10] suggested that a fume hood should be placed above the fryer to avoid inhaling toxic fumes that bring many negative effects to factory workers' health. Our shrimps Tempura frying process is shown in Figure 1 below. First, shrimps are preliminarily processed through different stages before frying. Then,

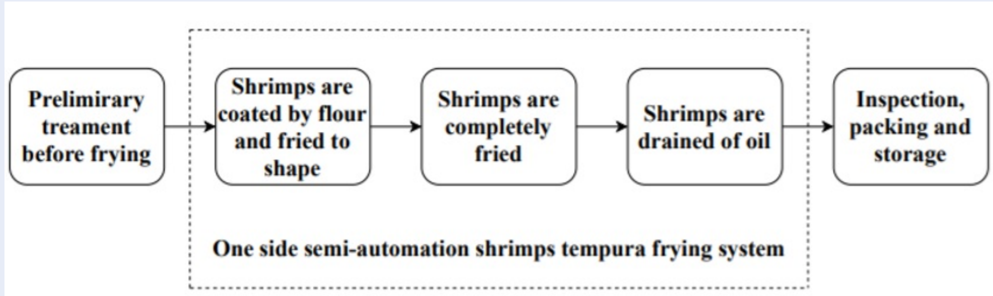


Figure 1: The whole process of the proposed system

they are put into frying tanks troughs by workers. During this frying process, shrimps are sprinkled with flour to create the outer dough. Then, the shrimps are transferred to the second frying tray to be deep-fried. Then, shrimps are dried to drain oil. Finally, the finished products are tested by some food safety standards or companies' standards before being packed and stored.

RESEARCH METHODOLOGY

In general, our proposed system includes 3 main functional modules. The algorithmic flowchart of the system is introduced in Figure 2 below. Module 1 (first time frying module) has the task of coating shrimps and frying it into the desired shape, including chains of mold bars driven by chains, a powder solution spraying system controlled by sensors, an oil tank, and driving motors. Module 2 (second time frying module) has the task of deep frying with frying time controlled by motor speed through an inverter, a conveyor for frying shrimp, and a conveyor for transferring shrimp through module 3. Then, module 3 will do the removal of the oil after frying includes a driving conveyor and a fan that blows hot air to drain the oil. The whole operation of the semi-automation Tempura production line is introduced as in Figure 2.

Actually, the AISI 304 and AISI 316 materials meet the requirements about food safety for the food equipment. However, the weight of the AISI 316 is heavier than the AISI 304 and also the stiffness of AISI 316 is harder than the AISI 304. Therefore, the manufacturing process of the AISI 316 needs much more specific machines and is hard to fabricate. Therefore, the ASIS 304 is chosen to be the material to fabricate the semi-automation Tempura frying machine.

The whole semi-automation Tempura frying production line is located in the specified frying place with a cool environment. The average temperature of the frying room is about 22^0C to 26^0C. And, all the workers who work on this production line have to wear protective suit to meet the standard of the company. Besides, the frying tank of the production line is designed and fabricated with two layers with the isolation layer therefore the heat loss does not waste too much to the environment.

The design and fabrication of the whole production line also keep the safety condition of the machine used in the food industry. The whole production line and all the equipment such as: shafts, meshes, chains, UCP bearing units, etc are fabricated from the stainless steel AISI 304. Also, the lubricant used to lubricate the connections among many mechanical parts in the whole production line is the specialized lubricant used in the food industry. However, this lubricant is used for the parts that are assembled outside of the frying system such as the stainless steel chain to transmit the operation from the motor to the operation shafts. And, for the parts that are installed inside the frying oil such as the UCP bearing units, we choose the specialized UCPs that can use directly the food oil to be the lubrication factor.

About the influence of the heat on the expansion or mechanical part of the whole production line, these factors are also considered in the design, fabrication, and assembly process to fit with the tolerance of the mechanical parts to make sure that the whole system is always works in good condition. Actually, the requirement for the frying temperature is 175^0C is the standard of the industries which produce the frying Tempura shrimps. In general, the frying oil also contains the batters from the powder solution and also the breaking shrimps. These factors will make the oil reduce its quality. Then, the oil filters are also installed into the Tempura frying production line in order to keep the frying oil always in good condition and help to improve the quality of the frying oil and also save money for the industry because it will increase the time for using frying oil.

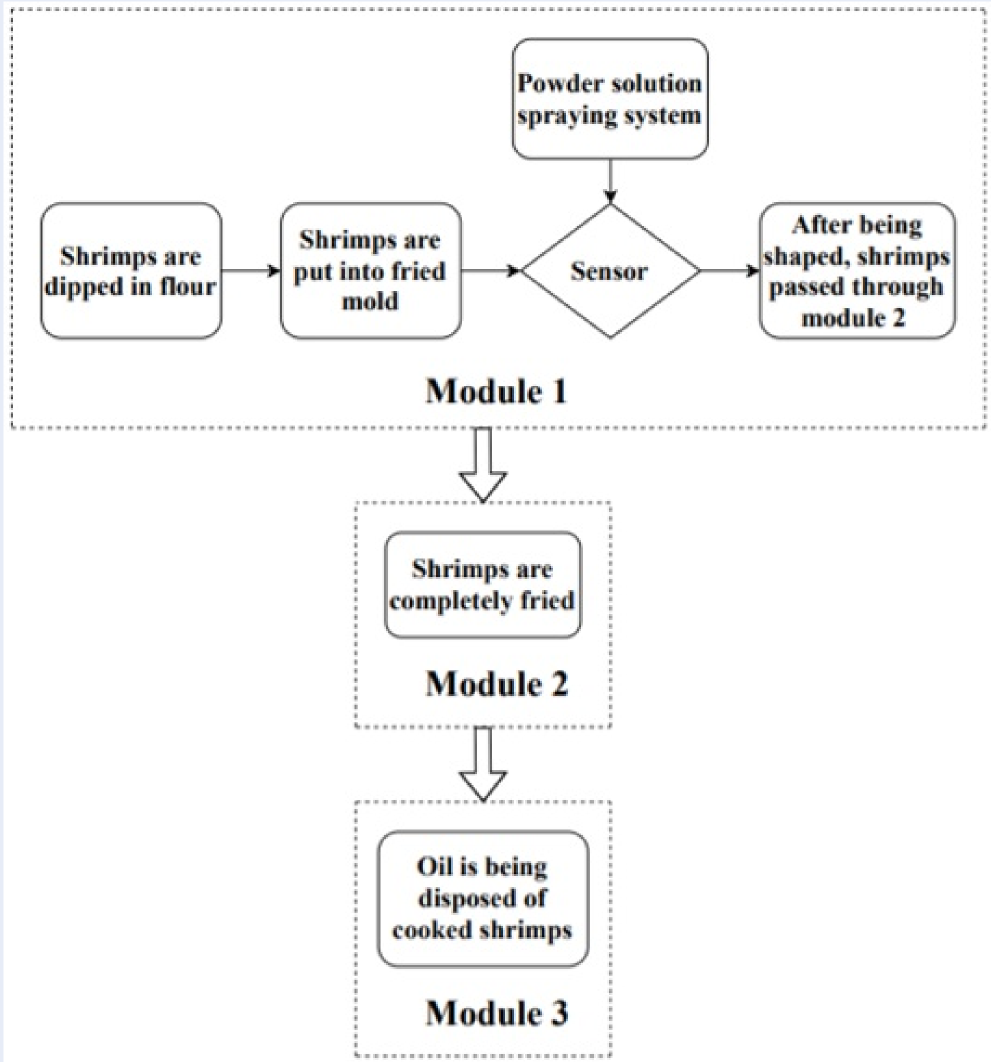


Figure 2: Main functional modules of the system

THE DESIGN OF MODULE 1

Operation principle of module 1

Shrimps are dipped in flour by workers and put in frying molds before being moved to the powder solution spraying system which is activated by the sensor. After being deep-fried, shrimp leaves module 1 and passes through module 2 to be completely fried. The operation process of module 1 is also introduced as the first part of Figure 2.

Design of frying mold

The average size of Vannamei shrimps used to make Tempura shrimps are about 14 cm to 20 cm in length. To make sure to fulfill all kinds of orders about Tempura shrimps' sizes, the frying mold is designed to be 200 mm. The structure of the frying mold is simply designed, easy to replace, install a new one when it is necessary, combined with the operating process of the system, the frying mold model is shown below. Besides, molds are covered with a thin non-stick layer to let the cooked shrimps easily to slough out from the molds as in Figure 3.

With the required productivity of 48000 pieces/day, for each worker is 12000 pieces/day, the frying mold system consists of 4 molds per row as depicted in Figure 4. Based on the mechanical structure, the mold is attached to the system through the outer mold structure, using bolts for convenience when it comes to fixing and replacement.

In order to drive the mold system from feeding position to powder-spraying position and then shrimp-

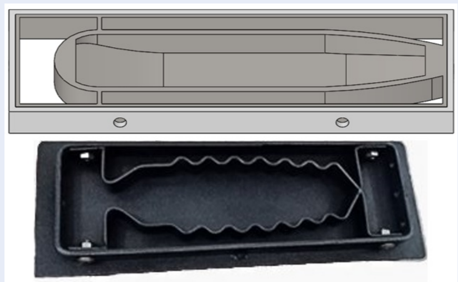


Figure 3: The design and real tempura shrimps frying mold

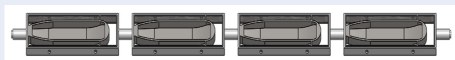


Figure 4: Frying mold array structure

take-out position. The system integrates the structure of the mold series installed on the chain conveyor to support the transport and ensure the productivity of the system when frying. The whole mold chain is designed as in Figure 5 to ensure the productivity of the production line.

We preselected the distance between the two rows of molds to be 130 mm and the distance from the position of placing the shrimp in the mold to the position of the powder injection tank is 390 mm, large enough for workers to work as comfortably as possible as well as to Installing more structural systems located inside the conveyor works with better space.

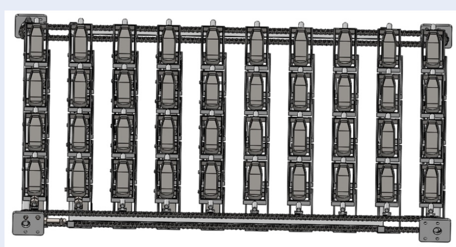


Figure 5: Chain conveyor system of frying molds

Calculate the drag force of oil

Apply the formula for calculating resistance in a liquid medium[11]:

$$F_D = \frac{1}{2}\rho v^2 C_D A \ (N) \quad (1)$$

F_D: resistance in a liquid medium

ρ: destiny of liquid

v: the relative velocity of the object relative to the liquid (m/s)

C_D: a coefficient that depends on the shape of the object

A: surface area of the object

With: destiny of oil $\rho = 800 \ \left(kg/m^3\right)$

$$v = \frac{s}{t} = 0,0433 \ (m/s) \quad (2)$$

For the shrimp frying mold, we have the following cross-sectional shape. The relationship between shape's parameters are depicted in Figure 6.

As above table, we have L/H = 2.3333 so $C_{D1} \approx 1,4$

The resistance surface area of each shrimp frying mold is:

$$A_1 = 0.0028 \ \left(m^2\right) \quad (3)$$

For the connecting rod between the shrimp fry molds, we have a cross-section with the following shape as in Figure 7:

For high-temperature oil, we assume the flow is turbulent, the coefficient, we deduce the coefficient of drag $C_{D2} \approx 0,68$

The resistance area of each connecting rod is:

$$A_2 = 0.0007 \ \left(m^2\right) \quad (4)$$

The shrimps frying system consists of 20 rows of frying rods and each rod has 4 frying molds. Assuming the resistance of the oil to other objects due to their small cross-sections, regardless of the resistance of the chain moving in the oil, the total resistance acting on the frying pan is calculated by this equation.

$$F_{D1} = 80\frac{1}{2}\rho v^2 C_{D1} A_1 + 100\frac{1}{2}\rho v^2 C_{D1} A_2 \quad (5)$$

F_{D1}: the total resistance acting on the frying pan

To ensure safety, we subtract the resistance of the chain, the friction force, the inertia force, the weight of the shrimp, the chain and other details. We take the coefficient of oil resistance as $F_{D1} = 5N$.

Calculate the chain tension

According to[7], the static tension of the chain is calculated:

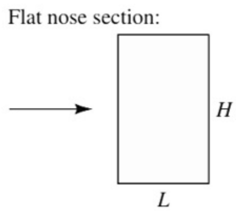
$$F = 9,81 \times \mu_c \times (W + 2,05 \times M \times C) \ (N) \quad (6)$$

And

$$kW = \frac{F.V}{60}.1,1.\frac{1}{\eta} \quad (7)$$

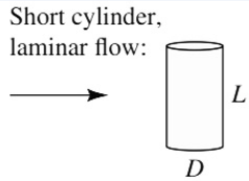
Where

F: maximum static tension of the chain



L/H:	0.1	0.4	0.7	1.2	2.0	2.5	3.0	6.0
C_D:	1.9	2.3	2.7	2.1	1.8	1.4	1.3	0.9

Figure 6: Resistance coefficient of frying mold



L/D:	1	2	3	5	10	20	40	∞
C_D:	0.64	0.68	0.72	0.74	0.82	0.91	0.98	1.20

Figure 7: Resistance coefficient of mold connecting rod

v: the conveyor speed (m/min)
C = L: length between two sprocket centers
M: mass of moving part per unit length (including bearing chain…) (kg/m)
W: Total weight on the conveyor
kW: Energy required to pull the conveyor
$\mu_c = \frac{1{,}9+0{,}15.d}{D}$: the coefficient of rolling and sliding friction of the chain where d and D are the radius of the pin shaft and the roller respectively, assuming the maximum coefficient is 0.8.
$\eta = 0.87$: the efficiency from the transmission motor to conveyors.
G = 9.81: the acceleration due to gravity (m/s^2)
Because the average size of shrimps used for tempura frying is larger than others, the velocity of the conveyor is calculated based on the average frying time needed:
We have:

$$F = 0{,}4086\ (kN) \tag{8}$$

So to ensure the chain can operate safely, and at the same time, the chain size must be small to reduce the size of the sprocket, thereby saving the space of the oil tank, reducing the volume of oil used, we choose the type of chain as stainless steel "KANA40SS-1".

Design of frying tank

The frying tank as in Figure 8 is designed with the bottom surface having different slopes suitable to reduce unnecessary space, to significantly reduce the amount of frying oil. At the same time, the inclined sides toward the oil outlet make the bottom debris settle easily in the refining process. The frying tank will contain all the frying systems. Besides, the frying tanks also have two layers which include the isolation layer in the middle to reduce the situation of heat transfer from the tank to the surrounding environment. This design also helps to reduce the heat loss of oil in the tank and also not to spread the heat to the surrounding environment. Because the tank is also impacted by heat, the checking of the deformation of the tank is also carried out as depicted in Figure 9. The deformation of the tank is not much and in the safety range.

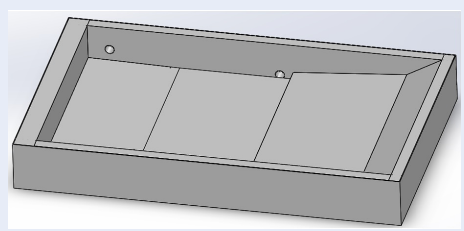


Figure 8: The design of frying tank

Design of the powder solution spraying system

The system includes an air compressor to pressurize the system, since the powder solution tank height design is just enough to allow pressure deviation due to

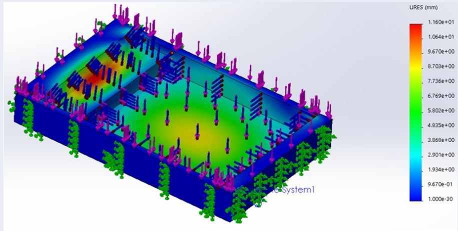


Figure 9: Checking the deformation of the frying tank

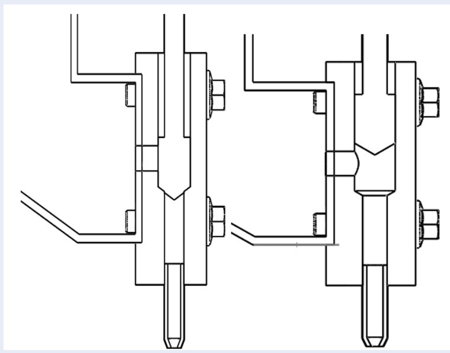


Figure 10: The piston in the closed state and opened state

negligible powder consumption, it is possible to maintain the pressure in the fixed powder solution spraying system. Thus, when the valve is activated, opening and closing will provide a fixed amount of powder solution. It is sprayed through these fixed tubes to cover the shrimps in the frying mold. In the closed state, the piston prevents the powder from falling. When the piston is moved upward by the pneumatic cylinder, the powder will flow through the space left by the piston. The detail design of the powder solution spraying piston is in Figure 10. Because the compressed air is injected into the powder solution spraying system, the oil-free filters are also used to eliminate the oil in the compressed air before injecting this air into the powder solution tank. The oil-free filters make the compressed air more purified and meet the food safety standard. The design of the powder solution spraying system is introduced in Fig.11.

Applying Bernoulli's law to real fluids in [11], we have:

$$\frac{1}{2}\rho v_0^2+\rho g h_0+p+p_a = \frac{1}{2}\rho \alpha v_1^2+\rho g h_1+p_a+h_{f1\to 2} \quad (9)$$

Where:

$\rho\ (kg/m^3)$: Density of powder

$v_0\ (m/s)$: Velocity of powder at height

$h_0\ (m)$: Powder ink height at initial time

$g\ (m/s^2)$: Acceleration due to gravity

$p\ (N/m^2)$: Air compressor pressure in the tank

$p_a\ (N/m^2)$: Atmospheric pressure

$\alpha = 2$: Kinetic energy correction factor for laminar fluid

$h_{f1\to 2}$: Energy loss coefficient of the fluid

$v_1\ (m/s)$: Powder velocity at the nozzle

$h_1 = 0$: Powder ink height at nozzle

In order for the spray powder not to be sprayed outside the mold, the maximum time to spray powder for shrimp is:

$$t=\frac{shrimplength}{conveyor\ velocity}=0.75\ s \quad (10)$$

We can choose powder spraying time as 0.5s.

The amount of powder to be sprayed for the average shrimp is about 1/30 liter / 1 shrimp, we have the amount of powder to spray for the average shrimp is:

$$Q=1/30/0.5=0.00007\ \left(m^3/s\right) \quad (11)$$

So the powder velocity at the nozzle is:

$$A=0.00004\ \left(m^2\right):\ \text{Total area of nozzles} \quad (12)$$

So the minimum compressed air pressure needed for the powder tank is:

$$p=\frac{1}{2}\rho\alpha v_1^2-\rho g h_0=0.04\ kg/cm^2 \quad (13)$$

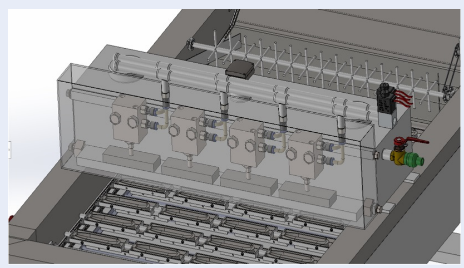


Figure 11: The design of powder spraying system attached in module 1

THE DESIGN OF MODULE 2

Operation principle of module 2

After the shrimps are coated with tempura powder and shaped frying in module 1, shrimps are transferred to module 2 for complete deep frying. Because the frying time of each shrimp size is different, we control the motor speed to get the right speed. After frying, shrimp will be put through module 3 to dry the oil. The design of module 2 is introduced in Figure 13.

Calculate the shrimp deep-frying net

Based on the average dimension of shrimps which is 162x34mm, the chosen mesh parameters for the net should be lower than the mentioned size of the shrimps in order to prevent them from falling through the net during the deep fry process. Furthermore, to avoid the catenary sag, the pitch diameter of the net is chosen to be 13mm which is equivalent to the pitch diameter of KANA 40SS chain. Therefore, stainless net BL-13-2-6-S is chosen according to Kansai's catalog.

Calculate the chain transmission for the conveyor

Calculate the chain parameters: Based on the given data from different shrimps processing companies, Table 1 below shows the total frying time needed for varying sizes of shrimps. All these parameters are measured by the practical shrimps frying process in the company.

Table 1: Time needed for deep frying shrimp

Shrimp size (unit/pound)	Frying temperature (^{0}C)	Frying time (s)
13/15	1755	≈02:35
16/20	1755	≈02:17
21/25	1755	≈01:40
26/30	1755	≈01:20
31/40	1755	≈01:05
41/50	1755	≈00:58
51/60	1755	≈00:53
61/70	1755	≈00:48

Based on Table 1, the frying time needed in the second frying system is about 120 seconds for biggest shrimp. In order to maintain the distance of shrimps while processing to ensure the appropriate frying time, the first group of shrimps being fried must be pushed forward by the conveyor before taking the second group for every 3 seconds.
The average horizontal dimension of the shrimp: 32mm. The safety factor is chosen as 1.2.
The minimum velocity of the conveyor:

$$v_c = 12,8 \ (mm/s) \quad (14)$$

The minimum distance between 2 sprocket center:

$$L_c = v_c \times t \times 1,2 = 1843,2 \ (mm) \quad (15)$$

Preliminary calculations for chain sprocket[7]:

$$x = 2\frac{a}{p} + \frac{z_1+z_2}{2} + \frac{(z_2-z_1)^2 p}{4\pi^2 a} \approx 300\,(sprockets) \quad (16)$$

Recalculate the center distance[7]:

$$a' = 0,25.p\{x-0,5.(z_2+z_1) + \sqrt{[x-0,5.(z_2+z_1)]^2 - 2[(z_2-z_1)/\pi]^2} = 1841,5 \ (mm) \quad (17)$$

In order to be able to deep-frying shrimps, one side of the chain needs to be inclined to drown the shrimp in hot oil, after calculating, the added length of the chain is equal to 406.4mm, which is equivalent to 32 sprockets as in Figure 12.

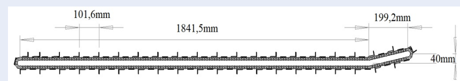


Figure 12: The overview of the chain

The above chain needs 32 sprockets, 42 bars used to push shrimps are connected to sprockets with the distance of each is equal to 101.6mm, which is enough to separate groups of shrimp. Calculate the weight of the chain:
The weight of components attached to the chain: KANA 40SS chain: 2x2.656 kg. From the above values, the total weight of the chain is around 60 kg.
Due to the load being evenly distributed on the chain, the load can be calculated as:

$$M = 14,2301 \ (Kg/m) \quad (18)$$

Calculate the drag force of oil[11]:

$$F_D = \frac{1}{2}\rho v^2 C_D A \ (N) \quad (19)$$

With $\rho = 800 \ \left(kg/m^3\right)$, $v = 0,0409 \ (m/s)$, $C_D = 2$, $A = 0,0188 \ \left(m^2\right)$
We have $F_D = 0,5283 \ (N)$
Checking calculations for the chain:
Calculating chain tension[7]:

$$F = 9,81 \times \mu_c \times (W + 2,05 \times M \times C) \ (N) \quad (20)$$

And

$$kW = \frac{F.V}{60}.1,1.\frac{1}{\eta} \quad (21)$$

Because the average size of shrimps used for tempura frying is larger than others, the velocity of the conveyor is calculated based on the average frying time needed:

$$v = \frac{L}{t} = 0,0409 \ (m/s) \quad (22)$$

$$F = 0,4086\ (kN) \tag{23}$$

$$P = 0,026\ (kW) \tag{24}$$

Calculate the motor power for the module II

Based on the pitch diameter that has been chosen above, the torque of the conveyor can be calculated as:

$$T = F_D.R = 0,1175\ N.m \tag{25}$$

With R is a radius of the chain sprocket. Based on the velocity of the conveyor v, rotational speed of the conveyor shaft can be calculated as

$$n_{bt} = \frac{60000 \times v}{\pi \times D} = 18,9814 \tag{26}$$

The power needed on the shaft conveyor to counter the torque is:

$$P_{ct} = \frac{M \times n_{bt}}{9,55 \times 10^6} = 0,0002\ (kW) \tag{27}$$

The total power needed:

$$\begin{aligned} P_{btn} &= P_{ct} + P_{btkc} \\ &= 0,0002 + 0,026 = 0,0262\ (KW) \end{aligned} \tag{28}$$

Based on above values, the motor GH 18 100W 30 SB G3 has been chosen for module II.

THE DESIGN OF MODULE 3

Operation principle of module 3

After the shrimps are deep-fried in module 2, they are brought to module 3 to clean and extract the excess cooking oil that remain inside the shrimps and the shrimps' powder cover. Then the shrimp is packed and preserved. As introduced in Figure 14, Module 3 (oil draining module) includes two main parts: (1) Mesh conveyor to drain oil and air circulation; (2) Industrial drying fan exclusively used for food with high power to separate the oil from the shrimp.

The conveyor width is must larger or equal to the module 2 conveyor's width make sure that the space for shrimp not be overlapped and drying better is enough. With the biggest shrimp's width being 240mm, we have the necessary width of the conveyor is mm. Including space between each shrimp is 60mm to easier for detaching shrimp to dry by the worker, we chose the space is 920mm. On average, there are 4 shrimps that come with this module every 3 seconds, from the biggest shrimp's size, to not be overlapped, the conveyor must move with the minimum speed at about 0,05 (m/s).

The time to dry the biggest shrimp is about 25 seconds (depending on the heat drying system used), we have the width of the conveyor is about 2 meters.

In this oil draining system, we have 2 control variables that affect the oil draining amount of the tempura shrimps. They are the air temperature and the air displacement. To choose the best option, we will use the experimental method. By gathering data and comparing it with standard through these criteria: the mass of oil separated, the shrimp's status after drying (color, shape, crunchy…) under different temperature and drying conditions. Thereby, we will find out the best solution for this drying cluster. Besides, this drying method also depends on input conditions, such as production speed, type of shrimp/powder solution/oil… Therefore, we should connect the drying system with the PLC system to modify parameters continuously.

RESULTS AND DISCUSSION

In this research topic, the whole mechanical design of the semi-automation shrimp Tempura frying production line is introduced. This Tempura shrimps production line is designed which is based on the manual frying process in the industries and specialized in the shrimp tempura production factory. All the material and equipment, which contact directly to the shrimps, the oil, are chosen as the stainless steel AISI 304 to meet the safety food standards. Besides, the oil filters are also installed into the system to filter the remaining batter, the breaking shrimps' detail to improve the quality of the oil and also to increase the lifetime of the frying oil. All the fabrication tolerances of the mechanical parts and the assembly tolerance when fabricating the whole production line are also calculated and chosen in suitable values to make sure that the production line can operate perfectly. The most important issue of this mechanical design needs pay much attention is the working condition. Because the oil is heated at around the temperature of 175^0C, then all the extension situations, the deformation situation, *etc* have been researched and considered very carefully. As discussed before, all the mechanical parts are designed and fabricated with the most suitable tolerances to make them be able to operate in the harsh condition of hot temperature. To reduce the heat loss and also make the good condition for the workers, the frying tanks are designed and fabricated with two layers with the isolated component in the middle between these two layers to prevent this phenomenon. Moreover, module 3 has the

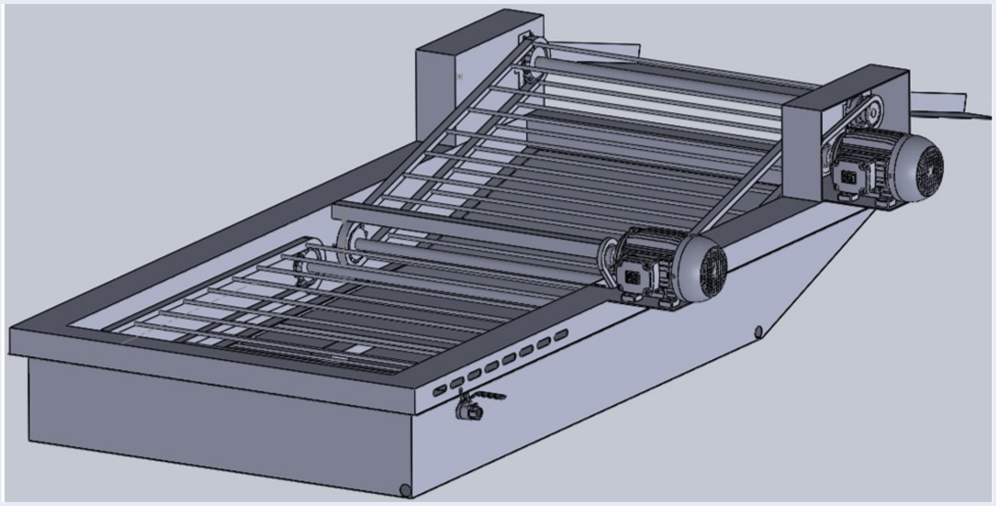


Figure 13: The design of module 2.

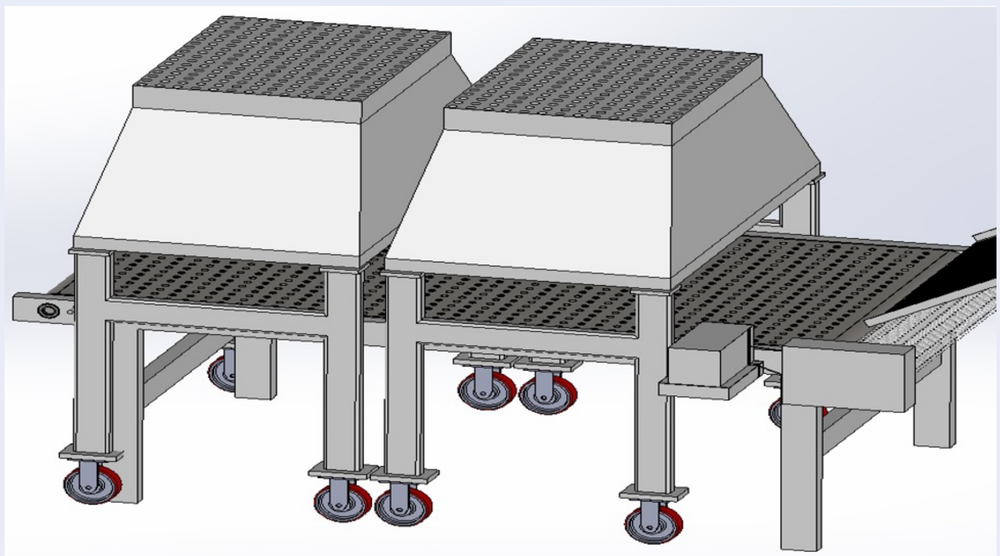


Figure 14: The design of module 3

greatest impact on the complete Tempura shrimps because this system helps to take the excess oil inside the Tempura shrimps. This will improve the quality of the Tempura shrimps.

At some primary experimental results, the operation of the whole shrimp tempura frying production line can work well with the desired results to meet the industry requirements. At present, the design of the mechanical part and also the design of the controller in this whole shrimps Tempura frying production line still have been researched to get better results and much more optimization about the power consumption issue, to reduce more the frying oil, to improve the productivity of the whole production line. And, the idea of the whole automation of the frying Tempura production line has been considered and researched.

The improvement and also the more innovations of the design have been carried to improve the quality of the production line and also help to improve more about the quality of the final product as the frying Tempura shrimps for the seafood industry.

CONCLUSION

The semi-automation shrimp tempura frying production line is designed based on simple mechanical operating principles, for easy installation, operation, and maintenance, as well as providing the system stability. Besides frying modules, the system also has a force oil draining module. This helps to overcome the disadvantages of traditional manual frying and other simple systems. Previously, shrimp after drying is taken out and just leave that for it to be drained, that way leads to loss of time and affects product quality (due to prolonged exposure to air). With a force oil draining module, shrimp can be put in the freezer right after leaving the line while still ensuring food requirements when reaching consumers. With this frying production line, the factory can increase productivity and also reduce the number of workers. At the desired design, this semi-automation tempura shrimps frying production line can improve the productivity up to 4 or 6 times and the amount of workers reduction is 5 times. This comparison is considered by the practical experimental results with the same productivity between conventional human manual frying process and semi automation frying process by machine. Therefore, the application of the semi-automation shrimp tempura frying production line to the shrimp processing industry will not only ensure quality, increase the productivity, but also optimize output costs through reducing traditional labor resources. As a result, this system can help the tempura shrimp production industry to develop with a much higher quantity and quality than before.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

AUTHORS' CONTRIBUTIONS

Tuong Quan Vo is the principal author and the corresponding author. He is in charge of the main ideas to sketch and build up the overall design of this system. He is also responsible for the sketch design of the mechanical, electrical – electronics and the controllers for this research topic. He writes the first draft, evaluate and correct the technical issues and English of this manuscript. Besides, he instructs all the members to complete their task of this research.

Trung Chanh Vo and Tran Thanh Cong Vu are responsible for completing the design of the mechanical system of module 1 and module 2, 3 respectively.

Tuan Quan Vuong contributes to the design of the powder solution sparying system of module 1.

Quang Minh Phan is in charge of the complete design of module 2.

Tan Dat Nguyen and Quang Long Le contribute to the final design of the module 3.

All the authors have read and agreed to the published version of this manuscript.

The authors fully contribute to this research work.

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Bài nghiên cứu

Thiết kế dây chuyền chiên tôm tempura bán tự động

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TÓM TẮT

Hiện nay, nhu cầu tiêu thụ tôm chiên Tempura là rất lớn tại các nhà hàng Nhật Bản tại khắp nơi trên Thế Giới. Có rất nhiều nhà máy sản xuất tôm chiên Tempura này để cung cấp cho các nhà hàng hoặc cho các siêu thị trên nhiều quốc gia khác nhau. Sản phẩm tôm chiên Tempura mang lại lợi ích rất lớn cho ngành thủy sản Việt Nam cũng như nhiều quốc gia khác trên Thế Giới. Tuy nhiên, hầu hết việc chiên tôm Tempura tại các nước đều được thực hiện thủ công và đòi hỏi cần có rất nhiều công nhân để đảm bảo năng suất của nhà máy. Do đó, chất lượng của sản phẩm tôm chiên này phụ thuộc rất nhiều vào kỹ thuật chiên của công nhân. Ngoài ra, để đáp ứng nhu cầu chiên tôm với năng suất lớn, cần có diện tích nhà xưởng lớn. Và, việc sản xuất hàng loạt như vậy dẫn đến chất lượng tôm chiên Tempura không đồng nhất, không ổn định và hao phí rất lớn. Do đó, nhu cầu của một hệ thống chiên tôm Tempuara tự động, bán tự động có thể giúp các doanh nghiệp giải quyết vấn đề khó khăn này. Ngoài ra, việc ứng dụng dây chuyền chiên tôm Tempura này có thể giúp các doanh nghiệp thay thế được các công nhân có tay nghề chưa phù hợp. Bài báo này trình bày thiết kế của toàn bộ dây chuyền chiên tôm Tempura một mặt bán tự động. Toàn bộ hệ thống bao gồm 3 mô đun chính. Mỗi mô đun có thể hoạt động như một thiết bị độc lập. Công nhân chỉ thực hiện việc bỏ tôm đã được phủ bột Tempura vào khuôn chiên và sau đó quá trình chiên sẽ được tự động thực hiện cho đến khi có được tôm chiên Tempura thành phẩm. Mô đun đầu tiên có chức năng định hình tôm và gọi là chiên lần 1. Hệ thống phun bột lên tôm cũng được trang bị lên mô đun này. Mô đun 2 có chức năng chiên tôm thành phẩm. Cuối cùng, mô đun 3 có chức năng làm ráo bớt dầu trong tôm sau khi chiên. Mô đun 3 sử dụng kỹ thuật dùng luồng khí nóng để đẩy dầu thừa ra khỏi tôm sau khi chiên.

Từ khoá: Tôm Tempura, thiết kế cơ khí, tự động hóa, mô đun, chiên, hệ thống

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