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Design Development of a Unit Operation for Chilli Paste Process

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ABSTRACT

The traditional method of chilli paste processes essentially consists of two main unit operations, namely blending of raw ingredients and cooking of liquefied chilli paste, accompanied by manual stirring. The transferring of blended food for cooking adds clean-up work and tends to waste time and energy. Substantive continuous stirring during the cooking process is essential, but time and labour consuming. In this study, a process design of a chilli paste machine has been developed with the aim to combine the process of blending and agitated cooking in a single appliance. A new design of machine called Chilli Paste Machine has been successfully built with the intention to overcome the issues present in making chilli paste. It comprises a set of blades that enable blending or stirring of chilli paste during blending and cooking processes respectively. A heating plate is installed for heating the chilli paste. The whole operation is controlled by a Programmable-Logic-Controller (PLC) Unit which allows automated control of the desired temperature parameters. The prototype machine was tested to ensure the performances of the machine design are met. A ready-to-serve batch of chilli paste was successfully produced using this newly designed machine.

Key words: Blending, stirring, heating, PLC, chilli paste

INTRODUCTION

Specialized food processing machinery is an essential asset for simplifying various food processing tasks and to bring convenience to the lives of human-beings. A processed food product may need to undergo one or several unit operations before it is ready to be served or is said to be safe for consumption. Therefore, modern technology continues to develop more and more specialized and technically advance apparatus that perform more than one unit of operations as part of food processing (Gisslen, 2007). This trend is further boosted by the drive towards higher, finer, more specialized and higher quality products in order to satisfy consumer demand along with a steadily rising standard of living. Moreover, due to the diversity of food processes and food products, several specialized unit operations have been developed in the food processing industry to fulfil these needs (Ibrarz and Barbosa-Canovas, 2002).

Chilli paste is served in Asian cooking as a popular condiment. It is used as an ingredient in soups, stews and also main dishes. The chilli pastes can add flavour and heat in any dishes (Russell, 2013). As a method of preservation, chilli paste is such a product that can retain its colour and flavour in a semisolid form that is convenient to use (Ahmed *et al*., 2002). Moreover, chilli paste is mostly served hot as a side dish for main food dishes among the peoples of South East Asia.

The traditional method of chilli paste processing consists essentially of two unit operations, which are mechanical and preservation carried out separately using different food processing equipment and cooking utensils. The mechanical separation involved is blending of raw solid ingredients, whereas the heat preservation is the cooking of liquefied chilli paste, or to be more precise, pan-frying together with manual stirring by hand. Usually, a food processor or a blender is used for liquefaction of the raw solid ingredients while cooking involves a conventional stove type heater. Substantial continuous stirring is required during the cooking process to avoid hot spots or burning of the chilli paste as well as to facilitate heat transfer during the cooking cycle.

These two-step processes take up a lot of time and man-power. The transfer of blended food for cooking adds work in terms of cleaning-up and the process wastes time and energy. Further, careful manual stirring during the cooking of chilli paste might be inadequate for a number of reasons, such as inattention due to other related cooking tasks. The choky smell released during the cooking process also tends to provoke an uncomfortable feeling in the people who perform the manual stirring. As a result of these distractions, the continuous stirring of chilli paste is extremely difficult to achieve by hand. In order to eliminate the problems faced during the making of chilli paste, a food processing machine that is capable of performing both blending and agitated cooking operations either simultaneously or consecutively in a single appliance is necessitated.

Some earlier designs combined both blending and cooking operations in one device by having blender blades and a heater together to perform both tasks. Basically, there are many inventions for making soybean milk, especially for household use, which essentially comprise of two main sections which are a section for blending the soybeans and a boiling section for the soybean milk. Peng (2007) invented and patented a blended soup maker in a United States patent. The blended soup maker has a blending mechanism for hands free soup making, which can be used to combine with heating of food into one single appliance or equipment. However, the operation of these various specialised foods processing equipment is not suitable for the food processing steps that the input ingredients of chilli paste should undergo. Moreover, these earlier devices are not fully automated as they might require manual control to change the fast blending speed to a slow stirring speed for blending and for the subsequent cooking operation respectively. The time for blending and cooking in these earlier devices has to be manipulated according to the quantities of food made as well as by personal experience in order to judge a suitable time for producing a consistent food quality for different food quantities.

Machine design deals with the creation of machinery with interrelated parts (machine elements) that work safely, reliably and well as stated by Norton (2006). Identifying and defining all motions, forces and energy changes is the essence of machine design. This is to determine the sizes, shapes and materials needed for each of the interrelated parts in the machine. Hence, the resulting machine can perform its function without failure. Therefore, proper machine design is required in obtaining better design of blender-cooker machine with specified function.

In this study, the objective is to design a blender-cooker machine that automatically functions both as a blender structure and a cooker structure. The present design aims to provide an automated chilli paste maker, which combines blending and agitated cooking into one single appliance in order to overcome the issues that are present in the traditional method of making chilli paste. Another objective of the present design is to provide a blender-cooker machine with appropriate blades which are able to perform appropriately in both blending and stirring operations. More specifically, the blades should work efficiently as a cutting blade in the blending operation and as a stirring blade in the cooking operation, respectively.

MATERIALS AND METHODS

Raw materials: The raw materials used are the basic ingredients of chilli paste, including dried red chillies (*Capsicum annuum*), water and palm oil (cooking oil).

Analysis of dried red chilli cutting force at various temperatures: This analysis was conducted using a TA-XT2 Texture Analyzer (Stable Micro Systems, UK). The purpose of this analysis was to obtain the cutting force required to cut chillies at different temperatures (between 40 to 100°C). The hypothesis is the maximum cutting force at a certain temperature represents the most optimum temperature (T1) for the blending process.

Engineering design process: There are researchers (Sokovic *et al*., 2005; Pahl *et al*., 2007; Ulrich and Eppinger, 2004) that have produce models for basic design process and their models representing structured flow of activity and information flow that required for the product development process design. For this study, the engineering design process followed a well-organized structure and systematic flow of activities (Ulrich and Eppinger, 2004) as shown in Fig. 1. Each stage identified the needs and constraints and evaluated the outcomes.

The first activity of the design process was to design a plan of a new machine that combined both blending and cooking chilli paste. At this stage, two important points were identified, which were (i) To identify the problems faced during chilli paste processing and (ii) To identify the design specification. Figure 2 shows the processing of chilli paste described in unit operations that should be undertaken. The problem was to eliminate the use of two unit operations which were the blender and cooking apparatus. The target was to design a machine that could perform the two operational processes in a single appliance either simultaneously or consecutively.

Based on an understanding of the problem definitions, the target design specification of the machine was generated as given in Table 1. In performing both blending and cooking

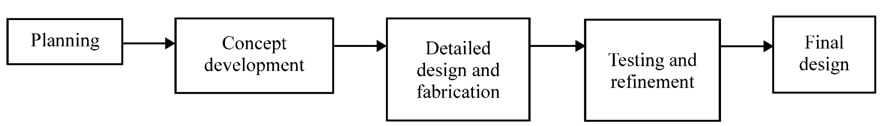

Fig. 1: New machine development process

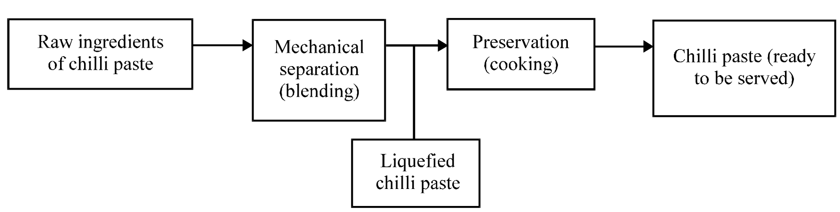

Fig. 2: Unit operations of chilli paste processing

Table 1: Design specifications for the machine operation and function

Operation	Section	Component	Function
Blending	Size reduction	Cutting blade (with cutting sharp edge)	To turn solid ingredients into liquid form by cutting them into relatively smaller particle sizes
Agitated	Heating	Heating plate	To heat and cook the chilli paste
cooking	Stirring	Stirring blade (with agitator design)	To induce the flow of chilli paste during the cooking operation

operations simultaneously, the machine design should have a size reduction (or liquefaction) section of solid ingredients and a heating section accompanied by a stirring section of the semi-liquid paste. These three important component parts play an important role in the machine operations and ensure that the input ingredients undergo the required processing steps in order to produce the targeted output, a chilli paste with the desired consistency which is ready to be served and safe for consumption.

The second activity was the conceptual design development. It consisted of two parts, which were (i) Collect and sort information on the existence of any similar food processing machine which have similar unit operations that fulfils the requirements of chilli paste processing and (ii) Generate a few design concepts based on the Pugh concept selection matrix and scoring matrix (Pugh, 1991) as the evaluation tools. The second activity was completed once the best selected conceptual design was selected.

The third activity was (i) To finalise the product design with detailed drawings and (ii) The fabrication of the prototype machine. All engineering designs and drawings were produced using the CAD software CATIA V5 R17. Prior to fabrication, cost effective and suitable materials were chosen for all components and machine parts.

Once fabrication was completed, then the fourth activity was started (i) By performing testing of the fabricated prototype machine and followed by (ii) Some modifications made to the prototype design based on the results of the testing. Finally, a new detailed design of the machine was produced and alterations were also made to the fabricated prototype machine.

Operational process: To ease the operation of the machine, the machine operation is controlled by a PLC program controller that was included inside the machine control panel. Prior to the design of the process algorithm of the prototype machine controller, an understanding of the principles of the process flow of the chilli paste making was required. Figure 3 shows the overall process flow of chilli paste making.

The machine operation starts with both blending and heating operations in parallel. The setting for blade assembly speed parameters is made before the machine operation. Two temperature parameters play an important part in determining the quality of the end product (chilli paste). The first controlled temperature (T1) is the temperature at which the blending operation ends, for which the particle size distribution of the suspended solid ingredient (chilli) greatly depends on the temperature. During the blending operation, the blades are rotated in a clockwise direction at high speed (R1) in order to utilize the sharp cutting surfaces along the leading edges of the blades for liquefying the solid ingredients, accompanied by heat, as shown in Fig. 4a. When the T1 is achieved and detected by the temperature sensor (thermocouple), the rotation of the blades stops. The blade assembly takes five seconds to prepare for the following cooking operation.

The cooking operation starts with the rotation of the blades in a counter clockwise direction at low speed (R2) where the wing flaps on the blade edges work to induce an upwardly directed axial flow of the semi-liquid food, as shown in Fig. 4b. Heat transfer from the heating plate is continued until the second predetermined temperature (T2) is achieved. The second controlled temperature (T2) determines the cooking time of the foodstuff during cooking operations. The cooking method employed in the present design is pan-frying. The end products should not contain any free water in its cooked state. Once there is no free water in the chilli paste, the temperature of the chilli paste will be increased to 100°C and at this time, the foodstuff will be in a well-cooked state, where the

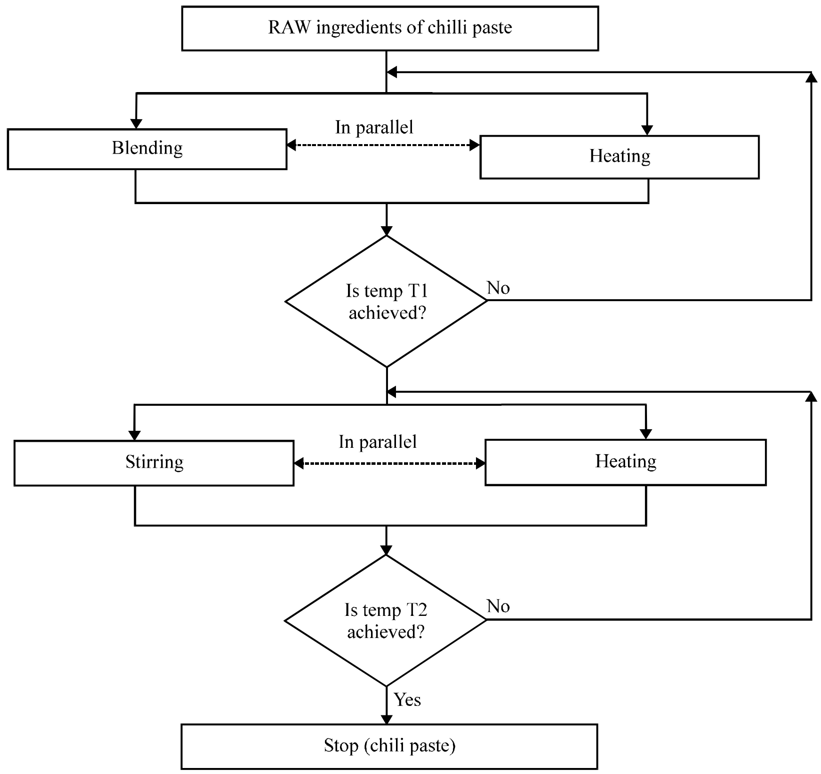

Fig. 3: Flow process of chilli paste making

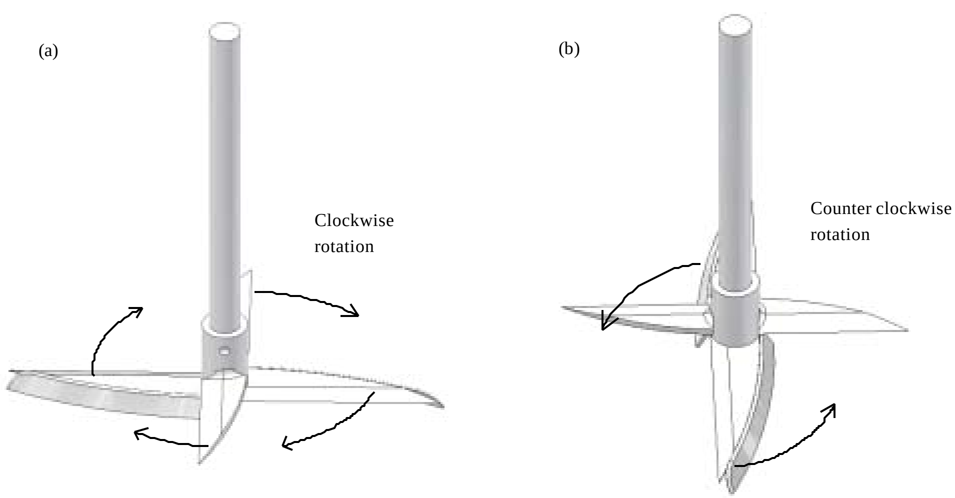

Fig. 4: Rotation of blade assembly, (a) During blending operation and (b) During agitated cooking operation

oil from the paste floats to the top. Therefore, 100°C can be used as the second temperature (T2) parameter to control the cooking operation of the machine and ensure that the chilli paste is well-cooked at that particular temperature.

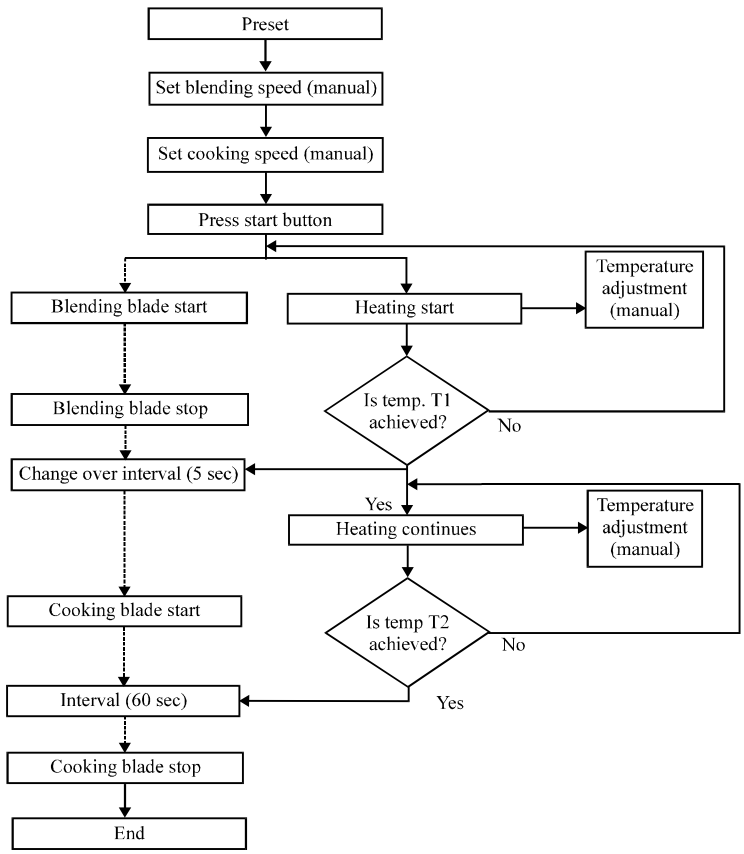

Fig. 5: Operational process algorithm of the prototype machine

The process algorithm of the prototype machine controller (based on the motor operation of the rotation of the blades and the heater) is shown in Fig. 5. The optimum setting for the rotation/speed (R1 and R2) of the blades and the temperature (T1) will be discussed in the next section.

Machine testing: The chilli paste prototype machine was tested for the blending and agitated cooking processes as well as the whole of the automated operation. Trial runs were conducted to check the performance of the prototype machine as well as the functionality of the various component parts and the PLC program. There were two process parameters (blade speed R1 and R2) of the prototype machine which were found to influence the quality of chilli paste.

RESULTS AND DISCUSSION

Comparison of present design concept with existing equipment: In order to produce a good conceptual design, the features of similar products available in the market were studied. Table 2 shows a comparison between some of similar specialised food processing equipment that performs both heating and blending operations with the present design concept. The examples are disclosed in United States Patent Application. The features of these existing machines were studied, analyzed and compared with the current design concept, including their mechanical and unique points. The similarities between the patented design and the present design in this study are the blending and the involvement of heating unit operations. However, the differences are the heating method and

Table 2: Comparison of existing specialised food processing equipment and present design concept

Criteria	Current design concept	Invention, Wang *et al.* (2005) WO/2006/056141	Invention, Peng (2007) US7780337	Invention, Bower *et al.* (2009) US8152083
Key description characteristics of end food product	Chilli paste maker Fine particles of chilli suspended in oil/fat phase with no free water	Soya milk maker Clarified soya milk liquid	Blended soup maker Soups with fine particles of ingredients	Food maker Food with a mashed composition, suitable for a baby
Processing unit operation	Blending of solid ingredients Pan frying of paste with stirring	Blending of soya beans Filtering of soya milk Boiling of soya milk without stirring	Blending of soup ingredients Boiling of soup with stirring stirring	Blending of solid ingredients Steaming of soup without
Input flow mechanism	Blending and cooking inside inner pot	Blending in the filter cup and heating of milk in jug	Blending and heating inside inner pot	Blending and heating inside receptacle
Cooking method	Dry heat-pan fry	Moist heat-boil	Moist heat-boil	Moist heat-steam
Heating medium	Oil (fat)	Water	Water	Steam (vapour)
Cooking process	Allow water vaporization for a longer time	Heating up to boil	Heating up for a set time interval	Heating up for a time interval by manual rotation of receptacle
Automation	Applied for whole operation	Applied for whole operation	Intermediate setting required	No automation. manual rotation of receptacle for switching of both operations
Cooking detection method	Thermocouple is used to detect temperature of well cooked food at 100°C and controller to end the operation	Thermocouple is used to detect temperature of liquid boiled at 100°C and controller to end the operation	Time setting is used. Skill needed to judge the cooking time of foodstuff	Manual control is used, depends on user experience to judge the cooking time of the foodstuff

medium, stirring, cooking process, automation and cooking detection method. Present design used dry heat heating (cooking) method while inventions by Wang *et al.* (2005) and Peng (2007). Oil is used as the heating medium in this study while water (Wang *et al.*, 2005) and steam are used in other inventions. Stirring which facilitate in the heat uniformity during cooking is applied in the present study and invention while there is no stirring in Wang *et al.* (2005). Automation is applied for the whole operation in the present design and Wang *et al.* (2005) invention. Other inventions are either have no automation and requires some intermediate setting. The cooking detection method used in this study and in Wang *et al.* (2005) invention is by thermocouple. This is better than manual control and time setting since the thermocouple will detect the cooking temperature and the controller will automatically end the operation.

Effect of temperature on blending operation : Understanding the effect of temperature on the blending operation is a prerequisite for developing an operating algorithm of the conceptual design machine. An experiment was set up to obtain the correlation between temperature and blending efficiency. Figure 6 shows the comparison of cutting force of the dried chilli with and without heat provided (at a constant temperature of 30°C). The maximum cutting force of the dried chillies is equivalent to the hardness of the dried chilli. It was found that the hardness of the chilli decreased with time and temperature. This is similar to the findings of Deshpande and Bal (2001) where the hardness of soybeans in their study decreased with the increase of the heat treatment duration and temperature of blanching. The temperature has a significant effect on reducing the hardness of the dried chilli and thus increasing the blending efficiency, if compared with a constant temperature

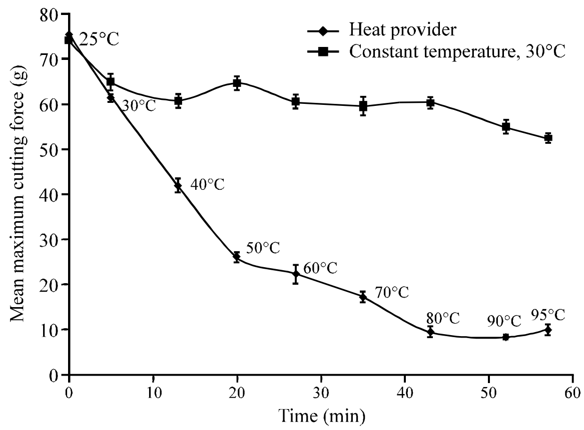

Fig. 6: Comparison of cutting force of dried chilli with and without heat provided

condition (at 30°C). It was observed that the hardness of the dried chilli became nearly constant at a temperature of 80°C after heating for nearly one hour. This result indicates that the particle size of dried chilli achieved during the blending operation is time and temperature dependent. Thus, it is assumed that the blending of dried chilli will be completed once 80°C is reached and this temperature was selected for the first control temperature, T1.

Detail design: There are researchers (Mazlina *et al.*, 2010; Yee *et al.*, 2011) that discussed on the detail design of machine begins with conceptual design up to fabrication and testing. Planning and specifications act as the basis of the conceptual design (Ullman, 2003). This study also has similar step of design development as described by the previous researchers (Mazlina *et al.*, 2010; Yee *et al.*, 2011). A new design of chilli paste machine has been developed as illustrated in Fig. 7. As stated before, the target performance of this machine is to perform automated blending and agitated cooking that possesses both blender and agitated cooker structures in a single appliance. The blender-cooker machine is designed to blend the chilli into smaller particle sizes by using the blade and then cook the chilli paste from the heat of the heating plate with constant stirring of the blade. This design will reduce the work of making chilli paste by combining two operations which are blending and cooking in one application making it suitable not only for home but also for industrial scale. The chilli paste machine according to the present design comprises fourteen main component parts as listed in Table 3 and illustrated in Fig. 7.

The new chilli paste machine comprises a blade assembly arrangement having a specific structure, by which food blending is obtained by clockwise rotation of blades and stirring of the food is achieved by a counter clockwise rotation of the blades. Figure 8 shows the configuration of the upper and lower blades and their structure, with each having a planar and horizontal centre and blade section positioned at 90° from each other. Each of the lower and upper blades is equipped with cutting surfaces along their leading edges. The upper blade is longer (14.2 cm) in dimension than the lower blade (10.5 cm). The edge sides of the lower blade are adapted to be projected at a downward angle to have wing flaps configured to induce an upwardly directed axial flow of the semi-liquid food and therefore works as an agitator during the cooking operation. Axial flow can assist in sweeping the suspended solids at the bottom of the cooking pot and to prevent burning.

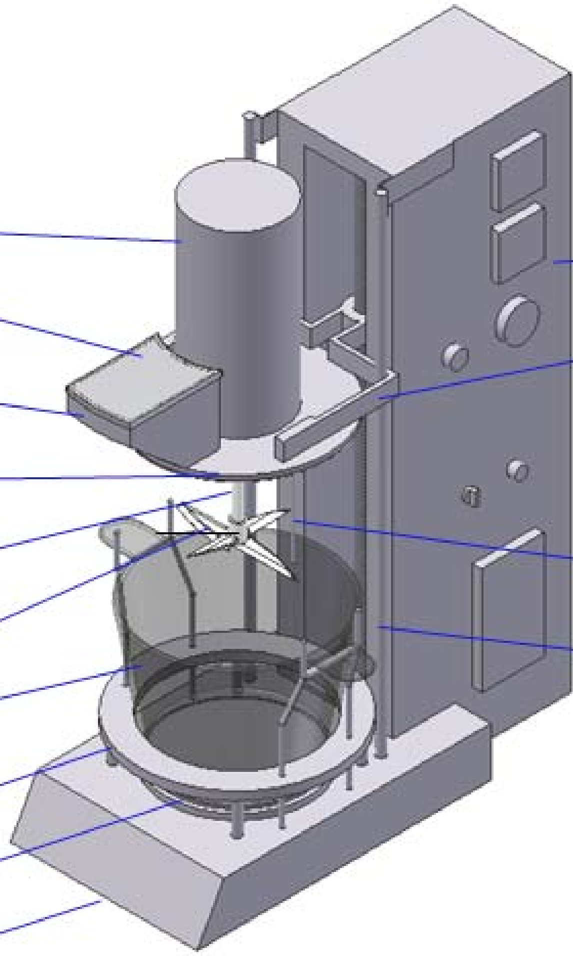

Fig. 7: Drawing of machine with major component parts labelled

Table 3: All component parts of the apparatus for blending and agitated cooking

Part	Description
Motor	Power of 0.5 hp
Hopper cover	To cover hopper inlet
Hopper	To allow feed in of raw material at the intermediate stage of the process and to allow steam release during the process
Cover lid	To close the open top of the container
Blade shaft	To connect the blade assembly and motor
Blade assembly	Consists of upper and lower pair of blades
	To act as a cutting blade during the blending operation and as a stirrer during the cooking operation
Container	To hold the foodstuff inside
Safety holder	To hold container in place and prevent vibration during operation
Heating plate	To provide heat for heating of the foodstuff in the container
Base support	To support the whole weight and structure of the machine
Lifting support	To direct the upright up and down action of the lifting arm
Thermocouple	Temperature sensor
Lifting arm	To lift the motor together with the cover lid up and down
Control panel	To contain PLC* unit and operational buttons

PLC is programmable logic controller

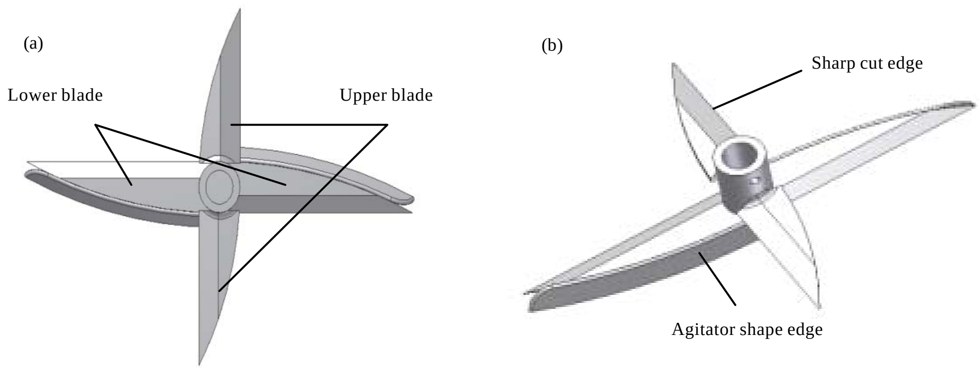

Fig. 8(a-b): Drawings of blade assembly (a) Top view and (b) Auxiliary view

Fig. 9: Chilli paste produced by the prototype machine using the optimum process parameters

Prototype fabrication: The final fabricated machine was shown in Fig. 9. The machine mainly consists of the motor, hopper, blade, container, heating plate and control panel. The description of each component has been described in Table 3. The material of construction for the machine was food grade stainless steel (SUS 316). The 316 grade stainless steel is normally used in food processing industries for food contact equipment due to its resistance against pitting, corrosion and non-oxidising acids such as acetic acid and phosphoric acid (Kress-Rogers and Brimelow, 2001). The machine operation is controlled by a PLC program controller inside a control panel and the various functions are described in Table 4. Prior to machine testing, the setting for the blade assembly speed parameter has to be made.

Machine performance testing: The target of this machine is to automatically process the raw ingredients (dried red chillies, water and oil) into chilli paste that is ready to be served. Many test runs were conducted in order to obtain the appropriate chilli paste machine performance as well as to determine the functionality of various component parts and the PLC program. PLC or

Table 4: Description of the control panel on the machine

Operational buttons and controller	Functional description
Temperature controller 1, T1 (80°C)	Controller with set temperature at which blending operation ends with stopping of rotation of blade assembly in a clockwise rotation
Temperature controller 2, T2 (100°C)	Controller with set temperature at which cooking operation ends with stopping of rotation of blade assembly in a counter clockwise rotation
Emergency stop	The safety measure for stopping operation of machine immediately during an emergency case
Start button	The button to start the operation of machine
Speed controller	Speed rate of controller response
Up/down button	The button to lift up and move down the power motor together with the cover lid

Table 5: Observations of the four process parameters

Process parameter	Observations
Temperature	
Controlled temperature, T1	A smaller T1 means a shorter blending time and consequently a larger particle size of suspended solids in the chilli paste
	T1 can be manipulated and if finer chilli paste is preferred, then a higher temperature can be set
	From the result obtained, 80°C can be taken as the temperature for obtaining fine chilli paste
Controlled temperature, T2	T2 is set at 100°C to ensure the chilli paste will be well-cooked, where oil from the paste floats to the top
	If a lower temperature is set, the chilli paste prove not to be cooked
Blade assembly speed	
At blending operation, R1	A higher R1 means a shorter blending time and a finer size of suspended solid particles in the chilli paste
	R1 is correlated with controlled temperature T1
At cooking operation, R2	A higher R2 means better heat transfer in the chilli paste, the faster the water evaporation in the chilli paste, the higher efficiency of bubbles escaping and thus the shorter the cooking time
	A higher R2 means better stirring flow of the highly solid suspended chilli paste and a lower risk of overcooking

Table 6: Optimum process parameters of the prototype machine

Process parameter	Optimum value
Controlled temperature, T1 (°C)	80
Controlled temperature, T2 (°C)	100
Blade assembly speed during blending operation, R1 (rpm)	2250
Blade assembly speed during cooking operation, R2 (rpm)	1200

Programmable Logic Controller is an industrial device used for controlling machines and processes by a stored program and feedback from field sensing and actuating devices (Jones, 1996). Overall, there are four main process parameters of the prototype machine which influence the quality of the chilli paste. The observation of manipulating the four process parameters are summarised in Table 5. When the temperature is set lower (T1), the blending time will be shorter which leads to coarser chilli particle size. At higher temperature, blending time will be longer and finer chilli particle size will be obtained. Thus, the quality of chilli paste depends on the consumer preferences. From the trial runs of the prototype machine, the optimum process parameters for producing fine chilli paste are summarized in Table 6. The prototype machine is designed with maximum mass per batch, 1.2 kg and the rotation speed range is within 0 to 2500 rpm. As highlighted in Table 6, the optimum value for rotation speed during blending and cooking operation were at 2250 and 1200 rpm, respectively.

The blending operation starts with setting the speed (R1 = 2250 rpm) with the blades rotating in a clockwise direction and will end once the temperature reaches T1 (80°C). Five seconds were set

Table 7: Comparison between chilli paste machine and conventional method

Chilli paste machine	Conventional method
Saves clean-up work	Adds clean-up work
Saves time	Time-consuming
Saves manpower	Manpower needed especially for tedious manual stirring during cooking process
Low risk of burning at the bottom of the cooking pot	High risk of burning at the bottom of the cooking pot
No experience or skills needed	Experience needed to judge the cooking time

for preparing the blade assembly for the subsequent cooking operation. Then, the blade rotates in a counterclockwise direction with a lower speed setting (R2 = 1250 rpm) and the cooking operation begins. The cooking method employed for this machine is pan-frying, thus the end product should not containing free water at its cooked state. Once there is no free water in chilli paste, the temperature of chilli paste will increased to 100°C and at this point, the chilli paste is well-cooked, which oil from the paste floats to the top. The cooking process is dependent on the amount of water used and independent of time. The machine will shut off the heating operations after 60 sec when T2 (100°C) is reached. The operation sequence ends at this stage. The chilli paste is now ready to be served (Fig. 9). Table 7 shows the advantages of using this new chilli paste machine compared to the conventional method. The prototype machine was successfully designed to eliminate inconvenience and to simplify the task of making chilli paste.

CONCLUSION

A new chilli paste machine was successfully designed and fabricated with combination feature of blending and cooking element. This machine processes the raw ingredients into chilli paste that is ready to be served. The machine performs blending and agitated cooking automatically without any manual input at the stage of changing from the blending to the cooking operation. The blades that are fixed in the machine do not require to be changed during the whole process (blending and cooking operation). The whole operation is controlled by a PLC Unit which allows for automated control at the desired temperature and speed parameters. The present machine has eliminated the need for transferring blended food in a blender or food processor to a pan for cooking as well as saves time and labour by eliminating the need for manual stirring by hand. It is expected that this newly designed machine could replace the traditional way of making chilli paste as it simplifies the tasks involved in making chilli paste. This new machine also has been filed for patent in Malaysia.

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