

DESIGN OF A NEW TYPE OF CONTINUOUS STACK-UP JUICE PRESS AND PROOF ON EXPERIMENTAL MACHINE

一种新型连续层叠式榨汁机设计与试验机验证

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ABSTRACT

The fruit-vegetable juice processing industry plays an increasingly important part in the agricultural commodities processing industry in many countries. Existing fruit-vegetable juice press machines in fruit-vegetable juice processing industry has difficulty meeting the need for high-nutrition and high-quality fruit-vegetable juice products. Thus, researching for a new type of juice press with low-energy, high-juice yield, and high-quality of juice products is significant to meet the demands of modern and high-efficient production of fruit-vegetable juice. A new type of continuous stack-up juice press was presented based on the analysis on demands of fruit-vegetable juice processing and on advantages and disadvantages of some typical industrial press machines. The mechanical structure and working principle of the juice press were illustrated. Moreover, an experimental machine, in which the basic filter-press unit is the core, was created to prove this technological solution. Juice press experiments of Ralls apples were conducted using the experimental machine. Results show that, when the driving motor rotates around 600 rpm, the juice yield rate is 81.16%, and the average value of the pressure force in the entire filter-press passage is about 1200 kilopascal. The quality of pressed juice is good for preserving most nutrients of raw materials.

摘要

果蔬汁加工产业在各国农产品加工产业中所占比重越来越大，目前果蔬汁加工行业普遍采用的果蔬榨汁机已很难适应市场对果蔬汁产品的高营养、高品质的要求。因此，开展低能耗，高出汁率，高出汁品质榨汁机的研究以满足现代化的高效果蔬汁生产的要求意义重大。论文在分析果蔬汁加工要求及现有一些典型工业榨汁机优缺点的基础上，提出一种新型连续层叠式榨汁机技术方案，对榨汁机机械结构及工作原理进行了描述，建立了以基本压滤单元为核心的试验验证机并进行了苹果汁的压榨作业试验，试验结果表明，驱动电机在 600r/min 转速下，在整个压滤通道内可获得平均 1.20Mpa 左右的推料压榨力，出汁率达 81.16%，榨出的果汁较好地保留了原料中的大部分营养成分，果汁品质良好，证明新型连续层叠式榨汁机方案切实可行，对推动农产品加工行业发展具有重要意义。

INTRODUCTION

In recent years, the market demands of fruit-vegetable juice and fruit-vegetable juice drink have increased, and the fruit-vegetable juice processing industry has become one of mainstay industries in the agricultural commodity processing field. The standard system and quality-control requirements of fruit-vegetable juice products are greater and stricter in many countries as consumers' needs of "safety, natural, fresh, and tasty" for fruit-vegetable juice products increase. These requirements lead to more advanced technology demands for fruit-vegetable juice processing devices, especially to juice press machines (Amaki K. et al., 2011; De Paepe D. et al., 2013). There is high application value and realistic significance to developing a new type of fruit-vegetable juice press machine with high productivity and good quality of juice products.

Universal hydraulic-filter juice press and belt-type filter juice press have dominating positions and are widely used in fruit-vegetable juice processing industry owing to their high productivity and better universality. The best-known universal hydraulic-filter juice press machines are the HPX-Series universal hydraulic-filter juice press machines of Swiss Bucher Unipektin and the 6TZ-Series universal hydraulic-filter juice presses that are jointly developed by China Agricultural University and other cooperators in 2003 (Domien De Paepe et al., 2015; Zhang S.H. Y. et al., 2008; Grimi N. et al., 2011; Le Bourvellec C. et al., 2004). The universal hydraulic-filter juice press has the following characteristics: good sealing performance during pressing process, sound hygienic conditions, high productivity, high automation level, high juice yield (82%–

85% for apple juice), and improved universality. However, this press has some defects, such as interrupted working mode, severe oxidative browning phenomenon of pressing post stage, complicated PLC controls and hydraulic driving system, and expensive acquisition and running cost. Another common juice press machine of the fruit-vegetable juice processing industry is the belt-type filter juice press, which is acceptable for large-scale juice production. This juice press has a continuous operating mode, high working efficiency, improved universality, and moderate cost. The most widely used models of belt-type filter juice press machines are produced by Germany FLOTTWEG company and Germany BELLMER company; the belt-type extracting juice press was then designed by Ensheng Guo (*Guo ESH. et al., 1997; Mollov P. et al., 2006; Nabila Labsi et al., 2013; Garcia-Torres R. et al., 2009*). However, the belt-type juice press has become obsolescent because of the drawbacks of open working environment, high browning levels, side leakage-prone of belt, high content of pulp, severe microbial contamination, and large consumption of wash water. Therefore, an excellent juice press machine should have high productivity, high juice yield, high quality of juice, and low energy consumption. Scholars and industry insiders have been carrying out a series of research and applications on main juice press machines. However, there is still no one type of machine with those characteristics.

A new type of continuous stack-up juice press is presented to realize the aims of continuous working mode, sealing filter-press environment without oxygen, large separating area, and short cycling time of press. The press machine consists of multiple sets of basic filter-press units with continuous filter-press passages and large separating area. They are concentrically stacked up and form a tandem sealing working environment, where the forward impetus of materials and press forces are from pumping pressure and push force of rotating push-wheel blades. The main structures and working process of the press are described.

The remainder of this paper is organized as follows. Section 2 describes the mechanical structure and the working principle of the new type of continuous stack-up juice press. Section 3 introduces the structure of an experimental machine and its passage pressures acquisition system. Section 4 presents the experiments to assess the performance of the new type of continuous stack-up juice press. Section 5 summarizes the conclusions.

MATERIAL AND METHOD

The Structure of New-Type Continuous Stack-up Juice Press

The structure of new-type continuous stack-up juice press is shown in Figure 1. This juice press consists of a pedestal, top lid, fixing guide-pillar, group of filter-press units, the top seal bearing, the bottom seal bearing, driving motor, coupling, and actuating shaft. Multiple large and laminar basic filter-press units made up the group of filter-press units, where all filter-press units were installed concentrically. The actuating shaft went through the center of the group of filter-press units and was connected with pushwheels of all filter-press units.

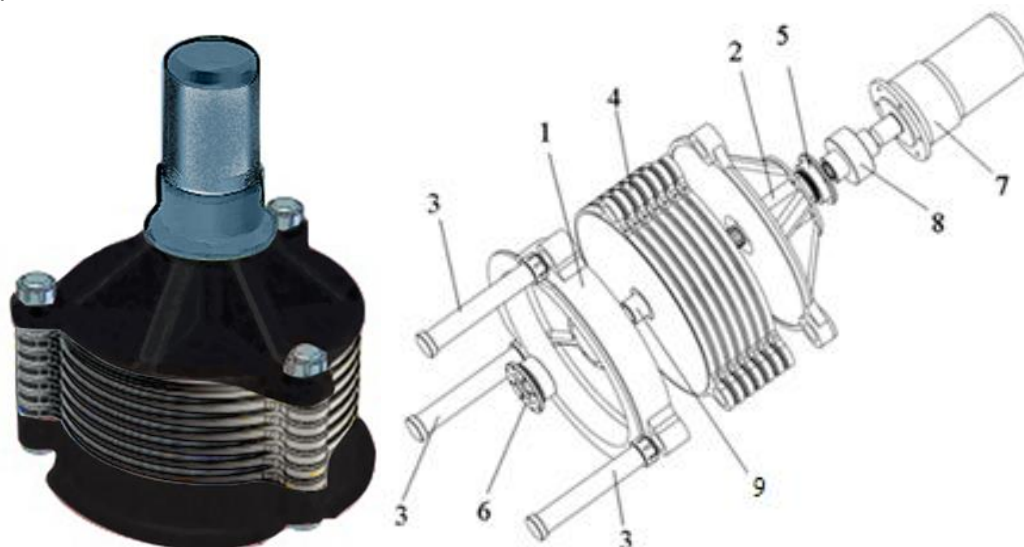


Fig.1- Structure diagram of new-type continuous stack-up juice press

1 - pedestal, 2 - top lid, 3 - fixing guide pillar, 4 - group of filter-press units, 5 - the top sealed bearing, 6 - the bottom sealed bearing, 7 - driving motor, 8 - coupling, 9 - actuating shaft

The right exploded view was created according to its left real object.

The Basic Filter-pressUnit

The basic filter-press unit is the core part of the continuous stack - up juice press, as shown in Figure 2. It consists of a pushwheel and the subassembly of juice collecting plate, where the pushwheel was arranged in the space of two subassemblies of the juice collecting plate.

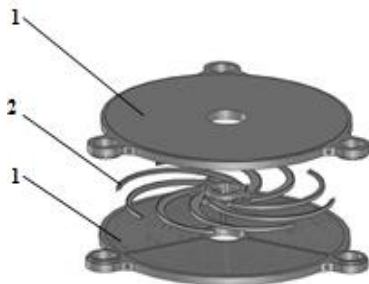


Fig.2 - The Structure diagram of filter-press unit
1 - subassembly of juice collecting plate, 2 - push-wheel

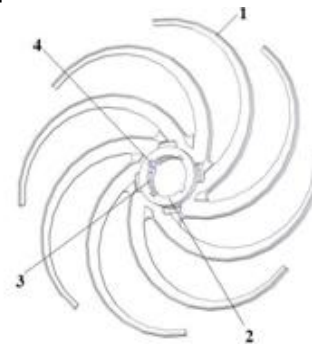


Fig.3 - The shape of push-wheel
1 - blade of push-wheel, 2 - wheel hub, 3 - feeding throat, 4 - keyway

The right view was created according to its real object of push wheel.

The shape of the push wheel is given in Figure 3. It is 20 mm thick. The radius of periphery is 600 mm, and the radius of the wheel hub is 100 mm. The push wheel has eight radial blades with caster angle, four axial direction keyways that connect with the keys of the actuating shaft, and four equispaced feeding throats along the circumferential direction. “The filter-press passage” is just formed by the gap between two adjacent blades and the other parts of basic filter-press unit. The caster angle structure for blade is chosen to facilitate the formation of high pressing forces that blades act on materials and uniform pressure distribution in the whole filter-press passage when push-wheel rotates.

The equations of blade curve be described as follows:

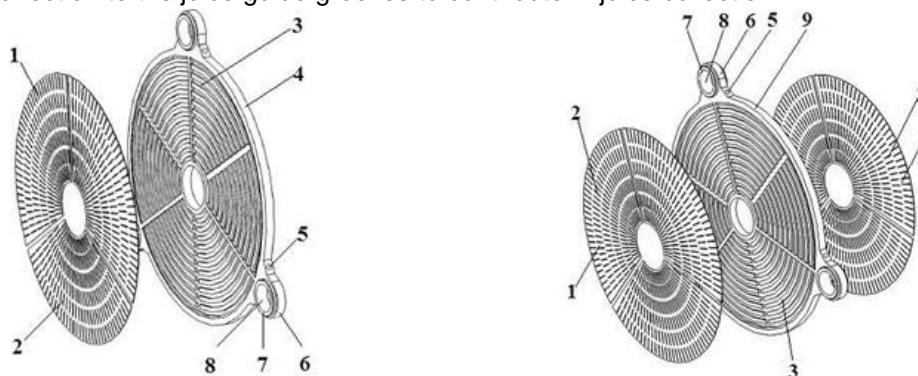
$$\begin{cases} r = -\frac{3(r-120)^2}{5120} + 60 & r \in [120,280] \\ r = \frac{3(r-600)^2}{10240} + 15 & r \in [280,600] \end{cases} \quad (1)$$

and

$$\tan \tau = \frac{dr}{r \times d\theta} \quad r \in [120,600], \quad \theta \in [0^\circ,150^\circ] \quad (2)$$

Define τ (in polar coordinates) as the caster angle, r as the radius, and θ as the radius angel.

The subassembly of juice collecting plates’ role is to collect juice. The subassembly has two types: the end and the center subassembly of the juice collecting plate. Figure 4 shows that both of them consist of the juice collecting plate and filter - nets, and the filter - nets are covered on the surface of the juice collecting plate. Moreover, the holes of filter - net were processed as long strips and laid along the perpendicular direction to the juice guide grooves to contribute in juice collection.



(a) End face juice collecting plate subassembly (b) Center juice collecting plate subassembly

Fig.4 - The constituting structures diagram of juice collecting plate subassemblies

1 - filter net, 2 - filter holes, 3 - juice guide grooves, 4 - end juice collecting plate, 5 - discharge holes of juice, 6 - chucking lug, 7 - location step, 8 - location hole, 9 - center juice collecting plate

All model graphs were created according to their real objects.

The end subassembly of juice collecting plate is arranged at the top and the bottom of the filter-press unit; thus, only one side of its juice collecting plate has juice - guide - grooves and is covered by filter - net. The center subassembly of the juice collecting plate is arranged at the middle of the filter-press unit. Thus, both sides of the center juice collecting plate have juice - guide - grooves and covered by filter - nets. All peripheries of all kinds of juice collecting plates have juice discharge holes that interconnect with the juice guide grooves. Moreover, each juice collecting plate has three chucking lugs that connect with the fixing guide pillar to locate with and compact all components of group of filter-press units to ensure the sealing and oxygen - free condition of inner press space. Furthermore, each juice collecting plate has an annular groove to place a hollow wear - resisting rubber ring to adjust the resistance of discharge residues and keep sufficient press force in the filter-press unit.

The Actuating Shaft

The actuating shaft feeds materials and drives the push wheel to rotate with it. Its shape is given in Figure 5. It is a special hollow pipe with a feeding throat of pulps (the entrance of pulps from feeding the screw pump), some equispaced outlets of pulps along the axial and circumferential directions (interconnecting with the feeding throats of the push wheel), four long keys (connecting with four keyways of the push wheel), spline - shape shaft end (connecting with the driving motor); and locating shaft shoulder (located with a group of filter-press units along axial direction). The actuating shaft goes through the center of a group of filter-press units and drives the push wheels of all filter-press units to rotate with it by the connections of keys.

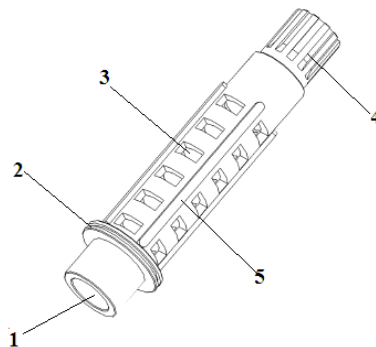


Fig.5 - The outside view of actuating shaft

1 - feeding throat of pulps, 2 - locating shaft shoulder, 3 - outlet of pulps, 4 - spline - shape shaft end, 5 - long - key

The model graph was created according to its real object.

The Structure of Experimental Machine

An experimental machine is set up to confirm the feasibility of the technical solution, as shown in Figure 6. The machine mainly comprises a base frame, feeding screw pump system, pre - filter system, hold - down mechanism (group of hold - down wheels), simplified filter-press unit, driving motor, damping adjustment device, and pressure measurement system of filter-press passages.

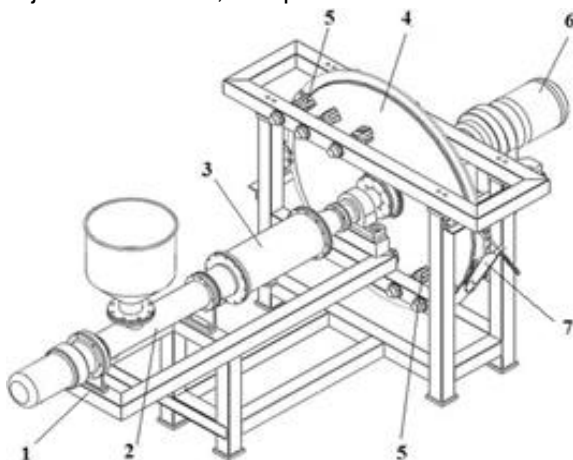


Fig.6 - The constituting structures diagram of experimental machine

1 - base frame, 2 - feeding screw pump, 3 - pre - filter system, 4 - simplified filter-press unit, 5 - group of tight compressing wheels, 6 - driving motor, 7 - damping adjustment device

The left model graph was created according to its right real object.

The push wheel in the experimental machine is simplified as the structure of two filter-press passages that belong to the same filter-press unit. The detailed structure is given in Figure 7. The structure mainly consists of two fins, a centering ring, and two sets of damping devices. The fin is made of alloy steel, and its thickness is 12 mm. The short cutting edge of the fin (I position) has the same curve shape as described in Equations (1) and (2). The long cutting edge of the fin (II position) is round and is 600 mm in radius. The centering ring has a central location hole (86 mm radius), some fixing thread holes, and two feeding throats (through - holes). Two fins are fixed on the centering ring by bolt connections, and the spaces between the short cutting edges of two fins are filter-press passages, which interconnect with two feeding throats of the centering ring. Moreover, two sets of damping devices are arranged at the outlets area of filter-press passages. The damping device consists of a damping pull rod, damping spring, nut, and damping block. Adequate pressure distribution is kept in filter-press passages, and overpressure protection around the outlet areas of filter-press passages is created by adjusting the damp spring to control the resistance of residue discharge.

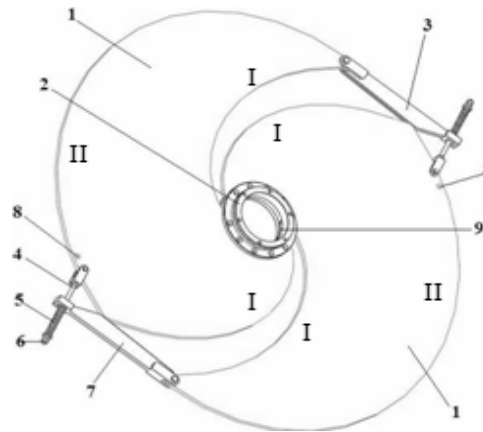
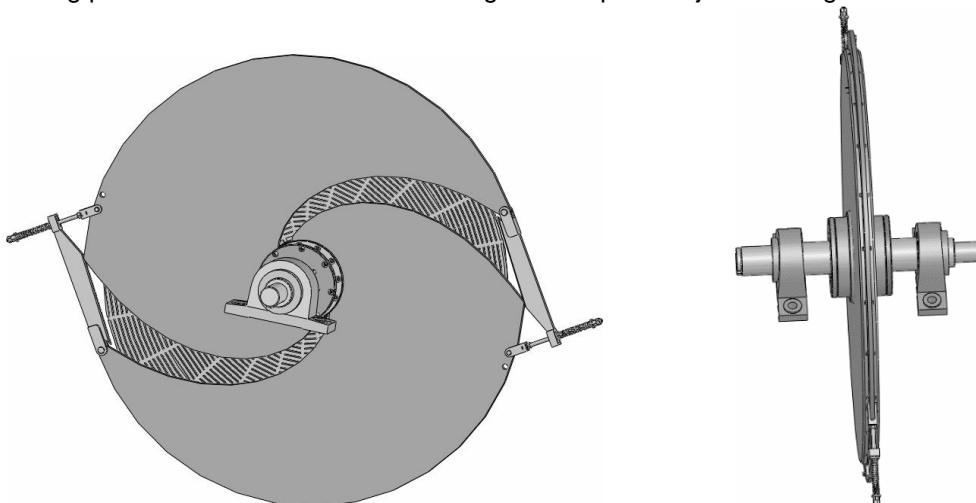


Fig.7 - The structure of the simplified push-wheel

1 - fin, 2 - centering ring, 3 - damping device, 4 - damping pullrod, 5 - damping spring, 6 - nut, 7 - damping block, 8 - mounting hole, 9 - feeding throat

The model graph was created according to its real object.

Two sets of end face juice collecting plate subassemblies are fixed on the flange of the actuating shaft by bolting connections, and the simplified push-wheel are installed between them. Two fins are attached on the base frame by bolt connections, as shown in Figure 8. The actuating shaft drives two sets of end face juice collecting plate subassemblies to rotate. Moreover, seals are installed between end face juice collecting plate subassemblies and actuating shaft to prevent juice leakage.



(a) One side of simplified filter-press unit

(b) Whole structure of simplified filter-press unit

Fig.8 - Graph of simplified filter-press unit

All models graphs were created according to its real object.

The Passages Pressure Acquisition System

This study arranges a passage pressure acquisition system (Figure 9) to obtain the pressures values of different areas of filter-press passages during the juice pressing process. Eight equispaced pressure taps are on the short cutting edges of each fin. Each of pressure tap is connected with a minor pipe. The pipe goes through the measure tap, reaches the exterior of filter-press passages, and connects with a pressure sensor (FreescaleMPX5700DP). The pressure sensor has two connecting points. One is used to measure positive pressures, and the other is used to measure negative pressures. The positive connecting point connects with the other end of the minor pipe, and the negative connecting point is exposed in air. Thus, juices in filter-press passages are pressed into the minor pipes and act on the positive connecting points of sensors.

The pressure values of all pressure taps would be detected and converted to voltage values by sensors. All voltage values would be transmitted to a data acquisition card (DAQ, MPS - 010602), which could acquire and store 16 channels analogue signals simultaneously. DAQ is installed on a computer. The real time pressures of filter press passages could be recorded, stored, converted, and displayed by a record - display system based on LabView software.

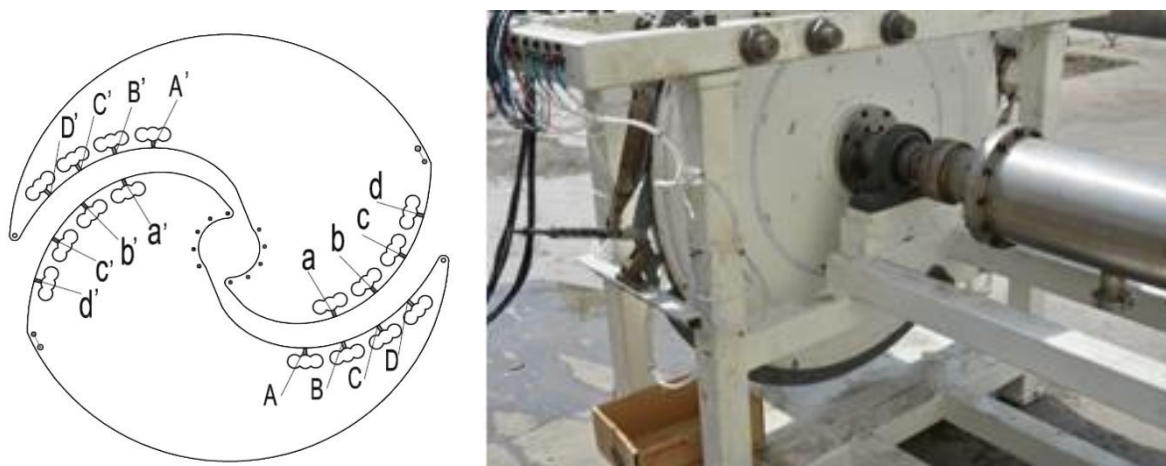


Fig.9 - Diagram of Pressure Taps Layout and Arrangement of Channel Pressure Acquisition System

The model graph was created according to its real object.

RESULTS

Instruments, Equipment, and Detection Methods

Instruments, equipment, and detection methods include Gary eclipse fluorescence spectrophotometer, T - 1000 electronic balance, Refrigerated cabinet TDL - A - 5 desk centrifuge, S10 high - speed homogenate machine, 722S visible spectrophotometer, PHS - 25 PH meter with digital display, MS300 hot plate magnetic stirrer, SPME manual sample injector, Water bath, H₂O₂, and Determination Kit for GSH. All reagents are of analytical grade (Markowski J. *et al.*, 2009).

Total ascorbic acid (TAA) was determined by fluorophotometry. Samples were homogenized at 8000 rpm in two percent oxalic acid protective solution (solid - to - liquid ratio was 1:1). About 3555 g of homogenates (particle size < 0.2 mm) were centrifuged in twenty minutes. The supernatant was extracted as further experimental samples. Reductive - form ascorbic acid (AA) was determined by 2 - 6 dichloro - indophenol titration method. Dehydroascorbic acid (DHA) is the difference between TAA and AA (Yao G. *et al.*, 2015). The samples were randomly selected. Three apples were in one sample, and three samples were in one group. Each group was determined for three times and took the average.

Soluble sugar was determined by the anthrone colorimetry method. Each sample was determined for three times, and the average was taken.

The content of malic acid was converted from the mass fraction of malic acid in titratable acid, and the conversion ratio is 6.7. The titratable acid was determined by NaOH potentiometric titration.

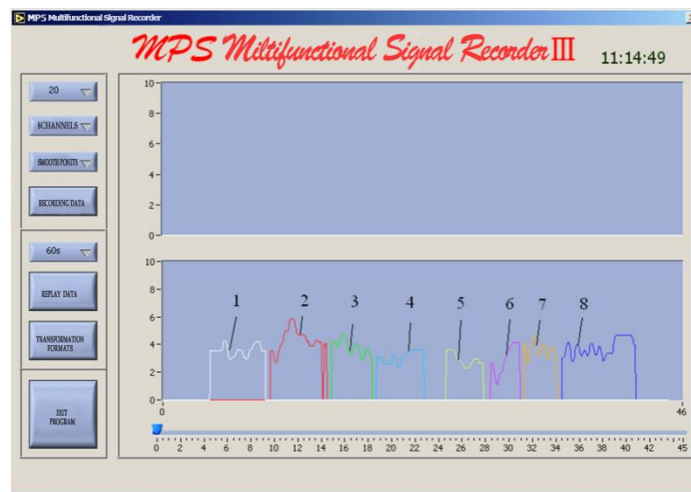
Sugar - acid ratio is the ratio of soluble sugar and malic acid. The contents of H₂O₂ and GSH in apples and apple juice were determined and calculated in terms of their different determination regulations and kits.

The on - sale, matured, free from contusion and putrefaction, free from live insects, and uniform size “Ralls” apples were chosen as the experimental materials. The Ralls apples were saved at 4 °C and washed by 200 mg/L of chlorine water before processing. Before pressing, each apple was cut into four pieces and broken up in the pounding crusher (Yao G. *et al.*, 2014).

The pounded apple mash was poured into the hopper of feeding screw pump. The mash was fed into the actuating shaft and filter-press passages to be pressed continuously. The average pressure of filter-press passages was obtained according to the output from passage pressure acquisition system. The whole working process of experimental machine is shown in Figure 10.



a) Starting experimental machine



b) Recording pressures of filter-press passages



c) Collecting juice



d) Discharging residues

Fig.10 - The working process of experimental machine

In the fig.10, b, the horizontal axis of this graph is a timeline (second, s), and the vertical axis displays converted voltage (volt, V).

Figure 11 shows the relation curve of actuating shaft speed, average of passages pressures, and juice yield. When the actuating shaft rotates at 400 rpm, the average press force of whole filter-press passage is 1030 KPa, and the juice yield is 62.64 percent. The ideal speed range of the actuating shaft is from 600 rpm to 800 rpm. The average press force of the whole filter-press passage is above 1100 KPa within the speed range. When the actuating shaft rotates at 600 rpm, the average press force of the whole filter-press passage is 1200 KPa, and the juice yield is 81.16 percent. However, the performance of creating press force and juice yield is lessened when the actuating shaft speed is more than 800 rpm.

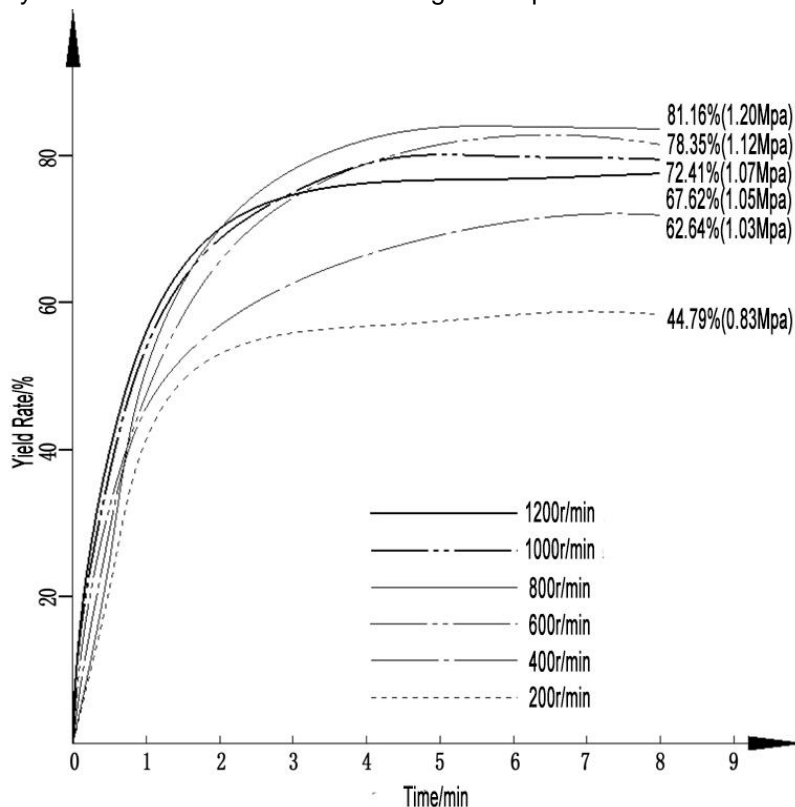


Fig.11 - The relation curve of driving motor speed, average channel pressure, and juice yield

Table 1 displays the comparison of primary nutrient content of apple before and after pressing. Squeezed apple juice keeps more nutrient content than a raw apple. The results demonstrate that the retention rates of TAA, AA, DHA, and soluble sugar were 71.29%, 63.96%, 82.27%, and 96.35%, respectively, which show almost no change in content of malic acid and sugar - acid ratio.

Table 1

Comparison of primary nutrient content of apple before and after pressed

Parameters	Raw apple	Apple juice
The mass ratio of TAA /(mg.(100g) - 1)	6.41	4.57
The mass ratio of AA /(mg.(100g) - 1)	5.05	3.23
The mass ratio of DHA /(mg.(100g) - 1)	1.41	1.16
The mass fraction of soluble sugar (percent)	12.61	12.15
The mass fraction of malic acid (percent)	0.56	0.54
The Sugar - acid ratio	22.85	22.84

CONCLUSIONS

A new type of juice press machine, continuous stack - up juice press, was presented; and an experimental machine was set up for confirmation. Ralls apple juice pressing experiments of Ralls apples were conducted on the experimental machine. The creativeness and aimability of this technological solution were proven according to the results of experiments. Design goals of high yield rate, high productivity, and good quality of juice were reached.

The conclusions are as follows:

(1) High productivity is achieved because of the creative design of the basic filter-press unit, which ensures that large quantities of materials could be processed in short periods for multiple inner smooth passages of material flow and juice collection and its large separated area. High productivity is also achieved because of its continuous working mode.

(2) High yield rate is mainly because of its high productivity and the special creating way of press - pressure, that is, the combination of pumping pressure and torque thrust of push-wheel blades. This combination could create high average press - pressure in filter-press units when actuating shaft rotates at some rotating speed of (such as 600 rpm). Materials could be pressed well.

(3) Good quality of juice mainly is ascribed to its sealed working environment and the continuous removal of residues.

Developing highly - efficient fruit - vegetable juice processing technologies and equipment is significant to promote the development of the fruit - vegetable processing industry and the agricultural commodity processing industry. More experiments need to be done to modify and improve design parameters and mechanical structures to contribute to improving overall design.

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