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Research Article

Innovative Design of a Rigid Package Container Applied in Ultra High Pressure Food Processing Based on TRIZ

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Abstract: An innovative structure of Rigid Package Container (RPC) was designed based on TRIZ for improving productivity. The technical contradiction of RPC was solved by TRIZ contradiction analysis methodologies and obtained solution principles. Then mechanical analysis on sealing process of o-rings and structural optimization on its key components of RPC were completed. Ultimately, optimized structures of RPC had been achieved. Experiments on the sealing properties had stated that this structure was reasonable and reliable in sealing, easy to assembly and disassembly, compact structure and light weight. Thus, this innovative RPC could be applied in many ultra high pressure vessels in food industry.

Keywords: O-ring seal, rigid package container, TRIZ, ultra high pressure

INTRODUCTION

Ultra High Pressure (UHP) technology is widely applied in various modern industrial fields in recent years. As a non-thermal technology of food processing, ultra high processing is applied in food industry in large scale and fast development because of integrality of bioactive compounds, the sensory and nutritional attributes of food, long enough shelf life of food at room temperature, energy-saving and environment-friendly, etc. (Denys *et al*., 2005; Ahmed *et al*., 2007; Mcinerney *et al*., 2007). The UHP can effectively avoid various disadvantages of traditional thermal technology of food processing. There are lots of superiorities in energy sources, chemical pollutions and demanding for foods of high quality (Zhao *et al*., 2002).

One of main problems of UHP technology is limited to food packages during Ultra High Pressure Food Processing (UHPFP). The package material should have sufficient toughness in order to ensure integrality of food and package. Therefore, it is very important to select package materials. Because irreversible deformation, metal cans, brittle glass bottles and penetrative papers package material are inapplicable to UHP food package. Plastic material can be widely used in UHP food package owing to good airproof in higher pressure process. But there are also many disadvantages for plastic material used in UHPFP, such as permeability, unsatisfactory barrier performance (Lambert *et al*., 2000; Qiu *et al*., 2005). Above all, it only suit to single, one-off usage, occupying large volume and less repeat usage. So it is very necessary to design and manufacture a novel RPC used in UHPFP. There are some outstanding advantages for RPC compared to those package vessels and package materials to process the solid or liquid food, batch processing, larger working volume, repeated usage etc. While the RPC should be simple in structure, easy to assembly and disassembly, compact structure and light weight, it will be a large amount of market demands for RPC with reasonable price. Certainly the RPC must be matched with Ultra High Pressure Vessel (UHPV) in existence. It is an effective method to solve the existed problems in food package in UHPFP. In this study, the theory of TRIZ is used to study the optimization plan for RPC, then to design its mechanical structure, analyze mechanically on the o-ring seals and do experiments for verifying sealing performance.

DESIGN OF A RIGID PACKAGE CONTAINER BASED ON TRIZ

Theory of Inventive Problem solving (TRIZ), which was created by Altshuller in the former USSR in 1946 and is now being developed and practiced throughout the world, is a theoretical foundation and methodology in innovation practice. It offers a wide-ranging series of techniques and methods to help researchers to invent innovate, solve the engineering problems in innovative and powerful ways. The theory has been applying for solving invention problem by the developed country such as Russia, America, Japan,

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Table 1: Technical contradiction analysis for the RPC

Worsening features		
Feature	No.	Solution principles
Weight of moving object	01	02, 26, 29, 40
Length of moving object	03	01, 07, 35, 04
Volume of moving object	07	35, 03, 28, 01, 07, 15, 10
Stability of structure	13	28, 10, 01, 39
Reliability	27	14, 01, 40, 11
Adaptability	35	15, 29
Productivity	39	10, 06, 2, 34

Feature to improve: Volume of moving object (7)

Table 2: Description of adapted solution principle

Solution principles	Description
01	Division
06	Versatility
07	Place one object inside another Place multiple objects inside others Make one part pass (dynamically) through a cavity in the other
10	Preliminary action

Europe, etc. Zhang *et al*. (2006) studied the innovative design of reciprocating seal for hydraulic cylinder based on TRIZ. Peng *et al*. (2009) stated that energy saving and output enhancement of pumping well based on the theory of QFD/TRIZ. Ko and Kim (2012) designed an actuation system for manipulator upper arm based on TRIZ.

Qiu *et al*. (2005) stated that volume of packaged food and water subjected to a high pressure will decrease. But its decrease was limited and can up to 12% according to different products. After pressure relief, the volume will be recovery. The key problem of RPC was its reversibility for the pressure effect. In order to complete high pressure processing, the RPC must move back and forth alternately subjected to high pressure effect, which had perfect sealing performance and credible position mechanism. Variable volume of RPC was too big to use the high pressure vessel sufficiently. When variable volume of RPC was too small, it will be destroyed by pressure action. So the parameter of mobile object's volume had different requirement owing to raise productivity and improve system reliability. The parameter of mobile object's volume was an obvious contradiction. TRIZ offered methods to overcome this contradiction. As one of TRIZ contradiction analysis methodologies, the technical contradiction analysis was adopted. The above problem belonged to technical contradiction and could apply the standard solution protocol to deal. The problem can be stated that it's need to improve volume of RPC to enhance productivity and maintain system reliability. This statement can be interpreted as a set of contradictions between the "a feature to improve" and the corresponding "worsening features" out of 39 TRIZ variables. For the current problem, the "feature to improve" can be defined as "mobile volume" which was the 7th variable (Table 1 and 2).

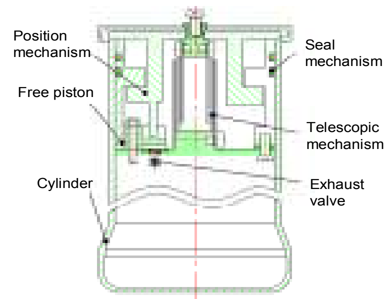

Fig. 1: Schematic diagram of RPC used in ultra high pressure food processing

A new design of RPC evolved from this invention principle was presented. The structure of RPC was consisted of six main parts as shown in Fig. 1. There were position mechanism to make sure free piston whether or not move to properly position, free piston to move freely when it was processed by pressure, seal mechanism to maintain good sealing performance when free piston moved up and down, telescopic mechanism to obtain variable volume for RPC by telescopic motion, exhaust value to discharging gas and needless water from the cylinder and cylinder to contain food products.

There was a thin layer of 1.5 mm to separate the RPC from the inner wall of the UHPV for flow of pressure transfer medium. The food products were inserted in a cylindrical RPC. The exhaust valve was opened for discharging gas and needless water from the cylinder. After the piston mechanism was fit to the correct position, the lid of RPC was rotated by external force. The lid and the free piston were rotated simultaneously. During rotating, the position mechanism was turned and the exhaust valve was closed. At the same time, the lid and the free piston were moved to appropriate position by position mechanism's movement. Thus, the free piston will be moved undergoing a high pressure.

Then, water was poured into the cylinder from holes on the lid at the beginning of pressurization. The free piston must be moved down for the supplement of water compression to make the pressure equal between cylinder inside and outside with pressure increased. Then the liquid food or solid food was treated by UHP.

Next, after subjected to pressures (400 or 600 MPa) for several minutes (5 or 10 min), the pressure was relieved. Due to pressure decreasing, water will be expanded and flowed out the cylinder. The free piston was moved back to the initial position. Then, the exhaust valve was opened by the position mechanism when the lid was rotated. At the same time, the movement of position mechanism to let the free piston come back to the initial position.

Finally, take out the food from the cylinder by rotating the lid of RPC. Then, the next work cycle could be begun.

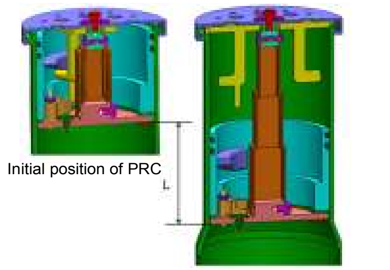

Fig. 2: Different position of PRC on different conditions

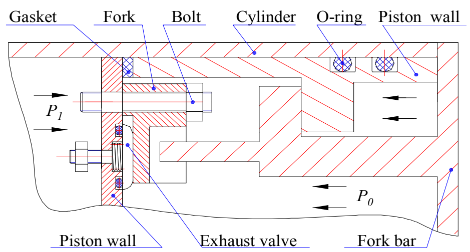

Fig. 3: Schematic diagram of sealing structure of rigid package container

Design of the cylinder: As mentioned above, water was used as the medium to transfer pressure. Thus, several requirements must be achieved for PRC. They were as followings: resistant to rust for avoiding contamination of food; enough rigidity to avoid the deformation while it was operated such as put into UHPV and taken off from UHPV; easy to clean to avoid the bacteria growth; good seal ability to assure no liquid flow between outside and inside of PRC. Therefore, stainless steel was suitable as the construct material of RPC for all components and the wall thickness of 1.5 mm could meet the structure requirements.

The work volume of RPC was 3.8 L because it was matched with UHPV in our lab with 5 L work volume.

Design of free piston of PRC: The characters of free piston should be achieved as followings: easy and quick assembly and disassembly with the cylinder and the stopper of UHPV; excellent sealability between piston and cylinder by good sealing structure; the free piston moving smoothly to change the volume of food in the inner of cylinder according the compress volume by high pressure, it could not be rotated while it was moving in the cylinder to assure come back the original position with fork.

Design of the telescopic mechanism: There were several functions for the telescopic mechanism, such as guiding, orientation and freely telescopic motion. The aim of the present study was to design a telescopic mechanism subjected to UHP. The key of its design was to design structure type and calculate its motion distance.

It was a fact that the motion distance of the telescopic mechanism was determined by water compressed volume (Fig. 2). This distance had been calculated by compressed volume to determine the basic length of telescopic mechanism, as shown in Eq. (1) and Fig. 2. To avoid circumferential direction rotation of the telescopic mechanism and correctly position of the fork, it is necessary to use rectangular structure. To make this mechanism more compact, three-level type has been designed in RPC:

$$L = {}^{V_c}\!/_{S} \tag{1}$$

where, L, Vc and S denote the motion distance of telescopic mechanism, the compressed volume of water and sectional area of telescopic mechanism, respectively.

Reciprocating sealing structure: It was necessary for quick actuating and closure of RPC because of continual using in batch UHPFP. So it was of significance to design sealing structure ideally for improving its service and fatigue life of sealing components.

Four sealing structures had been designed in the RPC. They were the piston wall, the exhaust valve and two bolts on the piston floor, respectively (Fig. 3). Owe to the two bolts belonging to static sealing, If there were enough forces to tighten the two bolts, their sealing performance were perfect. Principle of the sealing mechanism of the piston wall was same with the exhaust valve. So it was feasible to only analyze the piston wall.

It was generally known that the o-ring had many merits, such as simple structure, good sealing performance, meeting static and dynamic sealing requirement, small sealing groove and easy manufacture (Ana *et al*., 2009). It was necessary not only to make o-ring sufficiently compressed but also to obtain minimal friction to prevent spiral failure decreasing abrasion and energy loss to make sure the sealing performance of free piston. The sealing mechanism of o-ring was elastic sealing when the pressure was lower. However, it came true sealing by compressed deformation produced via assembly and itself deformation under higher pressure. Along with increasing of pressure and compressed deformation, friction force F_e between o-ring and the piston wall and friction force F_p produced by pressure difference would also increase. The friction force might influence the reliability of the free piston when this piston was reciprocating inside cylinder. So it was important to accomplish optimization design for reciprocating sealing structure. Its parameters were mainly consisted of compressibility, stretch value, contact width, grooves dimension and groove fit clearance etc., (Chen *et al*., 2011). Considered that the pressure was bigger instantly, the sealing structure of the free piston had been designed two-level o-rings to prevent extrusion and wrest of o-rings from grooves.

It was necessary to analyze dynamic friction force F_d by quantitative analysis (Fig. 3) based on stress and strain of the o-ring. By doing this, it could provide a useful basis for designing the free piston.

Dynamic friction F_d was the sum of F_p and F_e, where F_p was produced by pressure difference of pressure transfer medium; F_e was produced by compressed the o-ring. They were shown in Eq. (2):

$$F_d = F_p + F_e \tag{2}$$

Supposed that the material of the piston wall followed Hook's law. It was known that:

$$\varepsilon_\theta = \frac{1}{E}[\sigma_\theta - \mu(\sigma_r + \sigma_z)] \tag{3}$$

$$\varepsilon_r = \frac{1}{E}[\sigma_r - \mu(\sigma_\theta + \sigma_z)] \tag{4}$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_\theta + \sigma_r)] \tag{5}$$

where,

σ_θ & ε_θ : Stress and strain produced by circumferential force
σ_r & ε_r : Stress and strain produced by radial force
σ_z & ε_z : Stress and strain produced by axial force
μ, E : Poisson's ratio and Young's modulus of piston material

When the piston was moved toward the left, the dynamic friction force (Xu, 1992) produced by two o-rings was:

$$F = \frac{f\pi Dd}{1-\mu^2}\left\{\left[\pi e^2 E(1+4\mu\frac{d}{D}) + \mu(1+\mu)(\frac{3p_0+p_1}{2})\right]\right\} \tag{6}$$

where,

f : Coefficient of friction
D : Internal diameter of pistion wall
d : Diameter of the o-ring cross section
e : Compressibility of the o-ring
P_0 & P_1: The study pressure and products produced pressure

Ultimately, some results had been achieved by analysis and calculation. The groove width and depth and fit clearance of between the piston wall and the cylinder were 5, 3 and 0.036 mm, respectively.

SEALING EXPERIMENTS FOR RIGID PACKAGE CONTAINER

Experiments were carried out to verify the sealing performance, quick actuating and closure efficiency and strengths of RPC. The sealing experiment plan was shown as Table 3. Its setup type was WHGR 600-10×64 with maximum operating pressure of 600 MPa and internal volume 5 L (diameter 100 mm, height 640 mm). The working temperature range of the equipment was 5 to 40°C.

Table 3: Experiment plan of sealing performance for RPC

	Parameters	
Teams	Pressure/MPa	Time/min
First	150	5, 10, 15
Second	250	5, 10, 15
Third	350	5, 10, 15
Fourth	450	5, 10, 15

The test results had indicated that this structure was feasible and reliable in sealing and strength. Two o-rings were perfect after testing. It was easy to take out free piston from the cylinder, because the contact pressure between the o-ring and the piston wall was smaller. In addition, the telescopic mechanism limited steadily and reliably to the free piston to move in circumferential direction. All of components of the RPC were no deformations.

CONCLUSION

The technical contradiction of RPC used in UHPFP was found out by TRIZ contradiction analysis methodologies. Invention principles of this design were proposed to make optimization plan for RPC. The detail studies of the RPC were as followings from the theoretical analysis and practical experiments:

Firstly, dynamic friction force of two-level o-rings had been calculated by theory method. The groove width and depth and fit clearance between the piston wall and the cylinder were obtained.

Secondly, leakage of sealing structures by sealing experiments was zero. It had stated that sealing performance was excellent and the telescopic mechanism moved freely.

In a word, this innovative RPC was reasonable and reliable in sealing, easy in assembly and disassembly, compact structure and light weight. So it will have a promising future.

REFERENCES

Ahmed, J., H.S. Ramaswamy, A. Ayad, I. Alli and P. Alvarez, 2007. Effect of high-pressure treatment on rheological, thermal and structural changes in basmati rice flour slurry. J. Cereal Sci., 47: 148-156.

Ana, R.C., F.G. Estrella and N. Manuel, 2009. Volatile compounds in fresh meats subjected to high pressure processing: Effect of the packaging material. Meat Sci., 81: 321-328.

Chen, Q., S.Q. Zhang and X.G. Bu, 2011. Study on o-ring mechanism and characteristics in reciprocating motion. Chem. Eng. Mach., 16: 714-716.

Denys, S., A.M. Van Loey and M.E. Hendrickx, 2005. A modeling approach for evaluating process uniformity during batch high hydrostatic pressure processing: Combination of a numerical heat transfer model and enzyme in activation kinetics. Innov. Food Sci. Emerg. Technol., 1: 5-19.

Ko, H.K. and K.H. Kim, 2012. Design evolution of an actuation system for manipulator upper arm based on TRIZ. J. Adv. Mech. Des. Syst. Manufact., 6(1): 131-139.

Lambert, Y., G. Demazeau, A. Largeteau, J.M. Bouvier, S. Laborde-Croubit and M. Cabannes, 2000. Packaging for high-pressure treatments in the food industry. Packag. Technol. Sci., 13: 63-71.

Mcinerney, J.K., C.A. Seccafien, C.M. Stewart and A.R. Bird, 2007. Effects of high pressure processing on antioxidant activity and total carotenoid content and availability in vegetables. Innov. Food Sci. Emerg. Technol., 8: 543-548.

Peng, Y., W.H. Yan and H. Wu, 2009. The study on energy saving and output enhancement of pumping well based on the theory of QFD/TRIZ. Proceeding of the International Conference on Energy and Environment Technology, pp: 449-453.

Qiu, Y.X. and S.Y. Ye, S.H. Xu and Z. Li, 2005. Effect of super high pressure process to food package materials. Packa. Food Mach., 23: 7-9, (In Chinese).

Xu, F.R., 1992. Study and research on the total friction resistance produced by o-ring washers of the piston and piston rod in hydraulic cylinder. Drive Syst. Tech., 3: 21-28, (In Chinese).

Zhang, F.Y., H. Liu and L.J. Zhang, 2006. The innovative design of reciprocating seal for hydraulic cylinder based on TRIZ evolution theory. Proceeding of the International Federation for Information Processing (IFIP), 207: 440-449.

Zhao, L.C., Y.D. Tang and Z.Q. Qi, 2002. Super-high-pressure food- processing technology and its equipment. He Bei J. Ind. Sci. Technol., 19: 21-28, (In Chinese).