Horizontal CIP Apparatus for Food

Tomoya MINAMINO*1

*1 Heavy Machinery Department, Industrial Machinery Division, Machinery Business

High pressure processing (HPP) technology attracted attention in the 1980s as a non-thermal sterilization method, and its research, development and practical application were promoted in Japan. High pressure food processing equipment, which did not spread widely at that time, is now seeing increased demand due to recent situational changes in food companies in Japan. Conventional, vertical, cold-isostatic-pressing (CIP) apparatuses are difficult to install in the facilities of food companies; hence, a horizontal CIP apparatus, "FOOD FRESHER," has been developed. This paper describes the situation in high-pressure food processing technology and outlines the newly-developed FOOD FRESHER and its future development.

Introduction

High pressure processing (HPP) is a process of applying a high pressure above several thousand bars on food and has been proposed as a sterilization method to replace heat treatment. Full-fledged research and development began in the latter half of the 1980s in Japan. There also are studies on the utilization of HPP to obtain, for example, unique texture and flavor, as well as the sterilization effect. Since the 1990s, HPP has been practically applied and disseminated to general products in the United States. In Japan, interest in and demand for the practical application of HPP have recently been increasing.

Against this backdrop, Kobe Steel has developed a horizontal cold-isostatic-pressing (CIP) apparatus, FOOD FRESHER, for food manufacturers by applying the technology of CIP apparatuses, which the company has developing for many years.[1] In 2015, Kobe Steel delivered a 400 MPa machine, its first, for shucking oysters, and then it completed a machine with 600 MPa specifications. This paper outlines these high-pressure apparatuses and examples of the application of HPP.

1. Worldwide status of HPP

HPP is a technology mainly aimed at obtaining a sterilizing effect using the energy of pressure, instead of heat. Unlike heat treatment, pressure treatment generally does not promote any chemical change in food[2] and has the advantage of affecting neither nutrients nor flavor. Substantial research and development activities were initiated in Japan in the latter half of the 1980s. Various applications other than sterilization have also been studied. These activities have resulted in a wealth of data regarding, for example, the modification of proteins and starches, utilization of a high-pressure non-freezing zone (pressurized rapid thawing, pressure-shift freezing, and pressurized non-freezing preservation), control of enzyme reaction (inactivation and activation), and the effect on biological membranes (extraction and osmosis).[1]

Since then jams and rice products have been sold as high-pressure processed foods; however, the application to general products has been limited due, among other things, to its lack of a sterilization effect on spores and the difficulty of obtaining Food Sanitation Act approval for it as a method of non-heating sterilization.

Meanwhile, stimulated by the extensive activities in Japan, basic research has been carried out overseas, mainly in Europe and the U.S. Especially in the United States, the practical applications of HPP spread rapidly in the 1990's, and it is being applied widely to juice, meat, pet food, baby food, etc.[3] One of the most common high-pressure processed foods in the United States is avocado paste. Unlike heat treated products, this high-pressure treated avocado paste retains its original flavor and texture, while having a longer best-before date.

Recently, the Japanese food industry has been increasingly interested in foods without antimicrobial additives and in unique products with natural flavor and texture not found in conventional products. As a result, HPP is attracting attention again. This method not only improves the quality of foods but also extends the product expiration date, an achievement that has been difficult in the case of heating sterilization. Thus, HPP is expected to reduce the amount of waste and the number of deliveries, contributing to the resolution of environmental issues.

In addition, there is an increasing interest in high-pressure processing as a means of increasing production capacity. Applying high pressure to shellfish, such as bivalve shells, and crustaceans can facilitate shucking, the extraction of scallops and meat. It also offers the advantage of more easily preventing the contamination of products by shell fragments, compared with the conventional

shucking by hand. The marine product processing industry that deals with bivalve shellfish and the like suffers from the lack of shucking workers, and has already introduced high-pressure processing for shucking applications.[4] In Japan, HPP is being disseminated into food processing facilities in this way.

2. HPP apparatus

2.1 Construction of HPP apparatus

HPP employs a CIP apparatus using liquid as a pressure medium, or, a warm-isostatic-pressing (WIP) apparatus, which is based on a CIP apparatus and is equipped with a heating function up to approximately 90°C. Kobe Steel began the production of high-pressure apparatuses for industrial applications, such as metal, ceramics and electronic parts, in the 1960s and has sold nearly 900 units so far.[1] For industrial applications, CIP apparatuses with pressure capacities greater than 700 MPa and vessel volume greater than 15 m^3 have been used in production (**Fig. 1**). As shown in **Fig. 2**, the basic structures of CIP apparatuses are classified into the following two types in accordance with the difference in their pressurizing mechanisms:

(1) Intensifier type (Fig. 2 (a)): a mechanism that feeds a medium into a high-pressure vessel for pressurization by an intensifier and is mainly used for a mid- to large-size machine with a processing pressure of 600 MPa or below.

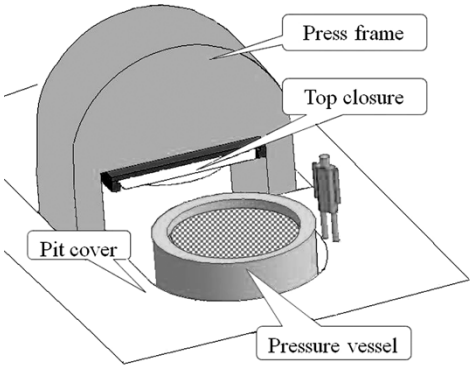

Fig. 1 Large CIP apparatus

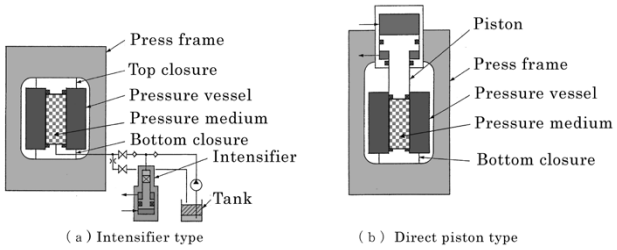

Fig. 2 Comparison of pressurizing system[1]

(2) Direct piston type (Fig. 2(b)): a mechanism that pushes a piston into a high-pressure vessel to directly pressurize the medium and is mainly used for a small machine with a processing pressure exceeding 600 MPa. In this construction, the pressure vessel and pressure cylinder are arranged in series, making the body of the apparatus larger than that of the intensifier-type. It requires no intensifier or ultrahigh-pressure piping, which simplifies the overall construction of the apparatus.

Kobe Steel applied the technologies of the intensifier-type and direct-piston-type machines described above and had developed a vertical-type high pressure apparatus for the food industry, as described below.

2.1.1 HPP apparatus for research and development

A direct-piston-type compact apparatus (Dr. CHEF) for R&D is shown in **Fig. 3**. The pressure specified for this apparatus is 700 MPa (processing chamber size, $\phi 60 \times 200$ mm), and it is also possible to build an apparatus with a maximum specification pressure of 1 GPa (processing chamber size, $\phi 50 \times 150$ mm). The apparatus is very compact, allowing manual swinging of its press frame that holds the axial force caused by high pressure, for example.

2.1.2 HPP apparatus for production

A high-pressure processing apparatus for cooked rice packs is shown in **Fig. 4**. This apparatus has a vertical arrangement with a height of approximately 5 m, in which work is put in and taken out from the opening on the top of the pressure vessel by a dedicated carrier device. Food processing requires high productivity attained through continuous processing. To that end, this apparatus combines two vessels with a pressurizing device and adopts

Fig. 3 HPP apparatus (Dr. CHEF) for research and development[1]

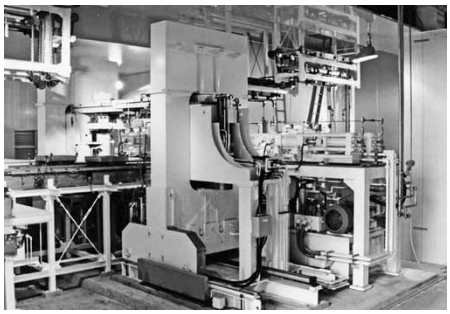

Fig. 4 HPP apparatus for production

Fig. 6 FOOD FRESHER (400 MPa, 100 L of process volume)

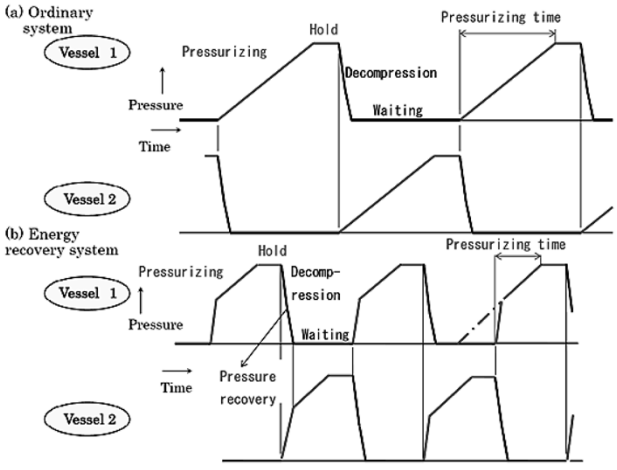

Fig. 5 Comparison of time-charts for high pressure processing[1)]

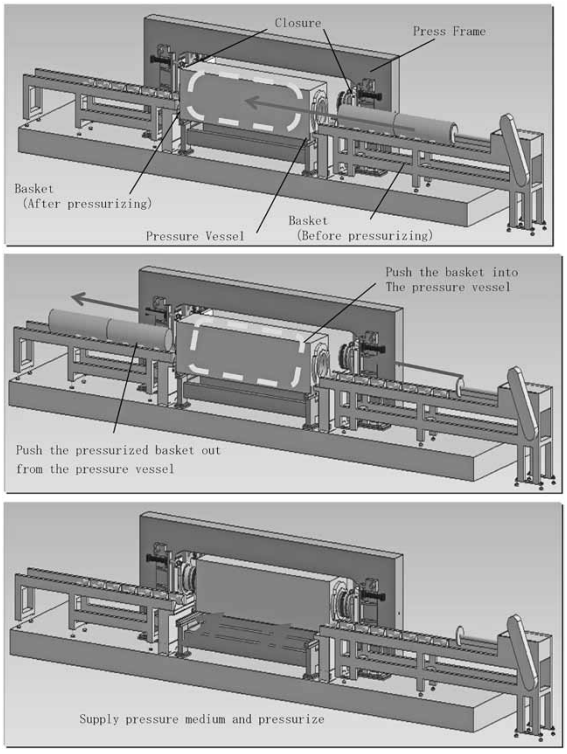

Fig. 7 Production process of FOOD FRESHER

a differential pressure recovery system, which has shortened the pressurization time to about half that of the conventional system and realized high productivity. **Fig. 5** (a) is a time chart for the apparatus operated by a conventional system, while Fig. 5 (b) is a chart showing the time when the differential pressure recovery system is adopted. These figures indicate the effect of cycle time shortening.

3. Development of horizontal CIP apparatus

3.1 Background of development

Due to a serious labor shortage and the aging of the workers involved in the shucking of bivalves, Kobe Steel received a request from the Momonoura Producer of Oysters Consolidated Company for the development of a high-pressure apparatus for oyster shucking. Kobe Steel's apparatus at that time was a vertical type, as described in the previous section, requiring a crane for work loading and unloading. Also, the heavy apparatus requires a high soil-bearing capacity for its foundation. Hence, it was difficult to install a vertical apparatus in the building at the delivery site.

To solve these problems, Kobe Steel developed a horizontal type CIP apparatus, "FOOD FRESHER," and delivered the first 400 MPa machine (processing volume: 100 liters) in 2015. **Fig. 6** shows the appearance of FOOD FRESHER.

3.2 Advantages of FOOD FRESHER

3.2.1 Low height and ease of operation

The process flow of FOOD FRESHER is shown in **Fig. 7**. As a basket filled with work is pushed into the pressure vessel, a high-pressure treated basket is pushed out of the vessel. Subsequently, the pressure vessel moves to the pressurizing position, and water-supply and pressurization begin.

Compared with the conventional vertical CIP apparatus, the horizontal CIP apparatus has the following advantages:

(1) The apparatus has a height of approximately 2 m (vertical type: 5 m) and can be installed in a building with low ceiling height.
(2) It has a greater footprint compared with that of a vertical CIP apparatus and reduces the floor load per unit area.
(3) The transport roller for inserting a basket filled with work into the pressure vessel is placed at the height of a person's waist. Hence, no special tool or device is required for transporting the baskets.
(4) The entrance and exit for the baskets are separated, making it easier to prevent the mixing of processed products with unprocessed products that have a similar appearance.
(5) The opening end of the pressure vessel is in the horizontal direction, and the pressure medium is always discharged outside after each treatment. This prevents impurities from accumulating, or from settling at the bottom, which facilitates hygiene control.

3.2.2 Light and compact

An HPP apparatus comprises a high-pressure cylinder and a press frame that supports the axial load caused by the internal pressure. The high-pressure cylinder and press frame account for most of the weight of the apparatus. In general, a high-pressure cylinder has either a single-walled structure, or a shrink-fit composite structure, whereas FOOD FRESHER employs a cylinder with a wire-wound structure (a structure strengthened by piano wire, which has a strength greater than that of forged steel, wound around the circumference of a core, constituting the cylinder) and has achieved significant space saving and apparatus weight reduction.

3.2.3 Compact intensifier with large discharge capacity

The food industry requires high productivity, and the cycle time of conventional CIP apparatuses must be at least halved. In the case of an intensifier-type apparatus, the largest portion of its cycle time is occupied by the pressurization of its intensifier. A general approach to shortening the cycle time is to increase the discharge amount by increasing the size of the intensifier. This increase in size, however, increases the weight of the components, which makes disassembly and maintenance difficult to perform at a food factory, which usually owns no facility for lifting heavy objects.

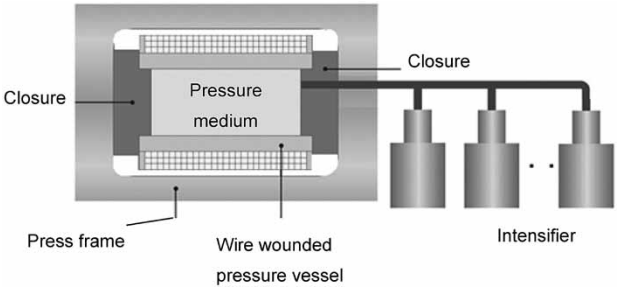

Fig. 8 Construction of high-pressure processing apparatus with several intensifiers

Hence, multiple intensifiers, each having a downsized body and increased plunger speed, were installed to increase the amount of discharge while suppressing the weight of each intensifier, which has shortened the cycle time. The construction of the high-pressure processing apparatus including the intensifier is shown in **Fig. 8**.

The seal portion becomes an important factor in increasing the speed of the plunger. Since food processing apparatuses use fresh water as their pressure medium, high-strength stainless steel is used for the pressure-tight parts of the pressure vessel, intensifiers and the like. Contact and sliding between the parts made of stainless steel tend to cause a seizure. The conventional CIP and WIP apparatuses use a pressure medium consisting of water with water-soluble oil added to it, which provides some lubrication effect on sliding parts and sealing parts. Fresh water, however, can provide only a minute lubricating effect. Hence, various measures, including the packing and backup-ring materials, surface treatment and shapes, were taken in order to realize high-speed motion and high-pressure sealing in such an unprecedented environment.

3.2.4 High-speed water supply

In order to shorten the cycle time, it is important to shorten not only the pressurizing step but also the water supplying step. Unlike the vertical CIP apparatus, the horizontal CIP apparatus discharges all the pressure medium at the time of work loading and unloading, and it is necessary to supply pressure medium to the empty pressure vessel for each cycle. The conventional CIP apparatus has a valve installed on its lid, and water is supplied to the pressure vessel via this valve. The water supply/discharge valve must seal the high-pressure medium, making it difficult to increase the bore diameter, and this sort of valve is not suitable for high speed water supply.

FOOD FRESHER has a water supply flange on the end surface of the pressure vessel and switches

the supply route of the pressure medium for the water supply process and pressurizing process, depending on the position of the lid, so as to supply pressure medium from the large diameter piping of the water supply flange. The water supply flange does not need to be sealed against the high-pressure medium, which allows the use of a feed path with a large bore diameter, enabling high-speed water supply.

3.2.5 Consideration for hygiene and safety

For food machinery, consideration for hygiene is important to prevent contamination of food by foreign matter and rust, for example. FOOD FRESHER uses fresh water as the pressure medium; hence, as a measure against rust, it employs many stainless-steel parts, not only for the wetted parts of the pressure vessel, intensifier, and piping, but also for peripheral devices. In addition, the pressure vessel and intensifiers are enclosed by stainless steel covers to ensure safety.

3.3 Development of 600 MPa testing apparatus and expansion of product lineup

The typical treatment pressure for bivalves such as oysters and crustaceans is approximately 200 MPa; however, there often are cases where higher pressure is required for treating other foods and beverages. In order to respond to the variety of needs, a 600 MPa apparatus (processing volume 50 liters) was developed and installed in Kobe Steel's Takasago Works. The appearance of the apparatus is shown in **Fig. 9**. Test apparatuses with this much processing capacity, 600 MPa, are rare in Japan. It allows customers not only to confirm the effect of high-pressure processing but also to simulate actual production, including production cost. In response to the demand for production apparatuses with various pressure capacities and processing volumes, a lineup of products has been prepared, as shown in **Table 1**.

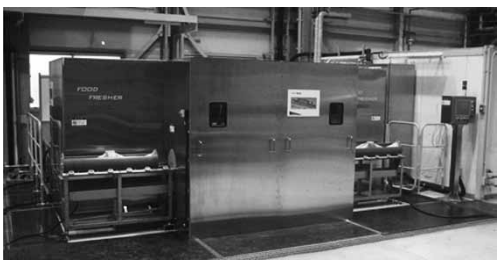

Fig. 9 FOOD FRESHER, testing apparatus (600 MPa, 50 L process volume)

Table 1 Lineup of HPP apparatuses

Application	Model	Pressure (MPa)	Process Volume (L)
Sterilization	FF6005	600	50
	FF6010		100
	FF6020		200
	FF6040		400
	FF4010	400	100
	FF4020		200
	FF4040		400
Shucking clams, crustaceans	FF2520	250	200
	FF2540		400
	FF2560		600
R&D	Dr.CHEF	700	0.6
		1,000	0.3

Conclusions

The development of a horizontal CIP apparatus, FOOD FRESHER, with advantages such as compactness and ease of operation, is believed to make the introduction of the HPP apparatus at food companies easier than it was before. For the further dissemination of high-pressure processed foods, it is important to lower their prices, and to this end, it will be necessary to improve the productivity of high-pressure apparatuses.

In high-pressure apparatuses, the equipment cost per unit volume decreases as the volume of the processing chamber increases,[5] and it is more economical to process using one larger apparatus than to process with multiple small ones. Hence, it is believed that the demand for apparatuses with vessels that are longer and have larger inner diameters will increase in the future. Large high-pressure apparatuses are capital intensive. Therefore, it is envisaged that a new management solution will be required, such as mass processing by a tolling service company, or equipment sharing between companies.

In addition, to improve productivity, it is important to ensure operational stability and to minimize downtime due to maintenance. In order to cope with such advanced operation, FOOD FRESHER can be equipped with a remote system for monitoring the state of the apparatus through IoT.

In the United States and other countries, the sterilization of beverages by high pressure processing has already been approved; however, this method, unfortunately, has not yet been approved in Japan.[3] The collaboration of the industry, government, and academia is indispensable in gaining approval. Kobe Steel will strive to contribute to the further development of HPP, making full use of its long-fostered technology for high-pressure apparatuses.

References

1) Y. Kishi. R&D Kobe Steel Engineering Report. 2008, Vol.58, No.2, pp.24-27.
2) K. Yamamoto. Food & Packaging. 2015, Vol.56, No.9, pp.540-549.
3) M. Kato. Food & Packaging. 2016, Vol.57, No.8, pp.476-480.
4) H. Shirakashi. THE REVIEW OF HIGH PRESSURE SCIENCE AND TECHNOLOGY. 2016, Vol.26, No.4, pp.333-335.
5) T. Naoi. Journal of the High Pressure Gas Safety Institute of Japan. 1988, Vol.25, No.6, pp.23-24.