Thinking Ahead

Cut the total cost of ownership for juice concentrate pasteurization by 23%

Combining heat exchanger and feed pump selection reduces energy consumption

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Summary

Energy consumption during food processing may fluctuate, depending on the product. The higher the viscosity of a product, the more energy is required. High product viscosity affects the pump efficiency as well as the heat transfer efficiency of heat exchangers on food processing lines; it also reduces throughput. This is true when pasteurizing thick liquid food ingredients, such as orange juice concentrate.

The viscosity of orange juice concentrate has a negative impact on plant capacity and energy consumption during pasteurization. However, by selecting a high-performance plate heat exchanger and a rotary lobe feed pump at the same time, the resulting energy savings can reduce total cost of ownership over 10 years by up to 23% compared to using a conventional plate heat exchanger and centrifugal feed pump. Investment in the right combination of heat exchanger and feed pump can deliver fast return on investment within the first year of operation.

Introduction

In 2017, 70 percent of the world's commercial orange juice was produced in Brazil and 65% of it was exported to Europe. This scenario is typical of juice production because favourable growing conditions for the different types of fruits are found in so few countries worldwide. The fruits are processed locally into juice and then exported across continents for consumption.[1]

Depending on the type of fruit and the target market, juice is either shipped as single-strength premium orange juice or concentrated to reduce transportation costs and then re-diluted in bottling stations close to the point of consumption. About 70% of the 20.6 million tons pure fruit juice consumed worldwide in 2017 was reconstituted from concentrate according to the strategic market research company Euromonitor. Methods used to concentrate the juice include vacuum evaporation, freeze concentration and reverse osmosis.

Both premium single-strength juice and juice concentrate undergo pasteurization or UHT treatment to ensure juice shelf life during shipping and storage. These heat treatment processes have a direct impact on juice production costs due to the amount of energy used. To keep energy consumption in check, most orange juice manufacturers use gasketed plate heat exchangers (GPHEs) as the preferred heating system for processing. This is because GPHEs are the most energy efficient heat exchangers and are well suited to handle various fluids regardless of consistency.

Alfa Laval Frontline Plate Heat Exchanger.

Alfa Laval SRU Pump.

However, GPHE performance is very sensitive to product viscosity. To ensure the profitability of fruit juice production, it is therefore important to adapt the design of pasteurization or UHT treatment process using GPHEs to the specific types of juice.

1 Beveragedaily.com

Energy consumption in the feed pump and heat exchanger

Energy consumption occurs at two levels during mild heat treatment such as fruit juice pasteurization:

- The feed pump uses electricity to provide the required flow and pressure to operate the GPHE.
- The GPHE itself uses steam or hot water to heat the juice and then requires chilled water afterwards to cool it.

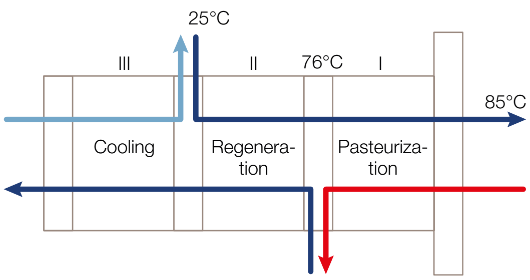
The GPHE is divided into three sections for pasteurization, for regeneration and for cooling (Figure 1). During pasteurization, the GPHE heats the juice to kill microorganisms. After heating, the juice is cooled in the regeneration section by transferring the heat to the cold juice entering the GPHE. The additional heating and cooling sections compensate for the energy loss.

The regeneration coefficient of a GPHE is equivalent to the percentage of energy recovered and generally falls within the range of 60–85% for juice applications. Adding or taking away plates in heat recovery section makes it possible to adjust the regeneration coefficient (Figure 2).

Another essential parameter of energy efficiency is the flow profile inside the heat exchanger, which can be either laminar or turbulent. Laminar flow, which is characterized by the fluid moving in layers parallel to the displacement direction, results in poor heat transfer between the juice and the heating media.

Turbulent flow, on the other hand, ensures efficient heat transfer. When the viscosity of a fluid is high, the flow becomes more laminar while, when the fluid velocity is high, the flow becomes more turbulent.

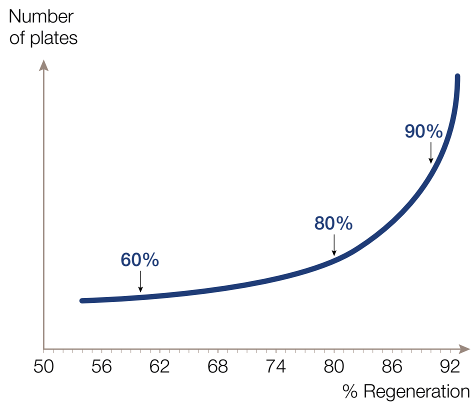
Figure 1. Three-section plate heat exchanger pasteurizer.



$$\text{Reg\%} = \frac{\text{Energy exchanged in regeneration}}{\text{Energy exchanged in regeneration and pasteurization}}$$

$$\text{Reg\%} = \frac{T_{Reg} - T_{In}}{T_{Pasteur} - T_{In}} \times 100 = \frac{76 - 25}{85 - 25} = 85\%$$

Figure 2. Effect of the number of plates on regeneration coefficient.



The impact of fruit juice viscosity on energy consumption

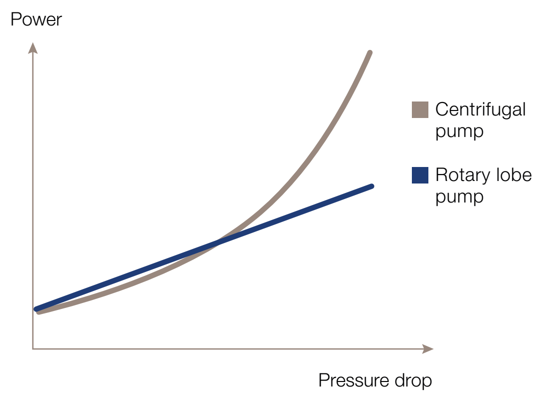
The viscosities of single-strength juice and of juice concentrates may differ widely, depending on various factors such as the types of fruit, the extraction method, the presence of fibres and the level of concentration (Figure 3).

During juice pasteurization, viscosity has a major impact on the energy efficiency of the GPHE and feed pump.

In a pasteurization unit designed for thin juices, treatment of a viscous product like a concentrate or nectar produces a laminar flow and, as a result, the heat transfer is poor. Increasing the fluid velocity is an option to restore and maintain a turbulent flow – and thereby high heat transfer efficiency. An increase in fluid velocity can be achieved by increasing the pressure drop across the plate heat exchanger by adjusting the number of plates in the unit. Here the selection of pump type becomes critical.

For fluids with viscosities above 100 cP, the relationship between pressure drop (or fluid velocity) and power absorbed at constant flow is linear for rotary lope pump.

Figure 4. Relationship between pressure drop and absorbed power for centrifugal and rotary lobe pump (constant flow, viscosity > 100 cP).



In contrast, for fluids with viscosities above 100 cP, the relationship between pressure drop (or fluid velocity) and power absorbed at constant flow is exponential for centrifugal pumps (Figure 4).

Figure 3. Viscosity of different types of juice and juice concentrate.

Fruit and juice type	Brix (°B)*	Viscosity (cP)**
Clear apple concentrate	72	9
Apricot	18	84
Orange concentrate	65	456
Passion	50	2016

* The Brix scale measures the percentage of soluble sugar content (expressed in saccharose) in an aqueous solution. It is an indication of the concentration rate for a given fruit type.

** Viscosity values measured at 20°C and a shear rate of 100 s-1.

The higher the viscosity of the juice or juice concentrate, the greater the energy consumption.

Juice concentrate pasteurization:

High pressure drop design cuts energy consumption

To determine the financial impact of GPHE and pump type in juice pasteurization, an Alfa Laval research team investigated the role of these components on the total cost of ownership of juice concentrate pasteurization over a 10-year period at a typical juice processing plant (Figure 5).

The team compared the energy consumption of four different pasteurization process lines using various combinations of heat exchangers and feed pumps. Low pressure drop and high pressure drop gasket plate heat exchangers were used with either centrifugal pumps or rotary lobe pumps as the feed pumps (Figure 6). The selection of pump size was designed to achieve the best possible arrangement to handle both the pasteurization process and cleaning-in-place (CIP).

Figure 5. Orange concentrate pasteurization duty.

Product	**Orange juice concentrate 65° Brix**
Specific gravity	1.3
Start / end temperatures	25°C
Pasteurization temperature	85°C
Cooling media	Cold water 10°C
Capacity / duty	14.6 m^3/hr (19,000 kg/hr)
Operation	8 hrs/day x 300 days/year x 10 years
Cleaning-in-Place (CIP)	1 hr/day x 300 days/year x 10 years

Figure 6. Selection and sizing of components of different plant designs for juice pasteurization.

GPHE design	**Low pressure drop**		**High pressure drop**	
Duty pressure drop	3.2 bar		10.3 bar	
CIP pressure drop	2.7 bar		3.2 bar	
Working flow / CIP	40 m^3/hr		20 m^3/hr	
Alfa Laval GPHE model and size	FrontLine 8/453 plates Low pressure drop design		FrontLine 8/443 plates High pressure drop design	
GPHE regeneration ratio	75%		81%	
Pump type	**Centrifugal**	**Rotary lobe**	**Centrifugal**	**Rotary lobe**
Alfa Laval pump model	LKH20/165	SRU6/260/LS	LKH35/196	SRU5/168LD
Pump motor size	6.3 kW 60 Hz	7.5 Kw 60 Hz	16.5 kW 60 Hz	7.5 Kw 60 Hz
Pump power absorbed/duty	4.8 kW	2.3 kW	14.2 kW	4.6 kW
Pump power absorbed/CIP	5.0 kW	6.2 kW	3.1 kW	6.25 kW

Figure 7. Capital and total cost of ownership for different combinations of plate heat exchangers and pumps.

Design	Capital cost (%)		Total cost of ownership/ 10 years (%)		Time to return on investment
	Value (€)	Relative (%)	Value (€)	Relative (%)	
Low pressure drop PHE/ centrifugal pump	76,571	100% (reference)	1,175,088	100% (reference)	Reference
Low pressure drop PHE/ rotary lobe pump	86,918	113.5	1,178,163	100.3	> 10 years
High pressure drop PHE/ centrifugal pump	79,159	103.4	920,344	78.3	1 month
High pressure drop PHE/ rotary lobe pump	86,823	113.4	902,170	76.8	4 months

Calculations for total cost of ownership over a 10-year period (Figure 7) include capital expenditures, based on typical prices for the selected Alfa Laval components, and operational costs using variable energy costs based on average industrial tariffs in 2018 for steam (0.058 €/kWh) and electricity (0.12 €/kWh) in western Europe.

High pressure drop GPHE delivers more than 20% savings in total cost of ownership

Over a 10-year period, the selection and use of a GPHE designed for high pressure drop reduced the total cost of ownership by more than 20% compared to the reference low pressure drop GPHE design. Return on investment was realized within a few months rather than years. Another benefit of selecting a high pressure drop GPHE design: a 50% reduction in CIP flow, down to 20 m^3/hr from 40 m^3/hr. This cuts cleaning costs and minimizes the environmental impact of water and chemical effluents.

When selecting a low pressure drop GPHE design, the use of a rotary lobe pump does not deliver tangible benefits compared to using a centrifugal pump; the total cost of ownership over 10-year period is similar. Selecting a high pressure drop GPHE design, on the other hand, provides an extra 1.5% diminution in total cost of ownership. In addition, using a rotary lobe pump increases the versatility of the plant, making it easier to manage more viscous juice types such as nectars without decreasing the flow rate or increasing energy consumption.

Although centrifugal pumps proved to be more energy efficient during CIP operations, those savings are marginal compared to the energy savings realized by rotary lobe pumps during the pasteurization process since, over the course of 10 years of operation, the majority of time that the feed pump is in operation for pasteurization far outweighs the amount of time it is in operation for CIP.

Choosing a high pressure drop GPHE cuts cleaning costs and reduces the environmental impact of water consumption and processing chemical effluents.

For cost-savings and greater process flexibility, choose the right combination of feed pump and heat exchanger

By selecting the right combination of energy-efficient plate heat exchanger and pump, it is possible to realize return on investment within the first year of operation. To do so, however, the equipment in place must deliver exceptionally high performance to ensure flawless operation.

Thanks to a highly robust design, standard Alfa Laval SRU rotary lobe pumps can operate at pressures of up 10 bars. Upon request, Alfa Laval can supply these pumps to handle 20 bars of pressure. The very low tolerance between rotor and stator minimizes slip at high pressure and ensures a high pumping efficiency. This enables the use of a smaller pump and reduces capital expenditures. It also minimizes the environmental impact of juice concentrate pasteurization by reducing effluents and carbon dioxide emissions over the lifetime of the plant.

Alfa Laval SRU rotary lobe pump.

The investigation of orange juice concentrate pasteurization presented here can be extrapolated to other types of medium-viscosity food preparations in the range of 100–1000 cP. This includes creams, toppings, whey protein solutions or other ingredient extracts.

Choosing the right plate heat exchanger and feed pump is a win-win scenario for dairy, food and beverage producers.

About the Alfa Laval FrontLine gasketed plate heat exchanger

- Designed for to meet the strictest demands regarding hygienic control, gentle product treatment, long operating time and superior cleanability.
- Capable of handling operating pressures up to 21 bar.
- Highly turbulent flow reduces the heat gradient between the product and the heating media due to the high pressure drop.
- Ideal for handling heat-sensitive products.
- Suitable for applications with specific hygienic requirements including dairy, food, beverage and brewery applications.

Alfa Laval Frontline gasketed plate heat exchanger.

About Alfa Laval

Alfa Laval is a leading global provider of specialized products and engineered solutions that help customers heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuffs, starch and pharmaceuticals.

Alfa Laval's worldwide organization works closely with customers in nearly 100 countries to help them stay ahead in the global arena. Alfa Laval is listed on Nasdaq OMX, and, in 2018, posted annual sales of about SEK 40.7 billion (approx. 4.0 billion Euros). The company has about 17,200 employees.

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