Optimal use of resources and energy during fruit juice extraction

| Concentrate | Direct Juice | Fruit Juice Extraction | HPX Technology | Juice Yield |

1 Introduction

After many years in decline, consumption of fruit juice in Germany increased in 2015 amounting to 33 litres per capita (Source: Association of the German Fruit-Juice Industry, VdF). Nevertheless, competition in the fruit-juice market remains tough and all manufacturers are faced with the challenge of achieving adequate margins. The basic requirement to achieve continuing success in the market is of course, manufacture of first class, high quality products. Optimal utilisation of the resources used, above all raw materials, energy and water, is decisive for achieving sustainably good margins.

In a recently published feature article, energetically optimised concentration of fruit juice was explained in detail (1). This present article will now describe how the resources used for extraction of fruit juice can be made use of in an optimal way and which new developments can contribute towards optimisation of resource efficiency. Due to its major significance for the German market, the manufacture of high-quality direct NFC apple juice will be looked at in particular.

2 Consumption of resources for the manufacture of fruit juice

The relevant resources consumed in the manufacture of fruit juice are the raw material (fruits), water, energy (electricity, steam), process aids (enzymes, fining agents, filter aids), additives (e.g. vitamin C) and cleaning chemicals.

Fruit

The most relevant resource for the manufacture of fruit juice in terms of volume and cost is the processed fruit. It is evident that the quantity of juice extracted per unit of fruit (= juice yield) is decisive for the resource efficiency. For industrial apple juice extraction the achieved yields range from about 70 to 95 % w/w, depending on the quality and size of the fruits, mash preparation (grinding, with/without mash enzymation, temperature), type of extraction system and applied leaching steps. The juice yield can either be determined by measuring the extracted juice or the residual pomace mass in relation to the processed fruit. If leaching (water extraction) is applied then a correction factor compensating the juice dilution has to be incorporated.

Water

Water is mainly consumed for cleaning of fruit and processing equipment. Consumption for fruit cleaning is heavily depending on the cleanliness of the received fruits. Dirt loads can vary extremely: from very clean (e.g. packing house rejects) to very dirty (e.g. dropped fruit from open soils). Most apple juice manufacturers use flume systems for transportation and pre-washing of the

Fig. 1: Flume channels

Fig. 2: Flume water separation

fruit (Fig. 1, Fig. 2). The flume water is constantly circulated and screened in order to remove the coarse particulate material. Still the water gets dirty over time and regularly needs to be exchanged, e.g. once a day. When exchanged every day the flume water consumption is approx. 25 l per t of processed apples. For final cleaning clean water is sprayed on the apples with spray bars or spray nozzles installed in downstream conveying and sorting equipment. A minimum of two separate injection points is recommended for optimum cleaning effect. Water consumption for final cleaning typically is 50-100 l per t of apples. The spray water is collected together with the flume water, resulting in a continuous „refreshment" of the water in the flume circuit. In total, the water consumption for fruit cleaning typically is approx. 75-125 l per t of apples.

For the final rinse tap water quality should be used. In concentrate manufacture vapour condensate can be used for previous rinse steps and for the flume system water, reducing the fresh water consumption by more than 50 %.

The water consumption for cleaning of processing equipment and for general cleaning purposes can vary largely. It depends on factors like chosen processing equipment, number and design of process tanks and pipelines as well as design and frequency of CIP sequences. As a general rule, good hygienic design of the process line avoiding large mixing zones between product and water or water and CIP solutions is a prerequisite for low water consumption. Respective sensors at pipeline junctions (e.g. conductivity or turbidity sensors) in combination with automated cleaning sequences enable detection of phase transitions thus reducing excessive product and water losses. Modern CIP systems recycle most of the standard alkaline cleaning agents and also some of the final rinse waters to be subsequently used as pre-rinse water. In concentrate lines vapour condensate can be used for most cleaning steps except for disinfection and final rinse.

Energy: Electrical power and steam

Table 1 summarises the typical energy consumption figures for the different unit operations of a Bucher line to process 30 t/h of apples into apple juice concentrate (AJC). The compilation does not include consumption figures for utilities and CIP.

In total approx. 10 kWh electricity and 200 kg of steam are required to process one t of apples into AJC. Approx. 40 % of the electricity is needed for the evaporation, followed by filtration and pressing. The main power consumers are pumps. Steam consumption is also dominated by the evaporation, which combines pasteurisation, pre-concentration, aroma recovery and final concentration. Steam consumption can largely be replaced by electricity if an evaporator with mechanical vapour recompression (MVR) is used (1).

Table 1: Typical specific energy consumption for Bucher apple juice concentrate line with a capacity of 30 t/h

Unit operation	kWh / t apples	kg steam / t apples	Comment
Flume system	0.5	-	mainly pumps
Fruit conveying	0.3	-	elevators, conveyors etc.
Milling	0.5	-	with Bucher CM50 grinder
Mash handling	0.2[1)] 0.8[2)]	-[1)] 26[2)]	[1)]: w/o mash heating [2)]: with mash heating (12 to 27°C)
Pressing	1.8	-	with Bucher HPX presses, 1x leaching
Filtration	1.9	-	with tubular UF
Evaporation	4.0	195	6-effect evaporator, incl. cooling and ice water circuits
Juice and water handling	0.5	-	transfer pumps, agitators
Total	**9.5 - 10.1**	**195 - 221**	**w/o CIP**

As pumps are the major power consumers they should be highly efficient (design and correct sizing). If variable capacities have to be met it is recommended to operate the respective pumps with VFDs. Generally, the good energy consumption figures in Table 1 are only met if the line is operated continuously. Frequent starts and stops result in significantly higher energy and water consumption and should be avoided. Good production planning and management therefore is equally important for achieving benchmark resource efficiencies as is the use of highly efficient equipment.

3 Bucher HPX presses for optimal use of resources

3.1 Significance of the juice yield

For decades, Bucher HPX hydraulic juice presses have set benchmark values with regard to juice yield achieved. As a rule, 4-8 % w/w more direct juice is extracted compared to belt presses. Due to the very low content of suspended solids in the juice, the loss from the downstream centrifuge is also lower than for belt presses, which further increases the „net juice yield“ compared to these. Optimal use of raw materials with the HPX technology is a very decisive economic advantage for manufacturers of direct juice, as raw material costs can be lowered by 5-10 % with the same juice volume compared to belt presses (Table 2).

Table 2: Example of raw material required per 100 kg direct juice from harvest-fresh apples

	Juice yield % w/w	Raw material per 100 kg juice	Raw material, relative %
HPX	84.0	119.0	100.0
Belt press	80.0	125.0	105.0

During manufacture of apple juice concentrate, an enzymatic treatment of the mash, heated to 25-30 °C if necessary, is state of the art. This allows a considerably higher “A-juice“ yield to be achieved from the presses than for direct juice and the throughput is also significantly higher. The pomace from the first pressing is normally mixed with water in a ratio of 1:1 to 1:1.5 and pressed a second time (leaching, belt press cascade). Due to the lower levels of soluble solids remaining in the pomace after this dilution with water, the juice loss is lowered and the concentrate yield increased accordingly.

Table 3: Typical raw material requirements and water evaporation per kg AJC (70 Bx) for apples with 11 Bx

	A-juice yield % w/w	Water for pomace dilution % of raw material	kg raw material per kg AJC	kg water evaporation per kg AJC	Water evaporation, relative %
HPX	87.0	15.0	7.0	6.3	100.0
Belt press	82.0	25.0	7.2	7.0	111.1

Overall, the second pressing with pomace dilution reduces the yield advantage of the HPX presses compared to belt presses in comparison to manufacture of direct juice, but this is still 2-3 % w/w. As the pomace requiring dilution with the HPX presses is only approx. 10-14 % w/w compared to 16-22 % for belt presses, relating to the quantity of apples, the water requirement for dilution of the pomace is correspondingly lower. During filtration the higher sludge volumes of belt press juice require more water for diafiltration compared to HPX juice. In total, the necessary water evaporation per kg apple juice concentrate with a belt press cascade is around 11 % higher than in lines using a HPX press (Table 3).

Summarising, it can be said that the apple juice extraction with HPX presses provides major advantages, in particular for manufacturers of direct juice, with regard to efficient utilisation of raw materials. Raw material efficiency is still around 3 % better for manufacturers of apple-juice concentrate. At the same time, the necessary water evaporation is significantly lower with correspondingly lower energy costs for the evaporation step.

3.2 Energy and water consumption: Improved efficiency with new Power Hydraulic HE

In order to further reduce consumption of resources during juice extraction, Bucher Unipektin AG developed a new generation of hydraulic units for the HPX presses which have significantly lower electricity and water consumption: Power Hydraulic HE (high efficiency). This new power unit uses a highly efficient electronically controlled pump to power the main cylinder. A second, frequency-controlled pump is responsible for moving the press drum and for the oil filtration and cooling circuits. When closed, a special compressed air powered device provides sufficient closing pressure for the press drum, requiring practically no electricity. Generously dimensioned valves and oil lines ensure minimal power loss and, therefore, little heat transfer to the hydraulic oil. In total, the electricity requirement for the hydraulic drives has been reduced through these optimisation measures by around 30 % compared to the previous model.

As the mechanical work actually carried out during pressing has not changed, the reduced energy consumption results nearly completely from reduced power dissipation. As a consequence, approx. 40 % less heat must be removed. This means it is standard for the new unit to be equipped with an oil/air cooler which provides the

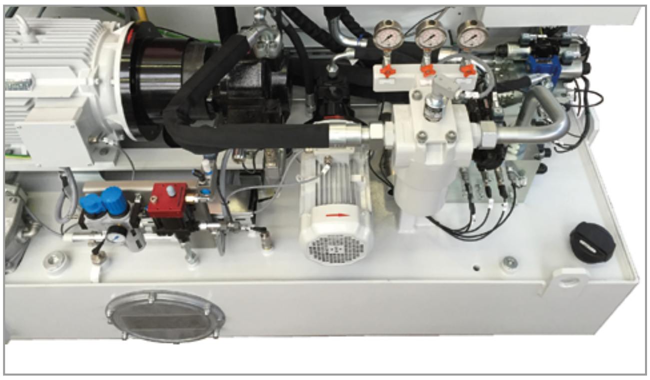

Fig. 3: Hydraulic unit Power Hydraulic HE

necessary cooling performance at ambient temperatures up to 40 °C. A water/oil cooler is no longer necessary and no cooling water is required.

High-quality components from renowned hydraulic specialists are used for the Power Hydraulic HE. Particular attention was paid during the development work to an easy maintenance concept. All components are easily accessible and the hydraulic circuits are consistently separated to allow simple diagnostics (Fig. 3). This results in maximum accessibility and reliability.

Within 2017, the Power Hydraulic HE will be released for the press models HPX 6007 and HPX 7507. Electricity consumption of these machines is approx. 1.3 kWh per ton of apples when pressing enzyme treated apple mash with leaching, or approx. 1.8 kWh per ton of apple direct juice.

4 Manufacture of direct juice: Top quality and yield with direct filling

While traditional „naturally cloudy“ apple juice has a typical yellow-brown colour (particularly in Southern Germany) very light coloured juice is increasingly demanded by today‘s market. The classic yellow-brown apple juice colour is created by natural oxidation of the polyphenols in the apples by the enzyme polyphenoloxidase (PPO). This process starts immediately after crushing of the apples when the substrate polyphenols and oxygen come into contact with the catalyst PPO. This oxidation reaction continues until the PPO is inactivated by heat treatment (pasteurisation). To prevent this browning, the whole process from crushing up to pasteurisation must take place as quickly as possible. In addition, ascorbic acid (vitamin C) is added to the juice and/or mash as protection against oxidation.

Direct filling: Apple buffer instead of mash buffer

As Bucher HPX presses apply a discontinuous batch process, the mash is normally buffered in large mash tanks to enable the presses to be filled quickly and efficiently. If light coloured cloudy juice is to be manufactured, mash buffering is a disadvantage because it increases the holding time and the browning or quantity of vitamin C required.

For this reason, Bucher has developed the direct filling process which eliminates mash holding time. The concept involves use of an apple buffer instead of a mash buffer: above the crusher, a buffer tank holding up to 3 t apples is installed and downstream from the crusher, only a small mash buffer tank with a volume of approx. 2 m^3. The mash is pumped from this small buffer tank directly into the presses with practically no holding time (direct filling) and pressed. The grinding performance of the Bucher CM 50 crusher used is so high (up to 50 t/h), that no performance loss occurs even with the very small mash buffer. Besides the high crushing performance, the CM 50 has the advantage that it introduces significantly less air into the mash than other crushing systems, thus clearly reducing the potential for oxidation. The Bucher process control ensures that only just sufficient mash is available, as the filling process requires at any one moment in time. On average, it takes only about one minute from crushing to entry of the mash into the HPX press.

Vitamin C: Added to the juice instead of to the mash

This very short holding time means that either addition of vitamin C to the mash can be avoided completely, or that its use can be limited to very small quantities, e.g. 100 -200 mg/kg. No or very little vitamin C in the mash has the advantage that it can be pressed better and that only little vitamin C is lost with the pomace.

During pressing with HPX presses, 70-80 % of the total juice volume of a press batch is extracted during the first 20 minutes of pressing. Even if the total time for a press batch is 60 minutes, the average holding time of the juice in the press is only about 15 minutes.

The main addition of vitamin C now takes place straight into the juice line after the press. Development of a slightly brown colour towards the end of the pressing batch is then immediately reversed because the oxidation reaction is still reversible to a great extent at this point.

Table 4 shows the development of vitamin C content and juice colour throughout a press batch (HPX 6007) with direct filling. The fruit processed were fresh crisp apples. No vitamin C was added to the mash. The inline vitamin C dosage to the juice was approx. 350 mg/l. The juice was pasteurised 10 minutes after sampling. The values shown are averages of three press batches. 15 minutes after batch start, already more than 70 % of the juice had been extracted; after 45 minutes, a juice yield of 85 % w/w had

Table 4: Development of vitamin C and juice colour during a press batch; HPX 6007 with direct filling; vitamin C added: 350 mg/l juice

Time from start of the batch min	Yield % w/w	Juice share %	Juice share accumulated %	Vit C mg/l	Colour Lovibond
5	36	41.9	41.9	305	4
15	61	29.5	71.4	212	4
30	80	22.7	94.1	175	4-5
45	85	5.9	100.0	134	5
Ø sample				251	4

been achieved and the press batch completed. As expected, rising shares of the 350 mg/l vitamin C added were used up with increasing pressing time. However, the average sample reflecting the whole batch still contained 251 mg/l. The average vitamin C consumption of approx. 100 mg/l can be considered to be very low and proofs the low oxidation achieved with the direct filling process. The juice colour measured as Lovibond 4 was also very light. A slightly darker colour of the juice after more than 30 minutes pressing has little effect on the overall juice colour due to the low quantities of juice being extracted after this period of time.

With regard to the juice quality, "normal" press batch times of 50-60 minutes are not critical, if the direct filling process is applied. The yield in later phases of pressing is, however, of very great economic importance: it is decisive for the economic efficiency of the process if the "A-juice" yield is 75-80 or 80-85 % w/w. Every additional litre of "A-juice" is hard cash for the manufacturer.

Light coloured apple juice manufactured using HPX presses in combination with the innovative direct filling method, is at least equivalent to juice from continuous de-juicing systems with regard to quality, colour and vitamin C requirement. This has prompted a leading German manufacturer of NFC juice to convert his complete production to HPX presses in combination with direct filling. This decision was made based on positive experience gained from several years of parallel operation of continuous de-juicing systems with the HPX direct filling technology. Other well-known manufacturers are also currently planning substantial investment in this technology.

5 Summary

Maximum yield is necessary to achieve optimal use of raw material resources during de-juicing of fruit. The juice yield of the first pressing ("A-juice") is decisive for profitability of NFC juice manufacturing. Using Bucher HPX presses in combination with the innovative direct filling process, excellent, light coloured juice is obtained with maximum juice yield.

HPX presses also achieve the best juice yield on production lines for the manufacture of juice concentrate. In addition, energy consumption is significantly lower than that of alternative de-juicing systems as less water is used for the extraction of pomace and filtration sludge and therefore, less evaporation is needed.

The new "Power Hydraulic HE" units of the Bucher HPX presses help fruit juice manufactures to achieve lower electricity and water consumption and optimal utilisation of resources and energy.

References:

(1) Zimmer E, Haverland H, Latz M: Energetically optimized concentration of fruit juices; FRUIT PROCESSING 9/10-2016, pages 142-147

Author:
Dr Edgar Zimmer,
Head of Technology + R & D
Bucher Unipektin AG