New Technologies 2022, 18(1): 40-52.

https://doi.org/10.47370/2072-0920-2022-18-1-40-52

MODERNIZATION OF OPERATING CHICORY FACTORIES USING CONTINUOUS PULSATING EXTRACTORS

Dmitry P. Iovlev[1], Mansur I. Farakhov[1], Roald R. Akberov[1]*, Ildar R. Stekolshchikov[1], Artem V. Akhmerov[2]

[1] *LLC Engineering-Promotional Center "Ingehim", 14/83 Shalyapin Str., Kazan 420049, Russia*

[2] *Kazan State Power Engineering University, 51 Krasnoselskaya Str., Kazan 420066, Russia*

* roaldakberov@yahoo.com

Note: *The original article was first published in Russian with abstract in English. The article was further translated from Russian into English by authors of the article. Below is the result of the translation. The original article in Russian can be downloaded free from the journal website: https://newtechology.mkgtu.ru/jour/article/view/561/522*

For citation: *Iovlev D.P., Farakhov M.I., Akberov R.R., Stekolshchikov I.R., Akhmerov A.V. Modernization of operating chicory factories using continuous pulsating extractors. New Technologies 2022, 18(1): 40-52 (In Russian, English abstract). https://doi.org/10.47370/2072-0920-2022-18-1-40-52*

Abstract

Chicory roots are a valuable source of inulin and other beneficial nutrients. The most common use in industrial processing is instant chicory powder production. Extraction is the primary process in the production. Conventional extraction methods, which include maceration, percolation and extraction in a screw extractor, have a number of significant drawbacks, including high capital and operating costs, low quality of the resulting extract, high equipment maintenance and short overhaul life. The purpose of the present study was to assess the technical feasibility of increasing extraction process efficiency through use of continuous pulsating extractors (CPE) developed by the Ingehim Company, in which a non-stationary, countercurrent mode of interaction of raw materials with the extractant is incorporated. Testing of engineering solutions implemented in CPE was carried out at a pilot pulsating unit (PPU). For extraction, roasted and crushed chicory roots (5-20 mm) from one of the operating chicory factories were used. The ratio of chicory to water during extraction was 1 : 4.5, which is 1.5-2.5 times less than in conventional extractors. A lower extraction temperature (maximum of 85°C) combined with a shorter extraction time (up to 1 hour) can help retain more inulin and other nutrients as compared to conventional methods. The results of the study at the PPU under these conditions confirmed the high yield of water-soluble solids (up to 98%) without additional grinding. A scheme for the modernization of a chicory factory equipped with the most common percolation extraction equipment having a feed capacity of 400 kg/h is proposed through using CPE. Rendered 3D images of the proposed equipment setup are shown. A comparative assessment of energy consumption for extraction using different methods

is given. The results of the study indicate the capability and high efficiency of CPE for extracting chicory, which is confirmed by a decrease of up to 3.6 times in the total specific energy consumption for obtaining 1 kg of instant chicory powder compared to conventional extractors. Lower capital and operating costs create a competitive advantage of using CPE for the modernization of existing chicory factories or the creation of new energy-efficient factories.

Keywords: *instant chicory, chicory powder, chicory extract, continuous extraction, countercurrent extraction, continuous pulsating extractor, percolator, modernization, inulin, inulin-containing products*

Chicory is an herbaceous plant with blue flowers from the *Asteraceae* family, commonly cultivated in the temperate zone as well as in the tropics on almost all continents. Of interest for industrial processing is root chicory (Fig. 1). The process of growing chicory is well established, sufficiently developed, and similar in terms of agro-technical measures to the cultivation of sugar beets and does not represent any particular technical difficulty. Moreover, chicory can be grown quite successfully in the climatic conditions of a large number of regions in Russia.

The chicory root has a rich mineral and chemical composition. The main useful ingredient of chicory is inulin. In a freshly harvested root crop, its content is up to 75% (on dry matter basis). Inulin is a natural polysaccharide that is used for dietary nutrition for diabetics. It is easily digested, plays the role of a powerful prebiotic, helps reduce blood sugar levels, improves metabolism and digestion, and increases the body's resistance to harmful bacteria with regular use. In addition to inulin, chicory contains vitamins, carotene, pectin, organic acids, macro- and microelements.

Fig. 1. *Root chicory*

These beneficial properties of chicory drive its high global demand. Thus, the global volume of chicory cultivation is over 500 thousand tons per year. The main producer of chicory in the world is Belgium, which provides up to 70% of the total global production. Other manufacturers occupy a smaller market share, namely the Netherlands up to 10.5%, France up to 8.5%, Poland up to 6%, South Africa and Ukraine up to 1.5%, Philippines, Croatia, Serbia and Kazakhstan each accounting for up to 1% of total global volume [1].

In industrial quantities, chicory can be processed to produce liquid, syrupy or powder extracts, inulin-containing foods and drinks and isolated purified inulin. However, today one of the common uses of chicory is the production of an instant chicory powder drink. In addition to presence of useful substances in chicory, it is similar to coffee in terms of organoleptic characteristics. Therefore, those who are contraindicated for caffeine can consume chicory as a

coffee substitute. The production of instant chicory powder is based on obtaining a liquid extract from roasted crushed chicory root. The resulting extract is subsequently filtered, concentrated and dried to a powdered commodity state.

Extraction (liquid chicory extract obtaining) is the primary process in the industrial production of instant chicory powder drink. The commercial product's quantity, quality and production cost depend on extraction efficiency. Conventionally, macerators, percolators or screw extractors are used to extract chicory. All of these types of apparatus have relatively low efficiency due to long process duration, high specific heat losses, energy consumption, labor inputs and operating costs. These problems are significantly aggravated when processing raw materials in large volumes, as well as in the presence of certain specific features of raw materials and their low specific gravity, seasonality of work and a short processing time of freshly harvested raw materials, etc. Therefore, the problems of optimizing existing technological processes and creating new energy-efficient chicory processing factories are extremely important.

A brief description of the conventional methods for obtaining an extract from roasted chicory is given below.

1. Maceration. The extraction section includes, as a rule, two or more parallel macerators (reactor, mixer). The batch mode of macerator operation is responsible for extremely high specific consumption of the extractant, relatively low concentration of the resulting extract, inevitable additional heat losses during loading/unloading of raw materials, high specific energy consumption, and long duration of technological operations (loading, filling, unloading, emptying, cleaning, etc.) accompanying the main extraction process, etc. To intensify the extraction process, macerators use agitators requiring additional operating costs.

2. Percolation. The extraction section consists of 6 to 8 sequentially operating percolators (a battery of percolators), each of which operates in the batch mode. As a result, a quasi-continuous process is created. Several batteries are installed to reach a given feed capacity. In using this method, the necessary extractant consumption is reduced; however, the extraction time inevitably increases by 2-3 times. For a more complete use of the working volume of percolators and an extraction efficiency increase, chicory is crushed to a fine grain (0.2-0.5 mm). This increases resistance to the extractant flow in the percolator. In addition, chicory swells during the extraction process. Therefore, extraction is carried out with an increase in pressure in the percolators up to 3 atm leading to the extraction temperature increase up to 120 °C. This extraction regime, combined with a long extraction time (about 6 hours), can lead to a significant loss of beneficial nutrients, including inulin. Although percolation is considered more efficient than maceration, it, like batch macerators, retains high specific heat, energy and operating expenditures as well as labor inputs. There is also a need for additional floor space to accommodate a large number of percolators. All this affects the final cost of the resulting product.

3. Extraction in a screw extractor. In this case, the extraction process is carried out in a more efficient continuous mode. To implement the continuous mode of the extractor operation, a mechanical conveying device in the form of a screw is used. Despite the advantage of continuous and countercurrent operation of the screw extractor compared to the above methods, it has a more complex design, high specific energy consumption, large size and weight, high initial investment cost and increased costs of maintenance and repair of moving assemblies. At the same time, only up to 60% of the screw extractor's working volume is used, and there is a relatively high non-uniform distribution of the material across the apparatus cross section. These factors contribute to increased capital and operating costs with lower energy efficiency, and the use of a complex moving assembly (screw) significantly reduces overhaul period and increases maintenance cost of the extractor.

Of the above methods for obtaining chicory extracts at chicory factories, percolation is the most commonly used method [2], carried out at temperatures up to 120 °C with an extraction time of about 6 hours. Despite the possibility of a significant loss (thermal destruction) of inulin and other useful nutrients under these conditions [3], percolation has an increased economic efficiency compared to the other processing methods.

For enhancing the extraction process efficiency, reducing costs and solving other aforementioned problems of conventional extractors, the Ingehim Company has developed a pulsed extraction method based on using a continuous pulsating extractor (CPE). The method is universal and suitable for extracting various types of agricultural or medicinal raw materials of plant origin such as sugar beet roots in sugar production [4], Jerusalem artichoke, coffee beans, chaga mushrooms, hops, licorice, rosemary, etc. In the case of chicory processing, the extraction process is carried out at a lower operating temperature (maximum of 85 °C) with an extraction time of under 1 hour. This significantly simplifies the process as compared to conventional extraction methods creating conditions for maximum preservation of useful nutrients, including inulin, in the resulting commodity product.

The operating principle of CPE is shown in Figure 2. Structurally, it is a single-casing vertical cylindrical apparatus. Raw materials in the form of chopped and roasted chicory roots are continuously fed to CPE's lower part. Hot water acting as an extractant is continuously supplied to CPE's upper part. The continuous movement of raw materials in the extractor occurs due to forced low-frequency pressure pulses imposed on the extractant from an external pulse creating system. In CPE's working area, chicory and water move in opposite directions, creating a countercurrent mode of interaction, which is considered as most efficient for achieving maximum extraction with minimum extractant consumption. The produced extract is continuously unloaded from CPE's lower part. Spent raw materials are continuously unloaded from CPE's upper part and transferred for processing or disposal. The extractor dimensions and amplitude-frequency characteristics of the pulsating effects ensure the CPE's specified feed capacity.

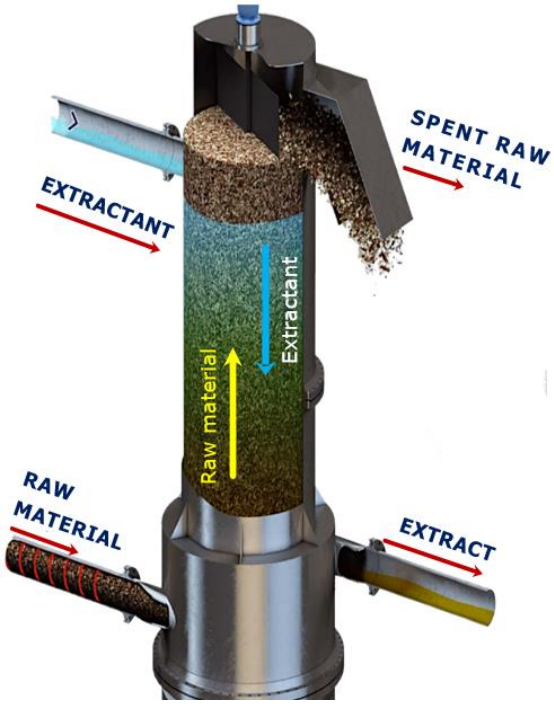

Fig. 2. *CPE scheme*

All technical and technological solutions applied in CPE are tested at the pilot pulsating unit (PPU) developed by the Ingehim Company (Fig. 3).

Fig. 3. *Pilot pulsating unit (PPU) for extraction*

PPU was designed with the purpose of conducting studies on the development and optimization of technologies for processing various raw materials of plant, animal, mineral or technogenic origin, as well as of obtaining extracts samples for the analytical determination of their composition.

PPU is comprised of the following units and assemblies. A loading hopper with a screw feeder is used to feed raw materials. A column with a diameter of 2½" (DN 77.5 mm) is used to carry out the extraction process. The working area extent used for extraction depends on the raw material and technological parameters and, if necessary, can be varied in the range from 0.25 to 0.5 m. The PPU's feed capacity is up to 5 kg/h and depends on raw material's type and condition. A supply pump and a container with a heat capacity of maintaining up to 95°C are used to supply the extractant. Screw unloading is used to remove the spent raw material. The obtained extract is pumped out of PPU and fed through the filtration system to the receiving tank. The PPU also has a pulse creation system and an automatic control & monitoring system. Stainless steel is used on all parts of PPU main elements in contact with the working media.

For experimental studies, raw materials were used in the form of roasted chicory roots with a crushed size of 5-20 mm (Fig. 4) (without additional grinding), provided by one of chicory factories of Russia. The extraction process was carried out in a continuous mode of supply and removal of both the raw material and the extractant. This significantly reduces the development of oxidative and bactericidal processes during extraction. The process temperature was 85°C, and the extraction time was 1 hour. The temperature and time were taken based on the condition to conduct the extraction in a soft, mild mode to preserve useful substances. The objective of the process was to achieve on the specified fraction of raw materials an extraction efficiency in a pulsed mode no worse than in conventional operating processes, which would allow for comparison in assessing the prospects for using CPE.

Fig. 4. *Roasted chicory crushed to sizes 5-20 mm and used for extraction at PPU*

Extraction of chicory in PPU was carried out at a reduced ratio of chicory to hot water, which was 1 : 4.5. This ratio is lower by 1.5–2.5 times compared to typical ratios of 1:7 to 1:10 in conventional extractors. Such a significant reduction in the required amount of the extractant is caused by increased efficiency of the used continuous and countercurrent extraction mode. In this mode, the maximum possible difference in concentrations of the extracted substance in the raw material and in the solution is constantly maintained at the chicory/water interface. The latter allowed obtaining a chicory extract with a concentration of up to 20% in PPU and achieve a degree of extraction of soluble solids up to 98% on a larger fraction of the initial raw material without additional grinding. The obtained results demonstrate an increased efficiency of the extraction process in a pulsed continuous mode of operation.

Based on the results of experimental studies, calculations and scale-up of an industrial CPE extractor were carried out for a feed capacity of 400 kg/h, which is typical for operating chicory factories. A techno-economic comparison of CPE versus conventional extractors is shown in Table 1. For a comparable feed capacity, the required energy consumption for CPE operation is one order of magnitude lower than for conventional extractors operation, and the costs of evaporation and drying are lower by up to 3.5 times, which indicates the high efficiency of pulsating extraction. Considering that the CPE does not require chicory to be finely grounded first, the cost of the raw material preparation stage (grinding) as well as the industrial hazards related to dust particulates are also reduced. The spent chicory particles after extraction are comparably large in size, which simplifies and reduces the cost of filtering, separating, and purifying the obtained extract. Calculations of CPE dimensions for a given capacity revealed that one apparatus 5 m in height and 1 m in diameter is sufficient for the process. In the case of macerators, the number of required apparatus is two or greater depending on the macerator volume, and in the case of percolators, at least 21 apparatuses are required, assembled into three parallel operating lines of 7 percolators each. This indicates a higher efficiency of CPE with lower capital costs for extraction equipment. When using CPE, the total specific energy consumption for obtaining 1 kg of instant chicory powder is up to 3.6 times lower compared to conventional extractors. In addition to the CPE economic efficiency, an essential factor is the possibility of obtaining a commercial product with high consumer properties. Conducting extraction in CPE at a lower required process temperature compared to conventional extractors, in combination with a shorter extraction time, can contribute to a smaller loss of inulin and other useful nutrients and improve the quality of the resulting instant chicory powder.

Table 1. Comparison of chicory extraction parameters in various extractors

Parameter name	Unit	Macerator (DEVEX, Germany)	Percolator	CPE (Ingehim)
Chicory particle size required for extractor's operation	mm	2-3	0.15-0.2	5-20
Initial feed (roasted chicory) capacity	kg/h	450	390	400
Amount of produced extract	kg/h	4500	2010	1600
Dry matter content in the extract	kg/h	300	320	320
Produced extract concentration	%	6.7	16	20
Phase ratio chicory : water during extraction	–	1:10	1:7	1:4.5
Process temperature (max)	°C	85-95	100-120	80-85
Process pressure (max)	atm (g.)	0	2-3	0.5
Number of used apparatus	pcs	$\geq 2^{*}$	21^{**}	1
Total working volume of apparatus	m^3	16	14.7	2
Electric energy consumption by extraction	kWh	110	70	10
Heat inputs to produce instant chicory powder with moisture content 10% (evaporation and drying)	kWh	2660	1060	800
Total specific energy consumption to produce 1 kg of instant chicory powder with moisture content 10%	kWh / kg of instant powder	9.24	3.53	2.53

Notes:
- * Two batch extractors (macerators), each having a volume of 8 m^3.
- ** Three batteries, each having seven batch percolators.

In a comparative assessment of the quality and performance parameters of extractors of various types (Table 2), CPE surpasses conventional extractors for production of chicory extract in all respects. A shorter extraction time and a more complete use of the CPE apparatus volume significantly reduce or completely eliminate oxidative and bactericidal processes. The absence of internal devices and moving parts in CPE increases the overhaul period of its operation compared to other extractors and reduces the cost of professional maintenance and overhaul.

Table 2. Qualitative comparison of extraction equipment parameters

Parameter name	Macerator (DEVEX, Germany)	Percolator	Screw extractor	CPE (Ingehim)
Extractor's operating mode	batch	batch	continuous	continuous
Presence of moving mechanical assemblies in the extractor's working area	agitator	none	screw	none
Repair and maintenance complexity	medium	medium	high	low
Total working volume of extractors	large	large	medium	low
Heat loss during operation	high	high	medium	low
Energy consumed by the extractor	high	medium	high	low
Total energy consumption for producing 1 kg of instant chicory powder	high	medium	medium	low
Operating costs	high	high	high	low
Total footprint of extractors	large	large	medium	small

In view of these distinctive advantages and high performance of the pulsating extractor, it is possible to effectively modernize existing chicory factories equipped with conventional extractors of any type to using the CPE and create new energy- and resource-saving factories with increased profitability and a lower payback period. Figure 5 shows a conventional flow scheme for the production of instant chicory powder from crushed roasted chicory roots using percolators with a feed capacity of 390 kg/h. The conventional extraction section consists of three extraction batteries that operate in parallel. Each battery uses seven batch percolators operating in-series. Each battery can have an autonomous set of equipment for subsequent stages of extract processing. As an alternative solution, output flows of extracts from the three batteries can be processed together. The figure shows the layout of batteries operating independently of each other (autonomously). Therefore, in addition to twenty-one percolators, six crude extract collectors, nine evaporators, three thick extract collectors and three dryers are used.

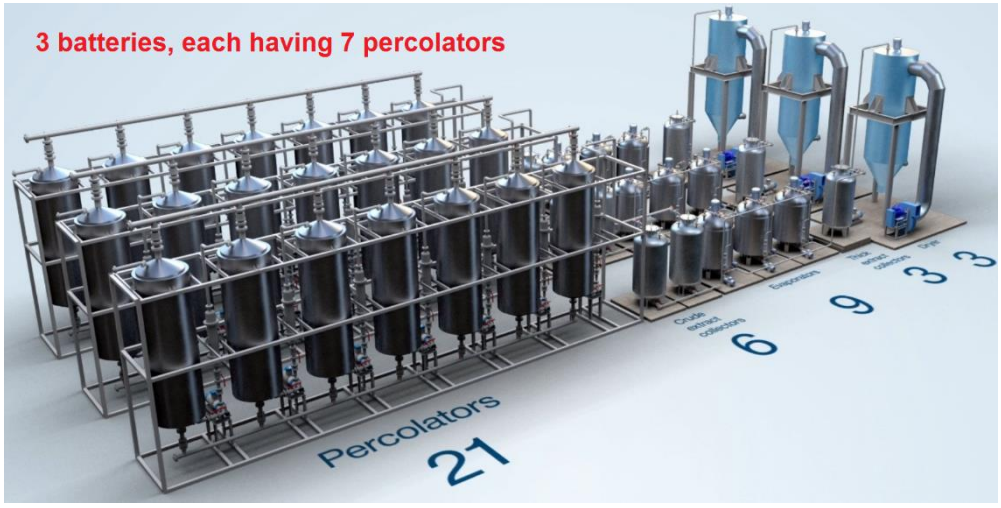

Fig. 5. *Conventional line for production of instant chicory powder with a feed (roasted chicory) capacity of 390 kg/h*

Fig. 6. *Comparable throughput line for production of instant chicory powder after modernization to the use of CPE with a feed (roasted chicory) capacity of 400 kg/h*

Figure 6 shows a scheme of a production line using CPE for a similar capacity. In this example, in addition to the advantage of using only one CPE instead of a plenty of percolators, it is also possible to reduce the number of pieces of equipment for subsequent stages due to reducing the amount of extractant consumed by extraction. Therefore, taking into account the CPE operation continuity, two crude extract collectors, three evaporators, one thick extract collector and one dryer will be required. This reduction in the total number of equipment significantly reduces the required floorspace, capital, operating and labor costs, the complexity of automation, piping, maintenance and repair of equipment. These advantages make it possible to modernize existing chicory factories that use percolators with great economic efficiency. The compactness of CPE allow it to be installed directly in the workshop, in parallel with the existing percolators, with the maximum preservation or reduction of associated equipment. Due to this, it is possible to increase the overall capacity of processing or to modernize step-by-step, which is a more cost effective strategy for factory owners with less upfront capital. A significant reduction in the resources when using CPE instead of conventional percolators allows the consideration of new trends in the development of production due to the separation of technological operations in place and time. It becomes possible to create new compact factories for the production of liquid chicory extracts near the fields where chicory is grown and to process the extracts into the final commercial product centrally at one large enterprise. This will result in a significant reduction and optimization of costs of

transportation and logistics, reduction of environmental pollution, development of rural infrastructure and creation of new jobs. The successful operation of factories processing plant raw materials near the harvest site will prepare a powerful base for the development and implementation of additional improvements for the processing of raw materials. In particular, considering the processing of chicory and taking into account the universality of the pulsating method of extraction, it makes sense to also consider the processing of chicory tops, which today are not processed and not used to extract useful nutrients that are contained in them [2]. Opportunities also exist for the use of spent chicory (meal), which is a waste product formed after extraction, in the form of feed additives or fertilizers. It could reduce the cost of these marketable products, since they would be produced and fully utilized on site without the additional cost of transportation and warehousing.

Based on the carried out work, the following conclusions can be drawn. The CPE extractor developed by the Ingehim Company allows extracting roasted crushed chicory roots with a high degree of extraction (up to 98%) of water-soluble nutrients on a coarser grinding fraction (5-20 mm). At the same time, the energy consumption for the extractor operation is lower by one order, the costs of evaporation and drying by up to 3.5 times, total specific energy consumption for obtaining 1 kg of instant chicory by up to 3.6 times compared to conventional extractors. Lower capital costs, ease of maintenance, and small footprint allow CPE to be installed as an add-on to existing chicory factories for modernization, and to create energy-efficient CPE-based production lines at new chicory factories. Running the process under mild extraction conditions can preserve more inulin and other nutrients contained in the initial raw material than conventional extraction technologies.

REFERENCES

1. FAOSTAT. Food and Agriculture Data. Rome: Food and Agriculture Organization of the United Nations. 2015. https://www.fao.org/faostat/en/#home

2. NIFTEM. Handbook of chicory, PM Formalization of micro food processing enterprises (PMFME) scheme. Sonipat: National Institute of Food Technology Entrepreneurship and Management, Government of India. 2020. http://niftem.ac.in/newsite/wp-content/themes/niftm/assets/pmfme/learning_material/chicorywriteup.pdf

3. Lohmar K., Theurillat V. Chicory beverages. In Encyclopedia of food sciences and nutrition (2nd edition). 2003. P. 1144-1149.

4. Guryanov A.I., Sinyavin A.A., Iovlev D.P., Faizullin I.K., Fassakhov R.Kh. Energy- and resource-saving efficiency of the diffusion apparatus in beet sugar production // Sugar. 2008. No.2. P. 44–46 (in Russian).