Model of a Sugar Factory with Fully Automated Production of Amino Acids and Amino Acid-Pressed Beet Pulp Pellets

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Research Article

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Abstract

The key factor in the industrial production process for the manufacture of the amino acid from the sugar industry is the industrial scale-up. To investigate the impact of the different geometry and physical conditions parameters on an industrial process several techniques such as computational fluid dynamics and scale down approaches have been applied. Process modeling can support the design and the optimization of all these processes. Model, considering the process operative parameters and process stoichiometry, using the data from Egypt Sugar Industry, give an estimation of the process efficiency, the product quality, selectivity as well as the condition for an optimal yield. Combining the results obtained by the model with the data obtained by the scale down devices, the optimal process configuration was identified in an early phase of development to achieve that not only the valuable amino acids can be recovered from soft beet juice, but also the fluid sugar simultaneously satisfies all requirements for the subsequent processes of sugar manufacturing. In this case, the choice of an ion exchanger is associated with the development of a method for extracting amino acids based on the study of the dynamic patterns of sorption and desorption, depending on a number of factors. These include: the shape of the ion exchanger, the degree of its granulation and cross-linking; parameters of ion-exchange columns; flow rate and temperature of working solutions; efficiency of the eluent. Furthermore, for maximizing the utilization of the amino acids extract was added to the beet pulp for producing amino acid-pressed beet pulp (APBP) to be used as integrated animal fodder with highly nutritional value and subsequently high marketing value. The obtained results were indicated the overall recovery yields of 17 amino acids extracted from beet juice were 5.85% respect to dry substance and the percent of the elimination were 98.5%.

1. Introduction

Most of the non-sugar substances in the beet juice are worth the effort to recover but they are of economic importance because they are worth substantially more expensive. In addition, isolating them increases the yield of sugar. Ion exchange resins are routinely used in the beet sugar factory for sugar juice processing [1]. The main two applications for industrial cation exchange resin systems in the beet factory are for juice softening and molasses desugaring [2].

For sugar technician the amino acids in sugar beets are included in the so-called "harmful nitrogen" that is a factor in the sugar loss and difficult crystallization which increases the production of the molasses as by product and this the undesirable consequences in the production of beet sugar. The amino acids, which ultimately remain intact, reappear in the molasses. In the classical process of sugar manufacturing, the beet juice passes through different industrial treatment stages down to the final sugar product without removing the amino acids and eventually graduated with molasses [3–5].

Amino acids are produced through three different routes, namely, extraction from protein-hydrolysates, chemical synthesis and microbial processes (enzymatic synthesis and fermentation). In general, the main

bottleneck of these methods is that they are highly dependent on the availability of natural protein rich resources so that it may be difficult to satisfy the increasing demand of amino acids [6–8].

The chemical synthesis has been the classical pathway to produce achiral amino acids [9, 10]. However, the main drawbacks of the chemical synthesis are associated to the price of the catalyst as well as to the use of hazardous cyanide sources [11, 12]. The Bucherer-Bergs method is the most common industrial chemical process for the manufacture of racemic amino [13]. However, the drawbacks of this method are the long reaction times and the elevated temperatures [14].

The last route to produce amino acids is through biological processes such as enzymatically catalyzed synthesis and fermentation. However, the enzymes are usually expensive and their limited stability is one of the main drawbacks of this process [6].

Most of the current industrial processes for amino acids production are based on fermentation route. Under aerobic or anaerobic conditions, several microorganisms are used to convert the sugars present in a substrate into a broad spectrum of L-amino acids without further purification steps. Fermentation can be operated at mild conditions preventing product degradation [15–17]. Furthermore, the maintenance costs are significantly lower compared to the extraction processes [18]. However, it requires sterility and high energy consumption for oxygen transfer (for the aerobic fermentations) and mixing as well as water addition that impact on capital and operation costs. Moreover, requirement of bigger reactors, compared to the other amino acids production methods, leads to a high capital investment [19], but, due to its economic and environmental advantages, fermentation is the most used process at industrial scale [6]. New technologies using advanced synthetic biology and metabolic engineering techniques have been applied to increase the microbial cells productivity.

Furthermore, innovative approaches to increase the amino acids content by means of a protein up-concentration technique have recently been developed [20–22]. The thick juice (syrup) was used for production of amino acids and of the diamine putrescine by corynebacterium glutamicum [23].

The supercritical fluid extraction was also used to extract free amino acids (AAs) from sugar beet (SGB) and sugar cane molasses (SGC). Under the optimum condition 184 and 316 bar; 43 and 50°C and 76 min, the amino acids extracted form SGB and SGC molasses response surface methodology (RSM) were aspartic acid, glutamic acid, alanine lysine [24].

The operation mode of continuous production of amino acids can provide productivity and process outputs 2.5 fold higher than the fed-batch technology. In a larger scale, the different geometry and physical conditions may affect important parameters leading to a lower process stability, reproducibility and yields and to the formation of unwanted by-products that may affect the final product quality [25–27].

However, ion exchangers are still used for analytical purposes and fermented broth purification step in the manufacture of amino acids by fermentation but have not been yet used on an industrial scale to

manufacture amino acids. Therefore, the industrial processes to produce amino acids still need to be optimized. For this reason, many companies [28–30] and academic institutions started research in this field with the aim of finding more cost-effective and sustainable routes to produce amino acids [31, 32].

Amino acids for feed now play very important roles in improving the efficiency of protein utilization in animal feeding, and contribute to increasing protein supply. Amino acids should be supplied either in the form of protein or crystalline amino acids in feed to meet requirements.

Improving the efficiency of protein utilization in animal feeding with the application of amino acids for feed, will become more and more important in securing the protein supply and protecting the environment [33]. Consumers' concern regarding bovine spongiform encephalopathy has been forcing dairy farmers to limit the usage of animal protein such as blood meal in feed, which will further accelerate the usage of amino acids in ruminant feed [34].

Although the sugar beet juice appears to be an excellent and cheap starting material for the production of amino acids but practically did not be used as a source for their production, because of the significant economic disadvantages. Therefore, combining the two processes, through the production of amino acids from the juice by ion exchange chromatography during sugar manufacturing as an integrative manufacturing, it will be more economical advantages.

Therefore, the purpose of this innovative work is to investigate the extraction of the amino acids from beet juice by ion exchange chromatography method with automatic control system for an industrial installation which will be simple to practice on a production scale. However, with the economic advantages of ion exchange technology used to extract amino acids from beet juice, there are problems in their practical application in the conditions of industrial enterprises. They are associated with the selection of a selective ion exchange, which is achieved by experimental methods, and with control of the process in automatic mode. To do this, it is necessary to organize a timely sequence of the effective processes that ensure extracting the target components from the beet juice medium at the lowest cost, as well as to provide precise control of equipment operating parameters and their regulation according to the operation conditions selected.

2. Production Scheme Description

The production scheme is shown in Fig. 1. It starts from a traditional production of raw juice by water extraction of sliced sugar beet. Obtained raw juice is pumped to the juice purification station and the wet pulp is transported to the pulp presses. The pressed pulp is collected and transported to the drying station, and as the traditional process the dried pulp is directly transported to the pelletizing station for transforming the bulk dry pulp into pellets by pug mills with addition of water. The sugar rich raw juice gained in the extraction plants is purified according to the conventional "classical" method with milk of lime and carbonic acid. The carbonation process basically consists of precipitating calcium carbonate in the raw juice by adding a milk of lime solution and then contacting in with a carbon dioxide rich gas under controlled conditions of temperature and alkalinity. Under these conditions, as the crystalline

calcium carbonate precipitate form and grows, it absorbs insoluble and semi–colloidal matter present in the liquor as well as a proportion of the ash and color bodies. The mud juice will be dehydrated and de-sweetened in filter presses, whereas the clear juice will be directed to second filtration by thickening filters candle filter the juice again is separated into clear filtrate and mud. The clear filtrate juice is subjected to the decalcification (juice softening) by three-strong acid cation exchanger design, two in exhausting and one in regenerating or on standby, to remove the final traces of the lime salt, also known as hardness, which left in the juice after purification (soluble Ca and Mg salts) and so the juice is called hard clear juice. In the classical process of sugar manufacturing the thin clear juice (refers to soft juice) coming from the decalcification station is to be concentrated in the evaporation station up to a thick juice consistency of approximately 73% DS in Falling Film Evaporator. According to this conventional method the amino acids, eventually graduated with molasses. Therefore, the soft juice can be fed to the strongly basic anion exchange resin, as it comes from the softening process because the softening treatment has made it easily capable of percolation and free of impurities that might log or gum the ion exchangers, to further processed by the method of this innovative work to amino acids and conventional commercial sugar products.

The subjected matter of this work is a process for extracting amino acids from soft juices before entering the evaporation station, that the soft juices are passed through strong basic anion exchangers (Amberjet™ 4200), on which the amino acids which have been preserved unaltered in the purification and decalcification processes, are retained and they are thus removed from the juice, that the anion exchangers are eluted with ammonium hydroxide (5%), that the amino acid-rich eluate from the ion exchanger are concentrated by Robert-Evaporator, and the concentrated amino acids solution are subjected to the beet pulp pelletizing plant for mixing with dried pulp instead of imbibition water in certain portion (2%) before pelletizing in order to adjust the final nutritional value of the animal fodder according to market requirements. It is the object of the innovative work to produce amino acids from beet juice during sugar manufacturing, by a simple method for subsequent application on a production scale.

3. Experimental

3.1. Reagents and chemicals

All chemicals used in experimental work were analytical grade and used without further purification.

3.2. Apparatus

Amberjet™ 4200 strongly basic anion exchange resin in the Cl^- form type 1 with functional group trimethyl ammonium and a uniform particle size (0.6–0.8 mm) was provided by Rohm and Hass Company. The uniformity and mean particle size of Amberjet 4200 resin have been optimised for use in industrial equipment with a total exchange capacity ≥ 1.3 eq/L. Laboratory-scale studies were performed with glass column of 4.4 cm internal diameter (Vantage® L44x500), from Merck Millipore, Darmstadt,

Germany. The Äkta explorer™ 100 chromatography system (GE Healthcare, Uppsala, Sweden) was used to supply flow to the column.

3.3. Analysis

Amino acids compositions and curves in beet juice and beet pulp were determined using amino acid analyzer equipment (EZChrom) as described by AOAC [35]. Chemical analysis of the beet pulp was carried out on dry weight basis following AOAC Methods [36].

3.4. Raw material

The soft juice (with about 16% dry substance) which had passed through the regular manufacture procedure (a factory produces 1.15 kg of juice per each kg of beets), after decalcification process, with a pH of 10 and a temperature of 70–80°C was collected. The composition of the thin clear juice is varying according to quality of beet, factory processes and fertilization. It can be simply summarized that 90% of its solid substance is sugar and 10% consists of non-sugar substances. The non-sugar substances consist approximately of 60% amino acids (0.960 g/100mL).

3.5. Procedures for amino acids extraction in a lab scale

The thin clear juice obtained from decalcification which having a temperature of 70–80°C and pH ≥ 10 was tested for its amino acids content. 5 L of the thin clear juice is passed continuously through a small column (50 cm high × 4.4 cm dia.) contains 500 mL (33 cm bed height) of strongly basic anion exchange Amberjet 4200 Cl resin bed at flowrate 16.6 mL/min until the resin is nearly exhausted (saturated with the amino acids). An Äkta explorer™ 100 chromatography system (GE Healthcare, Uppsala, Sweden) was used to supply flow to the column. When amino acids broke through from the anion exchanger the percolation is stopped. The amino acid is used as the led substance, even a small number of amino acids can be reliably detected with ninhydrin reagent (2%). The elution and regeneration sequence include first an air – scouring step of the resin, followed by a backwash with the treated juice to loosen the resin mass, reclassify the resin particles and to remove foreign particulates. The backwashing cycle brings the resin to its original order because, during the service cycle, resin particles become classified (the largest particles remain at the bottom, while the smaller ones are distributed on a higher level). A backwash is provided by applying a uniform flow of treated juice from the bottom of the bed to fluidize the resin. Typically, the volume of treated juice required is about 2 bed volumes. The backwash stream is collected in a buffer tank, from which it is continuously pumped to the filters after the second carbonation in the regular sugar processing line. All eluting and regenerating steps are done in an up-flow mode as shown in Fig. 2. The resin is cooled to 40°C with cold soft juice and then it is cleaned from juice with cold water. The loaded resin is then eluted up-flow with ammonium hydroxide 5%. The amino acids content in the eluate was determined by using amino acid analyzer and amounted to the amino acids originally contained in the thin clear juice. The fixation capacity of the resins was calculated using the inlet and outlet acids concentration in the solutions. The eluate from column was concentrated in Robert Evaporator (tubular evaporator) to a dry substances content of 70%. The resin is then regenerated up-flow with 35°C cold treated juice, drawn from the product surge tank, containing 40 g/L NaOH (as 100%) to

return the resin to its original capacity. The resin is rinsed with 75°C hot treated thin juice. This operation has the purpose of washing away the sodium hydroxide and heating up the resin bed. The regenerated column is again fed with juice. The final concentrated amino acid solution is subjected to the beet pulp pelletizing station for mixing with the dried pulp in a certain portion (2%) that is the water portion which is added in the regular process, before pelletizing to adjust the final maturational value of the animal fodder. After being pressed into pellets, specific pellet coolers are arranged usually directly below.

4. Engineering Of Soft Juice Ion Exchanging For Amino Acid Extraction

For the up-scaling calculation and adjust the model and of amino acids production from soft juice with the actual operating data of sugar manufacture, values common in the Egypt Sugar Industry Plant were applied. Mass flow of sugar beet 10,000 ton per day (417 t/h). At a draft equal to 115% of processed beets, a factory produces 1.15 kg (or tons) of juice per each kg (or ton) of beets, the mass flow of thin clear juice equal to 478 t/h ≈ 446 m^3/h (juice density ≈ 1.07 kg/L). From this and other boundary conditions the system incorporates three ion exchangers in parallel design of each a capacity 223 m^3/h, two ion exchangers being exhausted on thin juice simultaneously. These are staggered with respect to exhaustion so that both do not require regeneration at the same time. The third cell is being regenerated or is in standby. The exhaustion cycle length of eight hours (breakthrough time) is necessary to properly turn around an ion exchanger and preserve the continuous operation. The cycle is so dimensioned, that the ion exchanger is removed from service before a high leakage amino acid will appear compared to that designed, at this time the next ion exchanger is placed on line. The cut-off point is determined by volume totalizing of treated thin juice. To design ion exchangers there are some aspects that should be taken into consideration, such as the volume of resin, the surface area of resin, the height of columns, the number of exchangers and the pressure drop. The data obtained from small-column (4.4 cm inside diameter) were scaled up directly to full-scale design provided that the surface loading rate and empty bed contact time are the same. To get the above-described parameters, the optimum volumetric flow rate was determined from the experiments at which a maximum breakthrough capacity was achieved. According to the values of the Egypt Sugar Industry Plant, the maximum bed height used in the industry is 3 m. The maximum bed height is established to prevent the big pressure drop that would affect the stability of the resin. A higher bed height is preferred but not exceeds the maximum and based on manufacture's production information, the minimum bed depth for Amberjet 4200 is 800mm.

4.1. Ion exchanger design calculation

In this calculation a flow rate of 100 L/h, the amino acid originally contained in 1L of thin juice was 9.60 g, the concentration of extracted amino acids was 9.34 g/L and the residual concentration amino acids was 0.26 g/L were taken from the experiment results. The required bed height in the ion exchanger has been assumed as 1.7 m based on sugar manufacture's information of juice softener.

4.1.1. Breakthrough capacity

The concentration of amino acids extracted by the resin = 9.34 g/L

$$Thebreakthroughcapacity = 9.34g/L \times 5L(juice) = 46.7g$$

$$= \frac{46.7g}{0.5L(resin)} = 93.4\frac{g}{L}$$

4.1.2. Pressure drops

Based on the manufacture's data, the maximum pressure drop for the resin bed is 200 kPa. Both of surface loading and bed height have impact on pressure drop through the resin. The relevant information can be found in pressure drop formula provided by manufacture. The pressure drop of ion exchange resin beds is calculated according the following formula:

$\Delta p\ (kPa) = h\ (m)\ x\ v\ (m/h)\ x\ FV\ x\ FT\ x\ FR$

h = Resin bed depth (m), v = Linear velocity (m/h), FV = Velocity factor

FT = Temperature factor, FR = Resin factor (specific pressure drop $(kPa\ x\ m^{-2}\ x\ h)$)

in this case, $FR = 0.8$, $FT = 1.1$, $FV = 1.3$,

Resin bed height (m) $h = 1.7\ m$

$$Linear\ velocity/surface\ loading\ (m/h) = \frac{100}{1000 \times \pi \times (0.022)^2} = 65.8\ m/h$$

$$\boldsymbol{\Delta p = 1.7\ (m)x\ 65.8\ (m/h)x\ 1.3\ x\ 1.1\ x\ 0.8 = 127\ kPa}$$

4.1.3. Service flow rate

The volume of the bed occupied by the resin:

$BV = area \times depth = \pi \times (0.22)^2(dm) \times 17(dm) = 2.6L$ $SFR = \frac{100\,(L/h) \times 1BV}{2.6\,(L)} = 38BV/h$

4.1.4. Volume of resin

Treated juice flow rate = 223 m^3/h $Totalrequiredresinvolume = \frac{Treatedjuiceflowrate}{SFR}$

$= \frac{223m^3/h}{38BV/h} = 6m^3$

4.1.5. Surface area of resin required

$$Totalrequiredsurfacearea = \frac{Resinvolume}{Resindepth} = \frac{6\left(m^3\right)}{1.7(m)} = 3.5m^2 Diameter$$

$$= \left(\frac{3.5m^2}{\pi}\right)^{0.5} \times 2 = 2m$$

4.1.6. Breakthrough time

$$Breakthroughtime = \frac{6.0m^3 \times 1000L/m^3 \times 93.4g/L}{0.26g/L \times 223000L/h} = 9h$$

4.1.7. Column height

An extra space is needed for the bed expansion during backwashing which is considerable risk of resin loss, of about 70%.

$Therequiredheightforbackwashing = 1.7m \times 70\% = 1.19m$
$Columnheight = 1.7m + 1.19m = 2.89m$ (Without considering of the height for resin support and inlet distributor)

4.1.8. Empty bed contact time (EPCT)

$EBCT = \frac{H}{v}$ $v = surfaceloading(m/h)$ $H = bedheight(m)$
$EBCT = \frac{1.7m}{65.8m/h} = 0.026 = 1.55min$ Based on the experiment results and calculation, the ion exchanger is designed as follows: Number of ion exchanger: 3-each with a capacity of 223 m^3/h. Bed height: 1.7 m. Column height (without considering of the height for resin support and inlet distributor) = 2.9 m. Surface loading: 65.8 m/h. EBCT: 1.6 minutes. Breakthrough time: 9 h.

4.2. Technical model description for automation of amino acids production

The suggested model for production of amino acids from beet juice was fully automated for computer controlling. A flowrate Switch (FT), Temperature Switch (TT), Pressure Switch, Level Switch, Dry substance Switch (DT), Level Control Valve (LCV), Temperature Control Valve (TCV), Flowrate Control Valve (FCV), Dry Control Valve (DCV), Butterfly Valve (UV) and Volume Totalizer (VT) on each process of the model production, regulates all requirements of flowrate, temperature, pressure and dry substance to increase the accuracy of control and to minimize material cost, also to satisfy the ion exchange conditions for achieving the best results and the possibility of integrating this operation with fully automatic factories in simple manure. The scheme of the automated installation for amino acids production from beet juice by ion exchange is presented in Fig. 3.

4.2.1. Ion exchanger charging

The softening juice from the soft juice tank is pumped to the two service exchanges each with flow rate 223 m^3/h, the quantity is controlled by (FT 21030) which is controlled by valve (FCV 21030), when the volume totalizer of any of the ion exchangers (VT21030) is reached to 1784 m^3 which corresponds to a "breakthrough" point (one cycle of 8 hours), the valve (FCV 21030) will be closed, then the feed is shifted to the available second or third exchanger, and then the first primary exchanger is purified and eluted or regenerated. The ion exchanger has (PT21029) and (PVC210129) which control the pressure of the ion exchanger to be (127 kPa), also has (LT 21028) and (LVC21028) which control the resin level to expand within 0.3 m of the distributor at the top of the ion exchanger. The fluid sugar solution then is supplied to tank (15121A) which is equipped with (LT15025) and (LCV15025) to control the solution level in tank to be not less than 30 cm. The solution is pumped by (EU21011) to the evaporation station, the quantity is controlled by (FT21026) and the valve (FCV21026) with flowrate 446m^3/h. The ion exchanger is switched to the subsequent stages of the elution and concentration the eluate.

4.2.2. Ion exchanger elution

The valve (UV21019) is checked to be open, then the water from tank (21006) is pumped by (EU21012) after to ion exchanger at up-flowrate 25 m^3/h, the quantity is controlled by (FT21022) which controls the valve (FCV21022) for cleaning the resins from juice residue. The tank (21006) is equipped with (TT21023) and (TCV21023) to control the temperature of water in tank to be 40°C. The concentrated ammonium hydroxide in tank (21001) with level (LT21050) is pumped by (Eu21003) and (Eu21004) to dilution tank (21002) where cold water is added (for reaching to concentration 5%) via control valve (LCV 21031) when the tank (21002) is reached to 3 m, the valve (LCV 21031) will be closed, the tank (21002) has (PT 21040) and (PCV 21040) which controlling the pressure of tank to be (-0.8 bar/m), also equipped with (TT 21048) and (TCV 21048) to control the temperature of the fluid to be 40°C. The solution in tank (21002) is pumped by (EU 21032) and (EU 21002) to anion exchanger with flow rate 25 m^3/h, the quantity is controlled by (FT 21032) which controls the valve (FCV 21032), when the level (LT 21031) of the tank (21002) become 5 cm the valve (FCV 21032) closes and the pump (EU 21001) and (EU 21002) stop. The eluate of the ion exchanger is supplied to tank (15121 B) which equipped with (TT 15092) and (FCV 15092) to control the eluate temperature to be 40°C. This eluate is pumped by (EU 21005) and (EU 21002) to the tank (21002), the quantity is controlled by (FT 21039) which controls the valve (FCV 21039) with flow rate (0 : 25 m^3/h). The solution in tank (21002) is pumped by (EU 21003) and (EU 21004) controlled by (FT 21034) which controls the valve (FCV 21034) to preheater, in plate type heat exchangers using different, vapors with flow rate from 5–15 m^3/h, then to the Robert-evaporator (21003) is directly heated with exhaust steam from the turbines. The concentrated solution from evaporator (21003) is pumped by (EU 21009) to tank (21004). The evaporator (21003) is equipped with (DT 21041) which controls the valve (DCV 21041) to control the Brix (dry substance) to be 70°. Also, the evaporator is equipped with (PT 21038), (PT 21039), (TT 21051) and (TT 21052) to control the difference in pressure and temperature between the steam chest and the juice in calandria and also equipped with level (LT

21040) which controls the valve (LCV 21040). When the level (LT 21036) in tank (21004) reaches to 3.5 m the valve (FCV 21034) is closed and the valve (FCV 21036) opens. The concentrated solution in tank (21004) is pump by (EU 21007) to beet pulp pelletizing station to be mixed, in before pelletizing by pug mills, instead of water imbibition and molasses to adjust the final protein content and its nutritional value to satisfies all requirements for animal fodder as shown in the Fig. 4.

4.2.3. Ion exchanger regeneration

The system incorporates a three-ion exchanger design with two exchangers being exhausted on soft juice simultaneously. These are staggered with respect to exhaustion so that both do not require regeneration at the same time. The third exchanger is being regenerated or is in standby. All regenerating steps are done in an up-flow mode and use soft thin juice drawn from the product surge tank. The regeneration sequence includes first an air from air compressor – scouring step of the resin. The valves (UV21018) and (UV21020) is checked to be closed and the treated juice from tank (15121A) is pumped by (EU21010) to ion exchanger at flowrate 12m^3/h, the quantity is controlled by (FT21021) which controls the valve (FCV 21021) for loosening the resin mass and freeing it from foreign matter. The backwash stream is collected in tank (15121B), from which it is continuously pumped to the filters after the second carbonation. The valve (UV21020) is opened and the cold water from tank (21006) is pumped by (EU21012) to the regenerant cooler (RC), the quantity is controlled by (TT 21017) and (FT21022) which control the valve (FCV21022) to control the temperature of the outlet soft juice from (RC) to be 35°C for cooling the resins to 35°C. Then the concentrated sodium hydroxide in tank (21005) is pumped by (EU21013) at flowrate 0.385m^3/h to regenerant cooler (RC), the quantity is controlled by (FT21024) which controls the valve (FCV21024) to get together with the cold treated juice and then the regenerant with 35°C cold treated juice is subjected in up-flow to ion exchanger. The regeneration effluent is collected in a buffer tank (15121B) and from there it is continuously pumped to the filters after carbonation system. When the level in tank (21005) is reached 5cm the valves (UV21018) and (UV21020) close. The up-flow fluid of hot treated juice with 70°C is continuously pumped by (EU21010) at flowrate 12 m^3/h to ion exchanger for washing away the sodium hydroxide and heating up the resin bed. The summary of the sequence processes of the innovative technical operation steps of soft juice ion exchanging are summarized in Table 1.

Table 1
Summary of the technical investigation of soft juice ion exchange process steps

NO	Step	Ion exchange medium in	From tank	Ion exchange medium out	To tank
1	Charging	Soft juice	Soft juice tank	Treated juice	Treated juice tank
2	Lowering			Treated juice	Treated juice tank
3	Lifting	Soft juice	Soft juice tank		
4	Lowering			Backwash effluent	Backwash effluent tank
5	Aeration	Air	Compr. air tank	Air	
6	Backwashing	Treated	Treated juice tank	Backwash effluent	Backwash effluent tank
7	Lowering			Backwash effluent	Backwash effluent tank
8	Cooling	Cold treated juice	Treated juice tank	Backwash effluent	Backwash effluent tank
9	Cleaning	Cold water	Cold water tank	Backwash effluent	Backwash effluent tank
9	Elution	NH_4OH (5%)	NH_4OH tank	Amino acids effluent	Amino acids effluent Tank
10	Regeneration 1	Treated juice + NaOH	Treated juice tank	Backwash effluent	Backwash effluent tank
11	Regeneration 1	Treated juice + NaOH	Treated juice tank	Regeneration effluent	Regeneration effluent tank
12	Washing 1	Treated juice-cold-	Treated juice tank	Regeneration effluent	Regeneration effluent tank
13	Washing 2	Treated juice-hot-	Treated juice tank	Regeneration effluent	Regeneration effluent tank
14	Washing 2	Treated juice-hot-	Treated juice tank	Regeneration effluent	Regeneration effluent tank
15	Lowering			Treated juice	Treated juice tank
16	Pause				

5. Results And Discussion

5.1. Ion exchange chromatography of amino acids

The process of this work and the ion exchange conditions were designed to be interrelated that not only the valuable amino acids are recovered from soft juice, which has a pH of 10 and a temperature of 70–80°C, but also fluid sugar solution is simultaneously obtained which satisfies all requirements for the subsequent processes of sugar manufacturing, therefore, the Amberjet™ 4200 strongly basic anion exchange resin was selected of industrial grade and has longer lifetime, high capacity for amino acids at high pH, more tolerable to high temperature and cost-effective operation. On account of swelling and shrinkage in technical operation, which was taken on the anion exchange resin that they are more difficult to manage, and substantially large amounts of water are needed to sweeten them i.e. the juice is greatly diluted [1]. It was overcome on this, where, there is no sweeten step in the innovative processes of this work, through the use of final treated juice drawn from the product surge tank to perform the backwashing, regeneration, and rinse in the operation system. The extraction of amino acids from beet juice with anion exchange column chromatography relies primarily on electrostatic attractions for adsorptions and electrostatic repulsions for elution. To achieve the maximum of adsorption capacity and elution efficacy, the amino acid should have a higher net ionic charge under column conditions and the high difference between the pH of the column and the isoelectric point of amino acid is needed.

5.2. Effects of pH and flow rate on the separation of amino acids

For the separation of ionizable soluble amino acids via the reversal of the types of net charges on the adsorbed amino acids, a proper of anion exchangers of positive charge which had an especially high capacity for amino acids, a high mechanical stability of small particles and a short diffusion path between the active groups was used. With anion exchanger, column pH was to be closer to 10 of a low enough for the isoelectric points (pI) of the main amino acids for bearing negative net charges and was attracted to the ion exchanger. Accordingly, on an amino acids molecule, there are negative net charges at pH > pI, However, there are zero net charges at a given pH for a non-electrolytes such as sugar and for a non-ampholytic aids group. It appeared that the poor separation of amino acids was limited to those with isoelectric points closer to the pH of the column. The amino acids are eluted from the anion exchanger using ammonium hydroxide solution (5%). The use of ammonium hydroxide for elution has the advantage of high amino acids concentrations in the eluting solution by providing ionic strength and pH to increase for achieving the pI of the amino acids and the electrostatic attractions changed to electrostatic repulsions for the elution. The separation of various amino acids is significantly affected by the pH of the solution. The cysteine is the most sensitive for the pH and temperature of the solution under separation. Cysteine must be eluted and completely separated directly after alanine. At the selected ion exchanger conditions of pH ≥ 10 and temperature ≈ 70–80°C cysteine was just be positioned between alanine and valine as shown in Fig. 4 and this indicated that the ion exchanger condition are suited for extraction amino acid from beet juice.

For operation time, the flow rate of the eluting buffer is important, as it determines the time of the extraction process. If the flowrate through the column is faster than the optimal, the fractions departing the column become unsymmetrical, leading to tailing, in addition the amino acid peaks can overlap, while, slower flowrate lead to many of proteins lose activity with time of extraction, so at flow rate 100 L/h, an acceptable extraction yield was achieved.

In Fig. 5 typical chromatogram of amino acids in the eluate of the ion exchangers are given, showing that 17 amino acids could be satisfactory separated, identified and quantified. The elutes of the anion exchanger are not discolored, apparently because of the use of the clear soft juice after decalcification, so that a direct crystallization of the pure amino acids is possible or concentrated through the evaporator to be used as nutrient additive for beet pulp pellets to increase its nutritional value.

The mean amino acids content in the fraction of the eluate of ion exchanger are presented in Table 2, concentrations are given in percent based on g/100 mL. The obtained results revealed that the eluate is contained 17 amino acids, among them 8 essential amino acids were found, with different ranges of concentration, in which more than 50% is glutamic acid. The overall extracted amino acids content to the amino acids originally contained in the thin clear juice was amounted to 98.5%, and as to the dry substance content of thin juice was 5.96%.

The desired results for amino acids production were achieved by the carefully selection of the ion exchange resin having an especially high capacity for amino acids and adequate retention time. The automation of the production of amino acids in the innovative work system has been instrumental in ensuring that the correct temperature, pH, and addition of ammonium hydroxide were maintained. Therefore, the control of material flows and ratios and other processes variables through the fully automated system had gone a long way toward obtaining the best results.

Table 2
Composition of amino acids (essential and non-essential) extracted from thin clear juice by anion exchanger.

Non-Essential Amino Acids	**Concentration, g/100 mL**	**Essential Amino Acids**	**Concentration, g/100 mL**
Methionine (Met)	0.021	Aspartic acid (Asp)	0.068
Isoleucine (Ile)	0.014	Serine (Ser)	0.024
Leucine (Leu)	0.069	Glutamic acid (Glu)	0.315
Tyrosine (Tyr)	0.032	Glycine (Gly)	0.013
Phenylalanine (Phe)	0.041	Alanine (Ala)	0.069
Histidine (His)	0.023	Cysteine (Cys)	0.032
Lysine (Lys)	0.078	Valine (Val)	0.030
Threonine (Thr)	0.036	Proline (Pro)	0.035
Arginine (Arg)	0.034		
Total amino acids	**0.934**	**Extraction recovery**	**98.29%**
Originally amino acids	**0.960**		**5.84% DS**

Beet soft juice-based production of amino acids by ion exchange chromatography integrated with beet processing for sugar production is described here for the first time. Regarding the results which were obtained from other authors with different methods:

Extraction from protein hydrolysates: L-lysine from was extracted Hair with recovery yield of 10 (%w/w) [7], mixture of amino acids were extracted from Deoiled rice bran with yield of 0.8 (%w/w) [37] and L-leucine, L- alanine and L-serine were extracted with recoveries 0.7, 0.1 and 0.2 (%w/w) respectively [38]. However, the drawbacks of this method are few kinds of amino acids [6], depend on the availability of natural protein rich resources [13], possible protein degradation [6], by-products [13] and wastewater generation [37, 39].

Chemical synthesis: L-glycine was separated by ammonolysis of trichloroethylene with yield of 40–70 (%w/w) [9] and DL-alanine was synthesized from the ammonolysis of (±)-2-chloropropionic acid with recovery yield of 78(%w/w) [10]. However, the disadvantages of this method are production of racemic mixtures additional optical resolution step is necessary to obtain only the L-forms [6], price of the catalyst [13] and hazardous sources [11].

Enzymatically catalyzed synthesis: L-alanine, L-glycine, L-phenylalanine, L-leucine and L-serine were extracted from Phenylpyruvate by Polyazetidine immobilized *E. coli* with recoveries 7.6, 5.8, 4.2, 9 and 4.3

(%w/w) sequentially [40]. However, the drawbacks of this method are Price and instability of the enzyme, not favorable for production of L-amino acids at industrial scale [6].

Fermentation using Corynebacterium glutamicum: L-lysine was produced from glucose 10% [6], glucose 50% [41] and glucose 10% [17] by MH20-22B/pJC23, AGM5 and Lys-12 strain respectively with recoveries 50, 90 and 120 g/L. While L-tryptophan acid was produced from Molasses (glucose) 25% by KY9229 strain with recovery yield of 35 g/L [42]. Furthermore the beet thick juice and sucrose were used for producing L-lysine, L-glutamate and L-arginine [23] by DM1729 [43], WT [44] and strain ARG1 [45] respectively as follows: L-lysine, L-glutamate and L-arginine accumulated to concentrations of 14.4, 45.3 and 50.3 mM with pure sucrose and 33.0, 56.5 and 43.9 mM with thick juice sequentially. The resulting volumetric productivity for L-lysine, L-glutamate and L-arginine with pure sucrose was 0.10 (depletion of carbon source after 20.3 h), 0.33 (depletion after 20.3 h) and 0.36 g/L/h (depletion after 24.5 h) respectively and with thick juice was 0.26 (sucrose from thick juice was depleted after 10.1 h), 0.64 (sucrose was depleted after 13 h) and 0.49g/L/h (sucrose was depleted after 15.6 h), sequentially.

Fermentation using Escherichia coli

BL21 (DE3) strain was used to produce L-lysine from Glycerol 1% with recovery yield 0.58 g/g of sugar [46]. Furthermore, L-phenylalanine was produced from Glucose 3% by MG1655 derivative strain [47] and from Glycerol and lactic acid 16% by US4.11/pF81kan (W3110 derivative) strain [48] with recoveries 51g/L and 0.15 g/g sugar respectively. Moreover, FB-04/PSVO3 (W3110 derivative) strain was used for producing L- tryptophan from Glucose 0.5% with recovery yield 13.3 g/L [49]. Among these methods of fermentation there are drawbacks represented in sterility has to be ensured, energy required for oxygen transfer and mixing [15], long time and High operational costs [16]. Also, when supercritical fluid extraction (SFE) was used to extract free amino acids from sugar beet and sugar cane molasses the extraction recoveries for SGB and SGC molasses were 42% and 31% for aspartic acid, 63% and 37%, for glutamic acid, 46% and 48% for alanine and 31% and 20% for lysine sequentially [24].

5.3. Amino Acids-Pressed beet Pulp Pellets (APBP)

The limiting factors of the by-product from sugar processing which is known as beet pulp for utilizing as animal feed are the low protein content and the high content of fiber, which are known to have a low efficiency of energy utilization in mono gastric, in addition, a crude protein gives relatively little information on the composition in amino acids and/or their availability [50]. The amino acids profile of final extract from beet juice showed that it is enriched with all essential amino acids as valine, methionine, leucine, isoleucine, phenylalanine, histidine, tryptophan and lysine, so the extract obtained was employed in the protein of animal feed supplements. Since animals use amino acids, the elementary components of proteins and it cannot synthesize some amino acids (essential amino acids) or since the amounts produced are insufficient, these amino acids must be supplied by the feed. Modern diets should solely be based on digestible amino acids, it generates more costefficient diets and can lower the environmental impact in comparison to a diet based on crude protein. In any case, the feed ration shall

take into account the need to satisfy all the requirements in essential amino acids, notably in methionine, cysteine, lysine, threonine, tryptophan, isoleucine and valine [51].

The chemical analysis of the beet pulp was found out a relative improvement in the amino acids-pressed beet pulp (APBP) product. The addition of amino acids to beet pulp not only increased the amino acids content of beet pulp but also, increased the values of crude protein. The improvement of crude protein from 8.40 [52] to 14.58 indicated a great deal for compensation the lacking of nitrogen percentage which is utilized in the formation of true amino acids as shown in Table 3.

Table 3
Nutrient composition (%) of APBP

Components	Result (%)	Components	Result (%)
Dry matter	93.50	**Minerals**	2.50
Moisture	6.50	**Fat**	0.72
Crude protein	14.58	**Sugar**	2.50
Crude fiber	18.40	**Nitrogen free extract**	49.30
Ash	5.50		

This composition indicated that the APBP can serve an energy source besides protein and amino acids particularly when may be fed to poultry. Amino acids composition of a beet pulp primarily determines its potential of nutritional value. The amino acids composition of the beet pulp and final APBP obtained are given in Table 4.

Table 4
Amino acids profile of beet pulp and APBP (%)

Amino acid	Beet pulp (%)	APBP (%)	Amino acid	Beet pulp (%)	APBP (%)
Met	0.33	0.62	**Asp**	0.65	1.24
Ile	0.22	0.42	**Ser**	0.35	0.72
Leu	0.67	1.29	**Glu**	3.45	7.24
Tyr	0.43	0.83	**Gly**	0.18	0.34
Phe	0.55	1.15	**Ala**	0.67	1.32
His	0.34	0.66	**Cys**	0.44	0.84
Lys	0.80	1.51	**Val**	0.38	0.72
Thr	0.53	1.05	**Pro**	0.48	0.93
Arg	0.47	0.90			

As evident from Fig. 6 the APBP contained 17 amino acids, 8 of which are essential amino acids, and has sufficient lysine and threonine contents which suggests that this APBP should be utilized feed supplement especially diet based on cereals. It has the potential to replace high portions of cereals in concentrate mixtures for dairy cattle. This indicated the possible exploitation of amino acids extracted from beet juice for the improvement of the nutritional value of beet pulp. Hence this work was focused on maximizing the nutritional value of feed additives by putting the essential building blocks of protein through the production of APBP rich in important amino acids for modern animal nutrition.

Conclusions

In this work, methodology for extracting mixture of plant-based amino acids from beet juice with successful automation under the operation conditions of sugar processing in order to preserve its functional properties has been innovated. The proposed method for controlling the plant for the ion exchange of amino acids is also applicable for increasing the efficiency of the production of amino acids from beet juice. The control of material flows and ratios and other variables of the effective processes were recognized through the fully automated system that ensure extracting the amino acids from the beet juice at the lowest cost, as well as to provide precise control of equipment operating parameters and their regulation according to the operation conditions selected for obtaining the best results.

From technical point of view as the method innovated in this work is easy to scale-up purpose and it has provided good solubolisation yields of amino acids from the beet juice to be used for subsequent application as nutrient additives for the by-product of sugar beet processing, beet pulp pellets, to increase its nutritional value and then can be used as integrated animal feed. As the scale up procedures are now established, the use of beet juice as the alternative raw materials for the production of the natural amino acids at industrial scale appear to be an interesting opportunity to maximize the benefit from the

intermediates in the process of sugar beet and to optimize the beet sugar manufacturing. However, a further work is still required to optimize process conditions coupled to industrial-scale tests.

Declarations

Compliance with Ethical Standards

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Conflict of Interest

The author Emad Mohamed Bayuome declares that he has no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by the author.

Originality of work

This work described has not been published before; that it is not under consideration for publication anywhere else.

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Figures

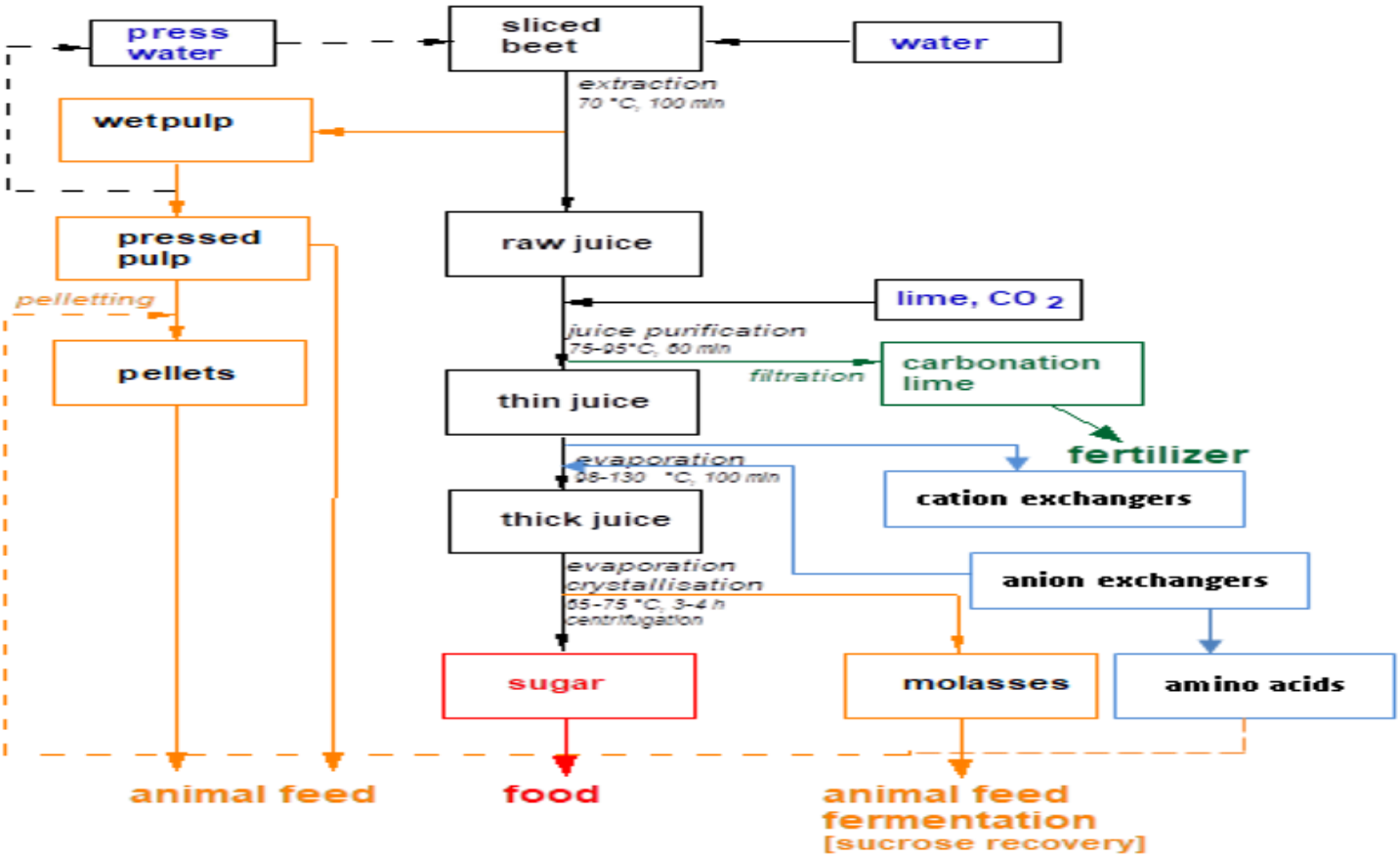

Figure 1

Innovative scheme of sugar beet sugar processing with amino acids production and common product uses

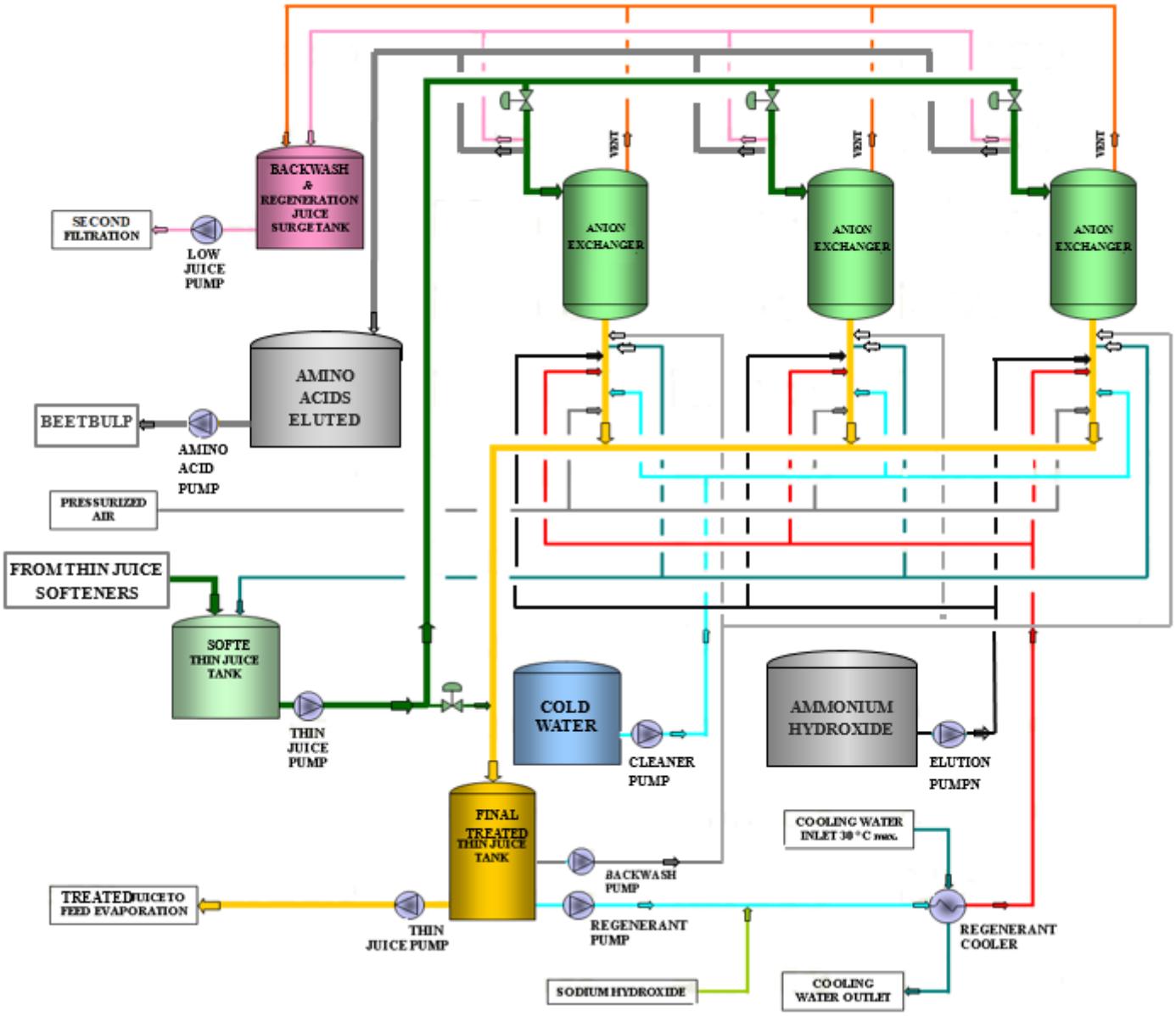

Figure 2

Flow diagram for amino acids production from thin clear juice, consisting of charging, elution and regeneration processes for anion exchangers

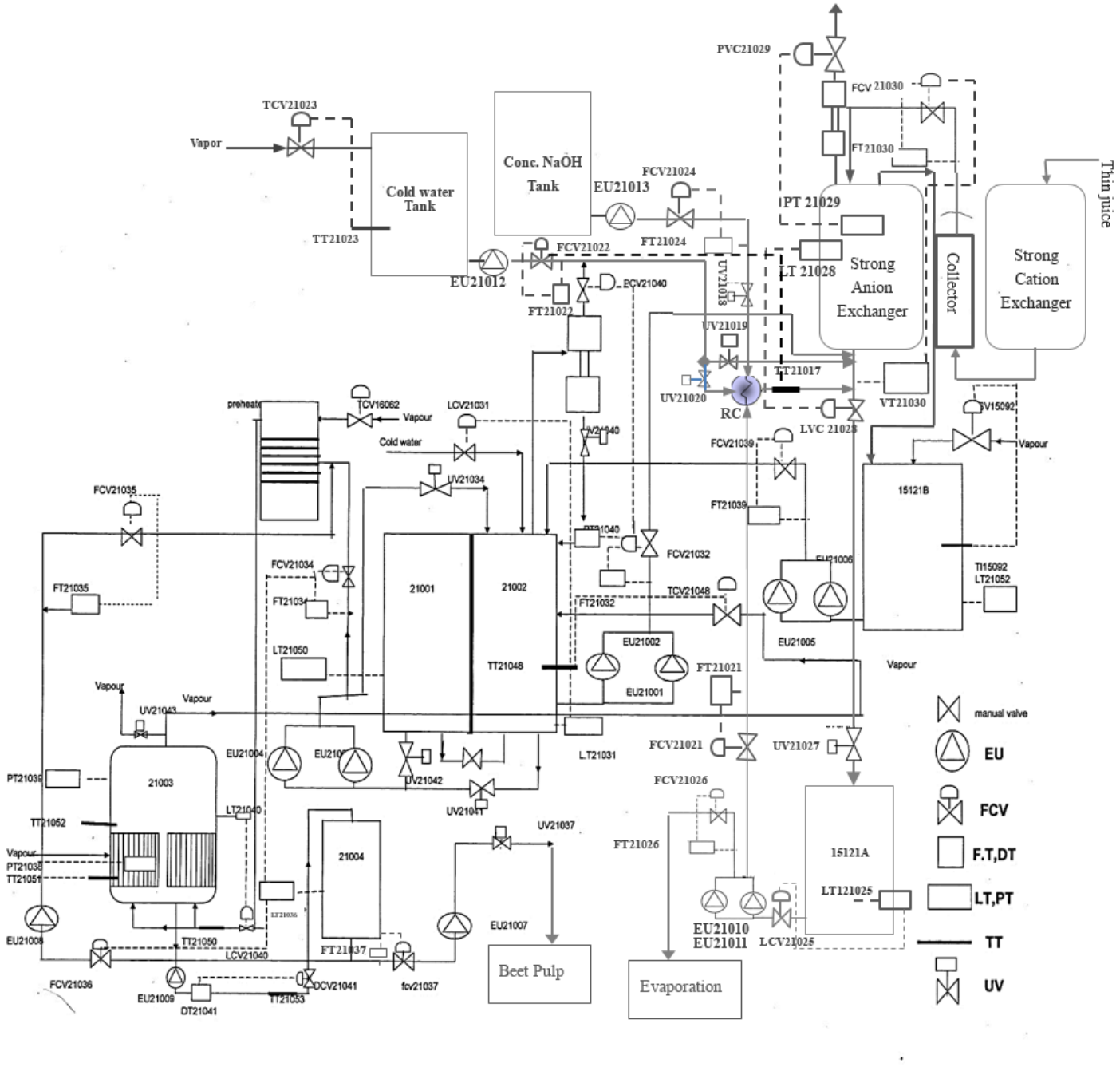

Figure 3

Installation scheme for ion-exchange production of amino acids

Fig. 4.

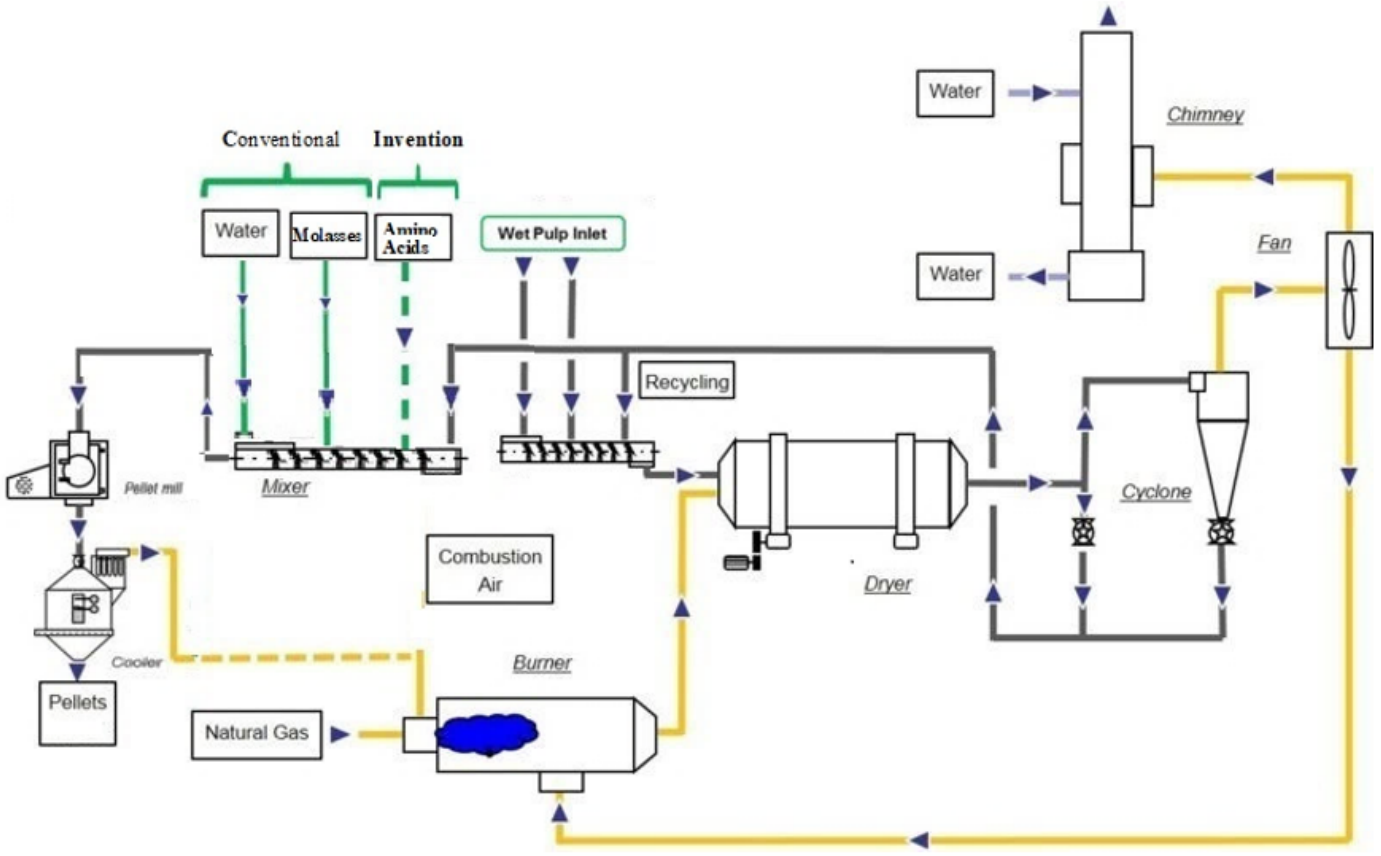

Figure 4

Innovative flow diagram for Amino Acid-Pressed Beet Pulp Pellets production

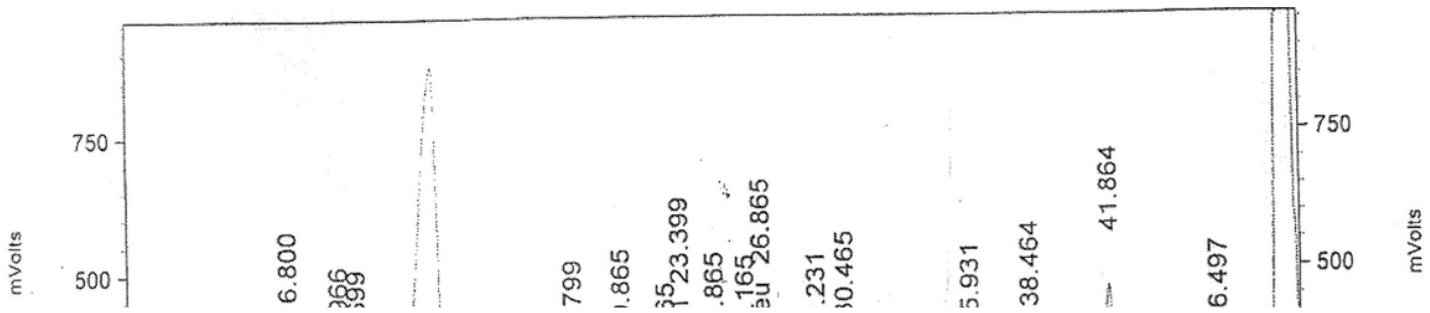

Figure 5

Elution profile chromatogram of amino acids extracted from beet soft juice on strongly basic anion exchanger resin at pH ≈ 10 and temperature 75°C.

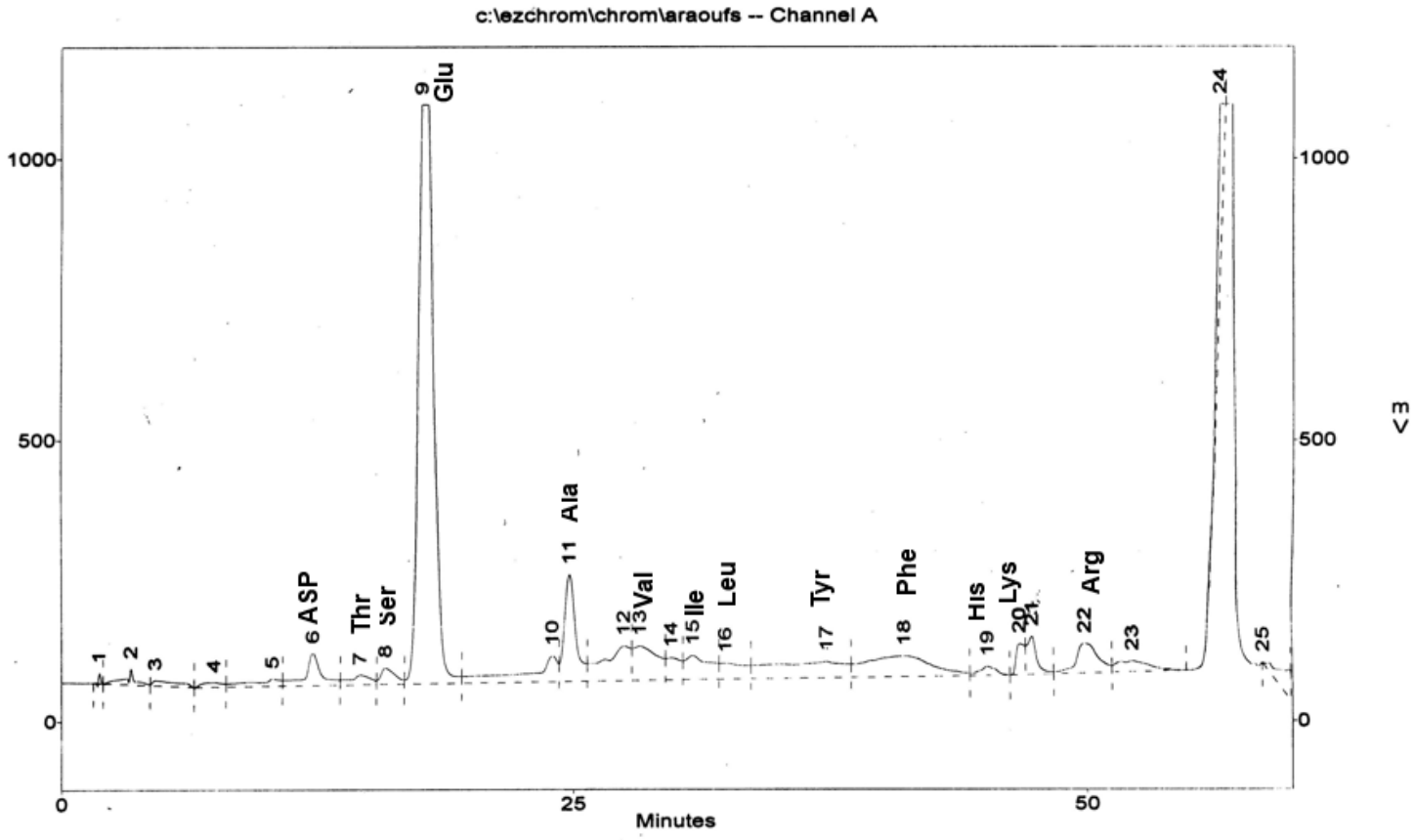

Figure 6

Chromatogram of amino acids in APBP