RESEARCH ON DETACHMENT PROCESS AND SEPARATION OF FROZEN SEA-BUCKTHORN FRUITS FROM BRANCHES
/
CERCETĂRI PRIVIND PROCESELE DE DETAȘARE ȘI SEPARARE A FRUCTELOR DE CĂTINĂ CONGELATE DE PE RAMURI

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ABSTRACT
Following the bibliographic and theoretical research carried out by the specialists of INMA Bucharest Institute, as well as the experience of sea buckthorn producers and processors, the experimental model of a high-performance equipment for separating frozen sea buckthorn fruits from the harvested mass (branches, fruits and leaves) was designed and made. Thus, the subject of this paper is the experimental research carried out on an improved equipment for detaching and separating frozen sea buckthorn fruits from the branches - ESFC. After an introduction in which the current state in the field was highlighted, the tested equipment was presented with the main functional parameters, adjustments necessary to obtain an optimal working regime suitable for the processed raw material. Following the experiments carried out, the main working indices of the equipment were determined, among which: the working capacity, the degree of separation of the fruits from impurities as well as the optimal functional regimes. Following the tests carried out, in two variants of arrangement of the paddle arms on the separation rotor, some conclusions were formulated, the most eloquent of which was that, for the equipment tested in Variant II equipped with the separation rotor, the highest values for the feed flow resulted for the angle of inclination of the paddle of 45^0 and the rotation speed of the rotor of 90 min^{-1} and a high degree of separation.

REZUMAT
În urma cercetărilor bibliografice şi teoretice realizate de specialiștii institutului INMA Bucureşti, dar și a experienței producătorilor și procesatorilor de cătină, s-a proiectat și realizat modelul experimental al unui echipament performant pentru separarea fructelor de cătină congelate, din masa recoltată (ramuri, fructe și frunze), astfel, subiectul acestei lucrării îl reprezintă cercetările experimentale efectuate asupra unui echipament îmbunătățit pentru desprindere și separarea fructelor congelate de cătină de pe crengi – ESFC. După o introducere in care s-a evidențiat stadiul actual in domeniu, s-a prezentat echipamentul experimentat cu principalii parametri funcționali, reglaje necesare pentru obținerea unui regim optim de lucru adecvat materiei prime procesate. In urma experimentărilor efectuate au fost determinați principalii indici de lucru ai echipamentului dintre care amintim: capacitatea de lucru, gradul de separare a fructelor de impurități precum si regimurile de funcţionale optime. In urma testărilor efectuare, in doua Variante de dispunere a brațelor cu palete pe rotorul de separare, au fost formulate unele concluzii dintre care cea mai elocventa a fost aceea ca, pentru echipamentul testat in Varianta II de echipare a rotorului de separare, au rezultat cele mai mari valori ale debitului de alimentare pentru unghiul de inclinare al paletei de 45^0 si viteza de rotaţie a rotorului de 90 min^{-1} si un grad ridicat de sortare.

INTRODUCTION
In the context of circular economy, the technical processing line follow the concept to use the entire plant/raw material harvested and processed, which means non-waste production (*Tkacz et al., 2021; Ivanišová et al., 2020).* This concept can be applied also on sea buckthorn frozen fruit technology, because the latest researches shown that the plant fractions are unconventional sources of potassium and calcium in leaves, but also the vegetative parts and seeds with endocarp have iron, copper and manganese.

So, the “morphological parts of sea buckthorn have the potential to produce food rich in high-antioxidant and anti-inflammatory components, such as phenolic compounds and triterpenes. *(Tkacz, et al., 2021).*

Nowadays researchers’ results published by prestigious specialists, provide important quantities of information on a large number of sea buckthorn species established on different geographical areas over the world, in order to guide the sea buckthorn capitalization technological processes to produce good products for phyto-pharmaceutical and food industry (*Van der Sman, 2020)*. “In the future, it will be beneficial to analyse lipophilic components and formulations based on the sea buckthorn fraction in vivo studies” (*Tkacz et al., 2021).*

The product obtained from the sea buckthorn which is used as raw material in the food industry, pharmaceutical and cosmetic industry is needed to implement nutraceutical-rich applications *(Van der Sman, 2020).*

Some mathematical theoretical studies were made on dedicated sea buckthorn equipment (*Aan and Heinloo, 2014; Milea et al., 2020)* designed to process berries, but if it is taken into consideration the fact that the sea buckthorn surface has oval shape and the bark outer surface is waxy and covered with short hairs *(Vișan et al., 2019*), those models must be validated.

In recent scientific literature on freezing foods, the thermal processing is of actuality and due to high energy consumption and food quality, the technical process is revised and updated in order to integrate new technologies developed in this field.

Considering that the sea-buckthorn berries have complex antioxidant solutions in combination with sugars in different concentration (depending on the species and the origin of the culture), the rapid cooling during the freezing process may result in partial freeze concentration. So, during the separation process, the temperature of the fruits must be kept under observation, to avoid the multiple transitions that usually occur in the freezing-thawing process (freeze concentrations, vitrification, devitrification, recrystallization, and ice formation) *(Roos and Drusch, 2015)*.

From the point of view of the technologies used worldwide, in terms of harvesting and separating the buckthorn fruits from the harvested branches, it can be said that they are quite varied, incorporating technical equipment that generally have the same detachment and separation systems *(Vișan et al., 2019).*

Also, scientific works have been written that approach, from a theoretical point of view, the work process carried out by the different work systems within the mentioned technologies *(Milea et al., 2020; -Yu. Zubarev A. et al., 2022; Longsheng Fu et al., 2015; Jing Zhao et al., 2023; James C et al., 2015).*

In England, at Quellendolf Saxony-Anhalt, the fruits are pre-processed in a very short interval, i.e. about 2 h, where: the branches will be chopped and frozen with nitrogen and the fruits are detached from the branches and separated from the plant residues with the help of a vibrating system, and a ventilation system cleans them of leaves and other impurities (*www.youtube.com/watch?v=Spgc-REEUa4; www.mz-web.de/jessen/sanddornernte-in-seyda-tonnenweise-geballte-vitamine-24789988)*.

In a technology used in Finland, after the branches are harvested, they are arranged on the conveyor belt that directs them to the back of the equipment where the brushes and metal beaters are positioned. The shaken branches are then left behind the equipment, and the fruits and leaves are transported to the front and pass through the sieves *(www.moz.de/landkreise/maerkisch-oderland/strausberg/artikel8/dg/0/1/975684/; www.nig-magdeburg.de/index.php?id=98&lang=2&hp=24)*.

In Hungary, there is a technology for the separation of frozen sea buckthorn fruits that was published in 2018. The operations that this technology carries out are: the frozen fruits are introduced into the equipment with circular sieves for separating the fruits from the branches, from this equipment the bare branches come out on one collector channel, and on the other collector sea buckthorn fruits + leaves, the latter are inserted into a sieve with a special semi-circular sieve, where large plant debris and damaged/dry grains/small grains are removed and only good grains and a small amount of plant debris are collected from this equipment. The processing flow is continued with a combined selector (vibrating sieves and air currents) to ensure a complete cleaning *(https://www.youtube.com/watch?v=s9VUmobIjeQ).*

In Italy, it is predominantly used a technology that includes several successive operations, such as: mechanized harvesting complemented by manual harvesting to reduce losses; unloading harvested material into transport containers and freezing; freezing raw material; drumming with vibrating systems, conveyors with rods; separation of fruits from plant residues with a sieve system; packaging for refreezing (*https://www.youtube.com/watch?v=xW5r7LZM2sI&feature=autoshare;http://www.weleda.co.nz/tuscany-italy/w3/i1039717/#.XIvI7ygzaUk; https://www.youtube.com/watch?v=NfZWwDSB3eI).*

In Asia, the BEYOND Company - Shanghai China, proposes a technological line adapted to the processing of sea buckthorn fruits. It developed this project (design, equipment manufacturing, installation and commissioning) and also took care of operator training.

The new technology developed by Shanghai realizes, first of all, the removal of vegetable remains (branches, leaves, etc.), from the material resulting from the detachment of the fruit from the branches *(www.china.cn/pic/3963705228_0.html; www.china.cn/pic/3963711516_0.html; https://french.alibaba.com/product-detail/grape-destemming-crushing-machine-grape-destemmer-and-crusher-grape-stem-removing-machine-60481359883.html?spm=a2700.8699010.normalList.76.4d4417d2lenuwr; www.china.cn/pic/ 3932550216_0.html; https://french.alibaba.com/product-detail/grape-destemming-crushing-machine-grape-destemmer-and-crusher-grape-stem-removing-machine-60481359883.html?spm=a2700.8699010.normalList.76.4d4417d2lenuwr).*

Considering the importance of sea buckthorn fruits for the economic environment, it follows that it is imperative to create a technology for separating the fruits from impurities that will provide an optimal raw material, from a qualitative point of view and obtained with as little costs as possible. Thus, this paper presents the technology elements that can be used to achieve the presented aspects.

MATERIALS AND METHODS

Experimental research activities presented in this paper are conducted on a technical equipment to separate the sea-buckthorn fruits from branches, symbolized ESFC, developed at INMA Bucharest, during an R&D project, respecting the frozen sea-buckthorn detachment process and separation used usually at international level, Fig. 1.

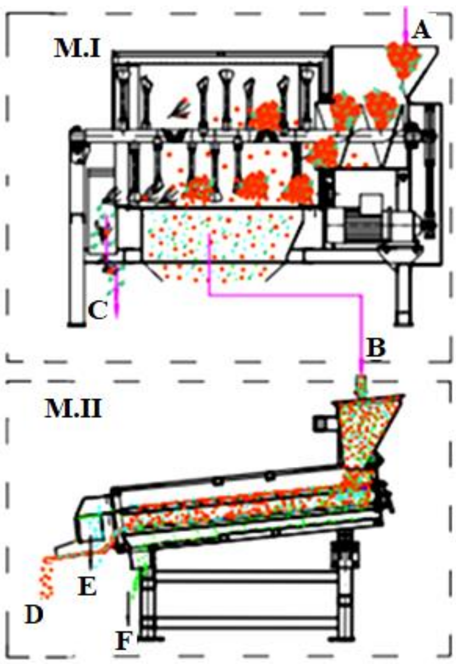

Fig. 1 –Technological process of frozen sea-buckthorn detachment and separation process designed for ESFC equipment (designed and manufactured technological process)

M.I - sea-buckthorn detachment module from branches; M.II –Sea-buckthorn separation; A – frozen raw material supply opening (fractions as: branches, leaves and fruits); B – separation material evacuation funnel (fruits + leaves/ impurity fractions); C – branches and twigs evacuation opening; D – sea-buckthorn evacuation opening; E – large and part of and light impurities evacuation trough; F – small and the other part of light impurities as well as heavy impurity evacuation trough;

The **M.I.** module represents the first process that must be made, respectively the module of frozen sea-buckthorn detachment from branches; this type of equipment is designed to separate the raw material in two main fractions wood fraction (branches and twigs) evacuated by C opening and vegetal fraction (fruits + leaves/impurity fractions) evacuated by B funnel, Fig. 1.

The working flow is longitudinal in order to increase the separation length and separation efficiency. Another special characteristic of **M.I** is the construction of fruit detached shaft that presents adjustable paddle (11*)* arms that are assembled in the main shaft (4) in several threaded sleeves in order to have variable geometries and working diameter, but also to adjust the paddles orientation angle and working regime. The detailed image and the components are shown in Fig. 2.

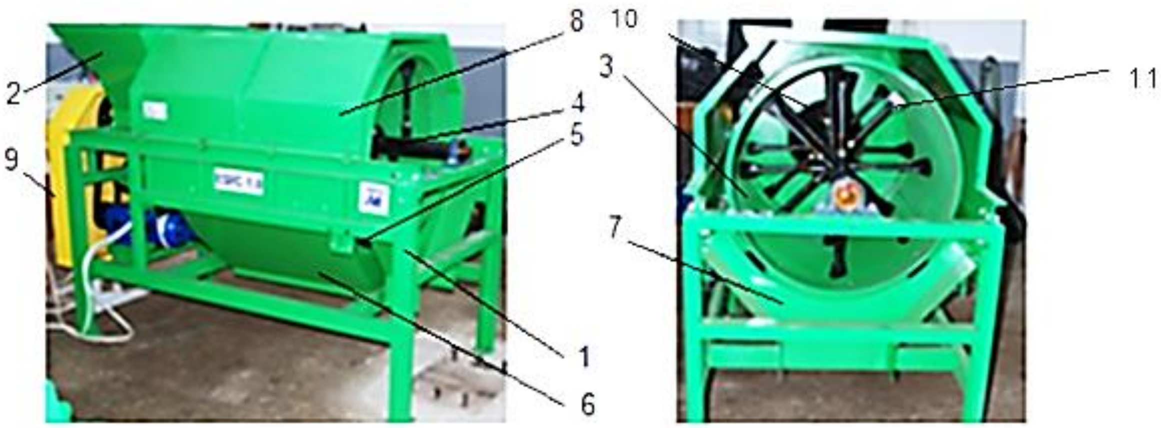

Fig. 2 – Module of sea-buckthorn detachment from branches (M.I)

1-metal support frame; 2- raw material supply opening; 3- cylindrical sieve; 4- fruit detaching shaft; 5- support and sieve roll; 6- vegetal material and small impurities evacuation funnel; 7- wood fraction and big impurities evacuation opening; 8- protection coverage; 9- belt drive transmission; 10 – helical winding; 11-adjustable paddle arms.

The main working part of the MI module, is the detachment rotor, shown in fig. 3. It is the active working body of the module and consists of a shaft (1), provided at the ends with axles for bearings (2, 3), on which some paddle arms are mounted, on a portion of its working length (6) in threaded bushings (4), secured by locknuts (7), and on the remaining portion of the shaft a helical coil (5) is welded.

The paddle arms can have adjustable working positions, both in terms of the working diameter and the angle of inclination of the paddle, thus influencing the working regime.

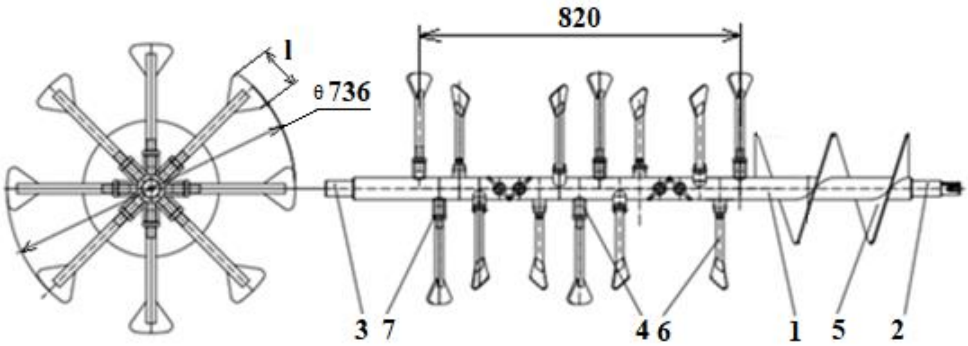

Fig. 3– The detachment rotor

1. Axle; 2, 3. Axle support; 4; Threaded bushing; 5. Spiral; 6. Paddle arm; 7. Locknut

The detachment rotor is composed of 17 paddle arms arranged on a propeller, whose pitch is 820 mm. The rotor propeller has a single step on which the paddle arms are arranged at equal distances, the propeller being of the discontinuous type, the material advances only when it is driven by the paddle. For this to happen, the paddles must be tilted at an angle that ensures the movement of the branches.

Starting from the imposed constructive and functional parameters, the working flow rate of the detachment rotor is determined according to relation (1).

$$Q = A \cdot \gamma \cdot \frac{p \cdot n_r}{60} \cdot k_v \quad (1)$$

In which:

Q is the flow rate, [kg/min];

A – area of the section of the material supply chute of the paddle rotor, [m^2];

p – working step of a paddle, [m];

γ –volumetric mass of the separated material (buckthorn branches with fruits), [kg/m^3];

n_r – rotation frequency of the paddle rotor, [min^{-1}];

k_v – reduction coefficient of the axial speed of the material;

l – the maximum width of the rotor paddle, [m];

α – the angle of inclination of the rotor paddle, adjustable, [deg.].

To finalize the sea buckthorn fruit separation process, the material resulting from **M.I** must be passed through a sea buckthorn fruit separation Module, **M.II**, shown in Fig. 4, which has the role of separating sea buckthorn fruits from leaf debris and branch fractures resulting from the detachment module. The main components are shown in Fig. 4.

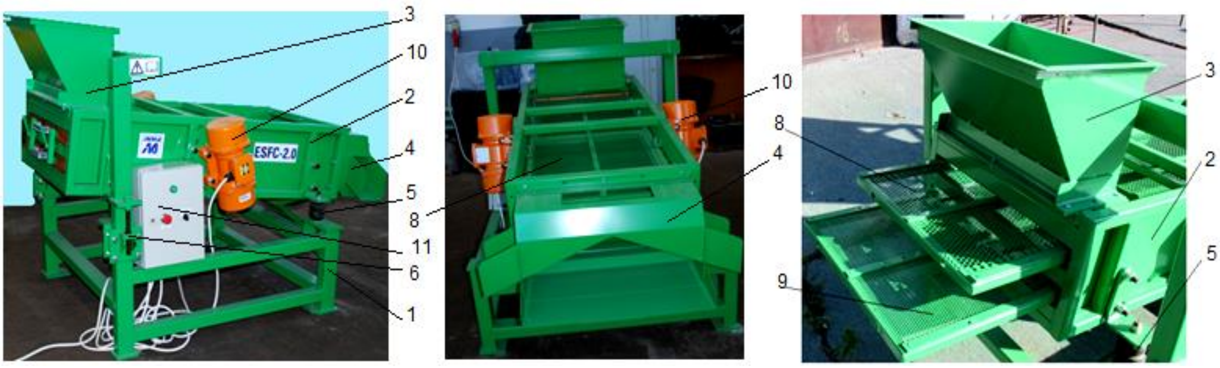

Fig. 4. Sea-buckthorn separation module (M II)

1-welded frame; 2- frame; 3- supply funnel; 4- fruit evacuation opening;5- vibration damping system;6- sliding system to support the mobile screens; 8- upper screen; 9- lower screen; 10- electric vibration generator; 11- electric panel to control the vibration frequency.

The main working parameters of the ESFC equipment are complex and largely influenced by the type of sea-buckthorn row material, fruit dimensions, fruit outer surface quality, life density, branches and twigs density, but also the thorn presence.

M.I *working parameters:*

- fruit detaching shaft speed 256 rpm (motor power 3 kW);

- the active diameter dimension (paddle arms) max 750 mm;

- the longitudinal displacement of the raw material (the orientation paddles angle in accordance with longitudinal shaft axis) 1000 mm;

- the rotational speed of cylindrical sieve 108 rpm, installed power 3.55 kW (motor power 0.55 kW), the cylindrical sieve has a maximum diameter of 800 mm and a length of 1000 mm.

M.II *working parameters*:

- adjustment of frame inclination angle in accordance with its longitudinal 5 ÷ 12 degrees;

- the length of the flat sieve is 1365 mm, the width is 590 mm, the adjustment of the maximum centrifugation force of the frame is 3.15 kN and its direction is generated by the electric vibration generator working frequencies and amplitude of 50 Hz;

- electrical power of vibrator motor 0.350 kW, maximum rotation 1000 rpm, the installed power is 2 x 0.350 kW.

For the technical solution of the machine, ESFC, a patent application registered with the number A-00398/2020 was submitted to OSIM (The Romanian State Office for Inventions and Trademarks).

The **main ESFC adjustments** are very important and are tailored for this modules that are working with perishable fruits. The frozen fruits must be very fast processed in order to avoid unfreezing and being damaged. This subject is part of the measuring methodology of the ESFC performance so:

The adjustments of the M.I working parameters are:

- the adjustment of the paddle rotor rotational speed, 111-56 min^{-1}- the optimum value is reached when the paddles impact force can detach the majority sea-buckthorn fruit from the branches without harming them and generate the raw material displacement. This parameter is designed to be adjusted using the electrical frequency converter;
- paddles working diameter 680 - 750 mm – the optimum value depends on the type of raw processing material respectively wood density (branches and twigs proportion) because in this way the M.I blocking can be prevented (phenomenon that usually happens in this type of equipment). Often, the paddles geometry has a helical profile;
- cylindrical sieve rotational speed is 108 rpm; this parameter reaches the optimum value when the fruit loses is smaller on *C* evacuation opening.

The adjustments of the M.II working parameters are:

- changing the inclination angle of plane sieve frames in accordance with longitudinal axis at 5…12 degrees;
- adjusting the centrifugal force direction of plane sieve frames by adjusting the position of electric oscillation generators (10), see Fig. 4. For tests, the electric vibrator is set to 80% of the maximum centrifugal force given by the producer.

The testing of ESFC equipment was drafted by INMA Bucharest researches, being an Experimental methodology under laboratory conditions in accordance with the specifications of its modules. The laboratory in which were made the experiments is placed near the freezing chamber from which is drawn out the sea-buckthorn raw material, and it is provided with electricity supply network to power both modules.

The work parameters and indices determined during the experiments were: work flow, productivity, fruit damaged degree; electric energy consumption; the fruit losses rate.

The measurement equipment underwent metrological verification and was calibrated, as further shown: digital multi-meter, OMEGA electronic thermometer - measurement range 0-50 ^{0}C; electric level indicator; Q338033 centrifugal tachometer – measurement range 60-24000 min^{-1}, watt-metric kit - measurement range 0-105 W, analytical balance.

The experimental researches were carried out for different values of the functional parameters in order to establish the optimal working regime for obtaining a quality final product with the lowest possible costs.

Thus, the constructive parameters of the ESFC equipment and the functional ones, used in the experiments, are:

- A = 0.0825 m^2;
- γ = cca.45 kg/m^3 ;
- p_{eI} = 0.054; 0.049; 0.042 m, achieved by tilting the paddle with the width of l_I = 0.060 m at angles α = 25^0; 35^0; 45^0, Variant I;
- p_{eII} = 0.100; 0.090; 0.078 m, achieved by tilting the paddle with the width of l_{II} = 0.110 m at angles α = 25^0; 35^0; 45^0, Variant II;
- n_r = 55; 70; 90; 110 min^{-1}, adjustable through the rotation frequency converter of the motor-reducer driving the paddle rotor;
- k_v - uncontrollable, because during operation it happens that some component parts of the branches (the tip of the branches or thorns) partially enter the holes of the rotating sieve, which covers the detachment rotor, or wrap around the paddle arms, situation in which it is difficult to move the branches. By conducting several tests, it was found that this phenomenon does not significantly depend on the speed of the rotor or rotational screen, and therefore a relationship cannot be formulated that expresses the coefficient of reduction of the axial speed of the material. In order to reduce this phenomenon, some paddle arms were removed, so that the axial distance between the arms was smaller than the minimum length of the sea buckthorn branches (approx. 150 mm), a situation that led to the reduction of the phenomenon of wrapping the branches on the arms. Thus, to determine the working flow, an average axial speed reduction coefficient of 0.55 was chosen;
- the working diameter of the extremity of the detachment rotor paddles of **M.I**, was 736 mm;
- n_s, cylindrical sieve rotation frequency of **M.II** = 108 min^{-1};
- the angle of inclination of the flat sieves of **M.II**, compared to the longitudinal axis, used in the tests, was 8 degrees;
- the equipment was tested using frizzing sea-buckthorn branches at -28^{0}C, with length between 300 ÷ 900 mm and bulkiness 3÷15 mm.

RESULTS

The results of the determinations for the working parameters of the ESFC equipment after the first separation module **M.I** and second passage through the **M.II** separation module, are presented in Table 1.

During operation, it was found that when entering the fruit detachment area, the branches sometimes jammed, making it difficult to advance the branches and often causing the detachment paddle rotor to jam.

Also, even if the angle of inclination of the paddles could be changed at the rotor paddles, the advance of the branches towards the exhaust mouth was very slow, a fact that greatly delayed the process and implicitly reduced the working capacity.

At the same time, due to the large number of detachment paddle arms, 17 pieces, the branches often wrapped around the rotor, which made it difficult to advance the branches and block the detachment process.

In such situations encountered, in order to eliminate or reduce the mentioned dysfunctions, the following changes were made in the technical and constructive documentation on the experimental model:

- the first three bushings where the paddle arms were mounted were removed from the rotor, in this way the entry space for the branches in the fruit detachment area was increased and the branches were no longer blocked;
- the width of the paddles was doubled by welding another paddle segment equal to the existing one, in this way the advance speed of the branches along the rotor was increased;
- to avoid wrapping the branches around the arms, the number of arms was reduced from 17 to 8.

Table 1

The working parameters of the ESFC equipment determined

No.	**Working parameters**	**UM**	**Designed (Theoretical Value)**	**The measured parameters values (average)**		
				First sorting, M.I		**Second sorting, M.II**
				Variant I	**Variant II**	
0	**1**	**2**	**3**	**4**	**5**	**6**
1	Working capacity of M.I	[kg/h]	500	348	450	
2	Consumed power of M.I, P_I	[kW]	3.55	2.7	3.3	
3	The rotational speed of the paddle rotor	min^{-1}		90		
4	Working capacity of M.II	[kg/h]	500			378
5	Consumed power of M.II, P_{II}	[kW]	0.7			0.62
6	Total consumed power of the process, P_t (line 2+5)	[kW]	4.25	3.32 Var.I; 3.92 Var.II		
7	Specific electricity consumption	[kWh/t]	8.5	9.41 Var.I ; 8.94 Var.II		

The mentioned changes can be observed in fig. 5.

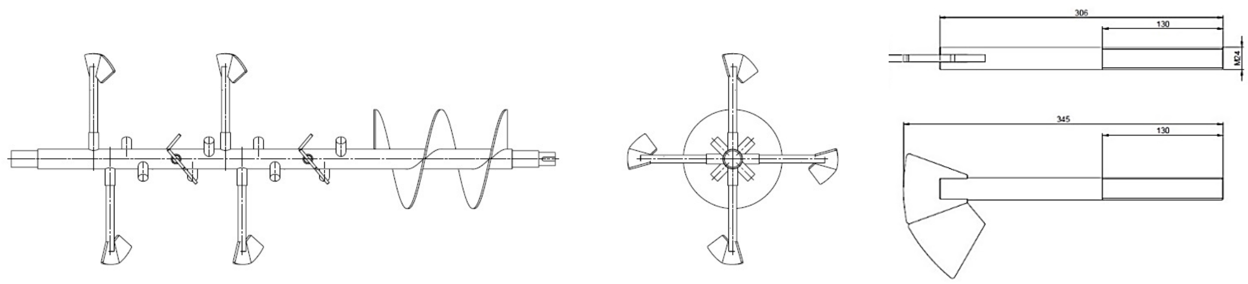

Fig. 5 - The detachment rotor - modified version

After making the mentioned changes of the detachment rotor "Modified version", in the Material and Method chapter and carrying out new tests, at the same speed of the detachment rotor, a visible improvement in the functionality of the equipment was found, in the area of detachment of sea buckthorn fruits, in the sense of reducing blockages with branches, simultaneously with the increase of their advance speed in the detachment drum by approx. 35 %.

In these conditions, the average feed flow increased by approx. 30%, under the conditions of a power consumption similar to the first variant.

At the same time, due to the fact that branch blockages in the detachment system were reduced, it increased by approx. 30% of the supply flow of the M II equipment and implicitly of its working capacity.

The variation of the working capacity of the **M.II** module depending on the inclination of the rotor arm paddle, in the constructive Variant II and its speed, is presented in Fig.6.

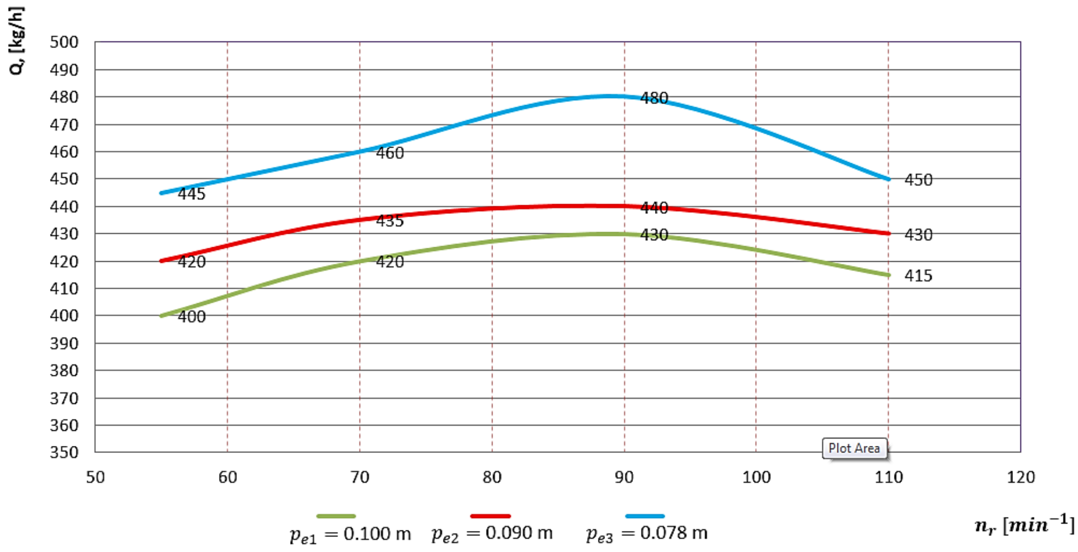

Fig. 6 - The variation of the working capacity of the M II module depending on the inclination of the rotor arm paddle, in the constructive Variant II and its speed

The qualitative indices of the resulting final product, are presented in table 2.

Table 2

The qualitative indices of the ESFC equipment determined

No.	Qualitative indices	UM	Designed (Theoretical) Value	The measured parameters values (average)	
				First sorting, M.I	Second sorting, M.II
1	The degree of fruit detachment from the branches of **M.I**	[%]	97-100	99.75	
2	Fruit damage rate in the detachment process of **M.I**, Gv	[%]	-	1.9	
3	Degree of sorting / screening, **M.II** for:	[%]			
	- large impurities, separated on the upper sieve, I_L		-	98.6	99.8
	- small impurities, separated on the upper and lower sieve, I_s		-	82.8	99.5
	- light impurities, smaller than the sea buckthorn fruits, I_l		-	92.5	99.8
4	Fruit loss rate in **M.II**, C_{fl}	[%]	-	0.8	0.55

The large impurities and some of the small ones can be manually sorted when the fruits come out of the **M.II**. The degree of separation of small and light impurities is reduced compared to the requirements of those who use the sorted fruits in the technological processes of the food or pharmaceutical industries, this is due to the fact that the impurities adhere to the surface of the fruits during the sorting process due to their moistening by the process of condensation, the material subjected to the process being frozen.

In order to finalize the process of separating small and light impurities from fruit, the product resulting from M.II it must be passed through a light impurities suction module after, beforehand, the material resulting from M II is dried, to obtain the purity of the fruits required by their beneficiaries.

In Fig. 7, 8 are presented some images from test made on ESFC equipment, respectively on **M.I** and **M.II**.

Fig. 7 - Images from the sea-buckthorn detachment module – M.I

Fig. 8 - Aspects from sea-buckthorn separating module - M.II

CONCLUSIONS

- The technical equipment that separates the sea buckthorn fruit from the branches, works in designed parameters such as: the inclusion in the functioning regime of the active parts (rotation axis and oscillating sieve) but also the adjustments established in the project phase;
- From the point of view of energy consumption and working capacity, it can be stated that they are lower than the initial estimates, this fact being the cause of the lower supply flow with branches, compared to the estimated one;
- From the point of view of the quality parameters (such as: fruits not detached from the branches, crushed fruits, impurities in the final product), it can be concluded that the values obtained for these parameters are acceptable, with possibilities for improvement;
- The variation of the supply flow with branches, depending on the rotational speed of the paddle arm, for different angles of inclination of the paddles and implicitly of the pitch of the spiral achieved by the paddles, does not faithfully respect the theoretical relationship (1), this fact having as cause the non-uniformity of the material and the feed flow rate. For the equipment tested in Variant II equipped with the separation rotor, the highest values for the feed flow resulted for the angle of inclination of the paddle was 45^0 and the rotational speed of the rotor was 90 min^{-1}. The variation of the supply flow with branches can be seen in the diagram in Fig. 6.
- The degree of fruit detachment from the branches of **M.I**, was 99.75 %;
- Fruit damage rate in the detachment process of **M.I**, was 1.9%.

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