BIOREFINERY OF SUNFLOWER WHOLE PLANT BY THERMO-MECHANO-CHEMICAL FRACTIONATION IN TWIN-SCREW EXTRUDER: REPRESENTATION OF LIQUID/SOLID TRANSPORT INSIDE THE BARREL

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Abstract

Biorefinery of sunflower whole plant can be conducted with water by thermo-mechano-chemical fractionation in a Clextral BC 45 (France) co-penetrating and co-rotating twin-screw extruder. An extract and a raffinate are produced separately and in a single continuous step.
The arrangement of screw profile makes possible to define three successive zones along the barrel, in which the three unit operations of the aqueous extraction process are taking place. (I) The grinding zone consists of a succession of 10 monolobes paddles, and 5 bilobe paddles. It ensures the conditioning and the grinding of solid matter. (II) The extracting zone begins with water injection. It is composed of a second series of 5 bilobe paddles to mix liquid and solid. (III) The pressing zone is the place where liquid/solid separation is realized. Screw configuration is then arranged with reversed pitch screws used to place pressure on the liquid/solid mixture, and positioned immediately downstream from a filter section.
Representation of liquid/solid transport inside the barrel is performed thanks to (i) the measuring of the filling of each screw element after visual observation, (ii) the characteristics of the corresponding solid, and (iii) the modelling of the contribution of each screw element to the residence time distribution of solid and liquid phases. Consequently, twin-screw extruder can be represented as the association of a grinder, a liquid/solid extractor, and a liquid/solid separator, in which material exchanges are intensified.
Thus, it is possible to predict the evolution of mean residence times of liquid and solid in the three zones of twin-screw extruder with the main operating variables: screw rotation speed, and inlet flow rates of whole plant and water.
The decrease of both screw rotation speed and inlet flow rate of whole plant, simultaneously with the increase of inlet flow rate of water, causes the increase of liquid to solid ratio in the extracting zone, and the increase of residence time of solid in the pressing zone.
These operating conditions (60 rpm for screw rotation speed, 5.0 kg/h and 20.3 kg/h for inlet flow rates of whole plant and water, respectively) are favourable to an efficient contact between liquid and solid (8.2 for liquid to solid ratio), and to the liquid/solid separation (156 sec for residence time of solid inside the separator). Oil yield is then around 55%, and residual oil content of the cake meal is only 13% of dry weight.
The oil is extracted in the form of oil-in-water emulsions. The emulsion stability is ensured at interface by surface-active agents: phospholipids, proteins, and pectins. Extracts are also made up of a hydrophilic phase. This major fraction contains water-soluble components: proteins, and pectins. Raffinates are rich in fibres, and they have also a significant content of proteins with thermoplastic properties. They can be manufactured into biodegradable agromaterials by compression moulding.

Biorefinery of sunflower whole plant by thermo-mechanical fractionation in twin-screw extruder: representation of liquid/solid transport inside the barrel

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Introduction

► The biorefinery of sunflower whole plant can be conducted with water by thermo-mechanical fractionation in a Clextral BC 45 (France) co-penetrating and co-rotating twin-screw extruder [1].

► Aqueous extraction is an environmentally cleaner alternative technology to the solvent oil extraction process from oilseeds [2-3]. It enables the simultaneous production from whole plant of two different oil-in-water emulsions (hydrophobic phases) and a protein isolate (hydrophilic phase) in the same process [1].

► The co-rotating twin-screw extruder behaves like a thermo-mechanical reactor. Its implementation allows the aqueous extraction of sunflower oil [1, 4-5].

► It is equipped with a filtration module to obtain separately an extract (filtrate) and a raffinate (cake meal), and wringing out the mixing from whole plant is efficient because of the natural abundance of fibers in the sunflower stalk (until 80%).

► This only apparatus is used to carry out three essential unit operations in a single step and in a continuous mode: (i) conditioning and grinding of sunflower whole plant, (ii) liquid/solid extraction, and (iii) liquid/solid separation.

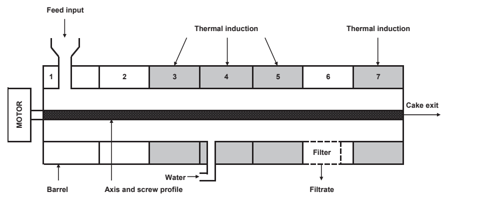
► The process can be considered as an original and powerful solution for fractionation and value-adding to sunflower since the obtained fractions may have applications as bases for industrial products [1].

► The representation of the liquid/solid transport inside the barrel of the twin-screw extruder is investigated in this study.

Experimental

► **Oleic sunflower whole plant** (15 mm homogenate) (La Toulousaine de Céréales, France):
6.0% of moisture content. – 6.4% of mineral content; 25.4% of oil content; 10.8% of protein content; 41.1% of fibers content (cell., hemicelluloses and lignins).

► **Twin-screw extruder:**



1		2		3				4		5		6		7		
T2F 66	C2F 50	C2F 33	DM 10×10 (45°)	C2F 25	BB 5×5 (90°)	C2F 33	C1F 33	C1F 25	BB 5×5 (90°)	C1F 33	C1F 33	C1F 33	C1F 25	C1F 15	CF1C -15	C1F 25

T2F = trapezoidal double-thread screw. C2F = conveying double-thread screw. C1F = conveying simple screw. BB = bilobe paddle-screw. DM = monolobe paddle-screw. CF1C = reversed simple screw. – The numbers following the type of the screw indicate the pitch of T2F, C2F, C1F and CF1C screws and the length of the BB and DM screws.

Schematic modular barrel and screw configuration of the Clextral BC 45 (France) twin-screw extruder (θ = 80℃ for thermal induction).

Results and discussion

► The arrangement of the screw profile makes possible to define three successive zones:
(i) The ***grinding zone*** consists of a succession of 10 monolobes paddles (DM), and 5 bilobe paddles (BB). It ensures the conditioning and the grinding of the sunflower whole plant.
(ii) The ***extracting zone*** begins with the water injection. It is composed of a second series of 5 bilobe paddles (BB) to mix the liquid and the solid.
(iii) The ***pressing zone*** is the place where the liquid/solid separation is realized. The screw configuration is then arranged with reversed screws (CF1C) that are used to place pressure on the liquid/solid mixture. These screws are positioned immediately downstream from the filter section.

► The representation of the liquid/solid transport inside the barrel is performed thanks to:
(i) the measuring of the filling of each screw element after visual observation.
(ii) the characteristics of the corresponding solid (dry solid mass and moisture content).
(iii) the modeling of the contribution of each screw element to the residence time distribution of solid and liquid phases [6].

► So, the twin-screw extruder can be represented as the association of (i) a ***grinder***, (ii) a ***liquid/solid extractor***, and (iii) a ***liquid/solid separator***, with intensified material exchanges.

Trial	1	2	3	4	5	6	7
Operating conditions							
S_S (rpm)	75	60	75	75	91	75	60
Q_S (kg/h)	7.4	7.1	8.7	7.5	6.9	8.5	5.0
Q_W (kg/h)	24.4	24.5	29.9	19.2	24.4	24.6	20.3
Filtrate (extract)							
Q_F (kg/h)	17.6	18.6	22.4	11.5	17.3	16.3	15.8
Foot content (%)	9.6	11.0	9.5	14.5	9.3	12.7	6.5
Cake meal (raffinate)							
Q_C (kg/h)	14.2	13.0	16.2	15.2	14.0	16.8	9.6
Moisture (%)	64.4	63.7	64.1	64.2	66.1	64.7	65.8
L_C (% dry mass)	16.2	14.5	15.4	18.0	16.5	16.1	13.1
P_C (% dry mass)	8.8	8.0	8.2	9.5	8.9	8.7	6.7
Extraction yields							
R_L (%)	53.5	59.7	56.7	45.2	52.2	53.0	64.9
R_P (%)	40.6	47.4	45.9	31.8	39.3	40.5	54.9
Energy consumed							
I (A)	13.3	15.9	14.6	12.1	10.9	13.5	14.8
SME (W h/kg)	98.2	97.9	91.8	87.4	104.1	86.8	128.5
Residence time distribution							
τ_F (s)	98	121	100	-	-	-	147
τ_C (s)	160	200	151	-	-	-	261

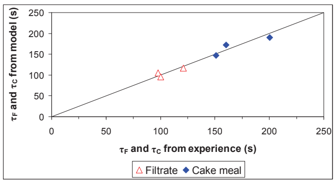
S_S is the screw rotation speed. Q_S and Q_W are the inlet flow rates of sunflower whole plant and water, respectively. – Q_F and Q_C are the flow rates of the filtrate and the cake meal, respectively. L_C and P_C are the lipid content and the protein content of the cake meal, respectively. – R_L is the oil yield based on the residual oil content of the cake meal. R_P is the protein yield based on the residual protein content of the cake meal. – I is the electric current of the twin-screw extruder. SME is the specific mechanical energy consumed by the motor per unit weight of sunflower whole plant. – τ_F and τ_C are the experimental mean residence times of the filtrate and the cake meal, respectively.

► Thus, it is possible to predict the evolution of residence times of liquid and solid in the three zones of the twin-screw extruder with the main operating variables: (i) the screw rotation speed, (ii) the inlet flow rate of whole plant, and (iii) the inlet flow rate of water.

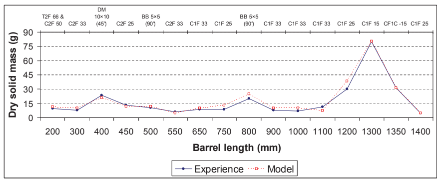
► The decreases of the screw rotation speed and the inlet flow rate of whole plant, with the increase of the inlet flow rate of water, cause the increase of the liquid to solid ratio in the extracting zone, and the increase of the residence time of the solid in the pressing zone.

► Such conditions (trial 7: 60 rpm for the screw rotation speed, 5.0 kg/h for the inlet flow rate of whole plant, and 20.3 kg/h for the inlet flow rate of water) are favourable to an efficient contact between the liquid and the solid inside the extractor (8.2 for the L/S ratio), and to the liquid/solid separation (156 s for the residence time of the solid inside the separator).

► Taking into account the oil content in the foot of the filtrate (12% of the oil from whole plant), the oil yield is then 53%, and the residual oil content of the cake meal is only 13% of dry weight.



Comparison of the experimental and modeled mean residence times of the filtrate and the cake meal (trials 1 to 3).



Comparison of the dry solid mass collected along the barrel after the sudden shutdown of the extruder with that calculated by the model (trial 6).

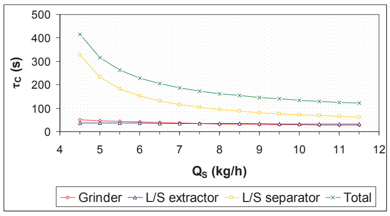
Conclusion

► The biorefinery of sunflower whole plant is possible with water using a co-rotating twin-screw extruder. The representation of the liquid/solid transport inside the barrel makes possible to predict the best operating conditions to obtain the highest oil extraction yield (until 53%).

► Oil is extracted in the form of two different oil-in-water emulsions: (i) the higher hydrophobic phase, and (ii) the lower hydrophobic phase. Their stability is ensured at interface by surface-active agents co-extracted: (i) phospholipids, and (ii) proteins. Pectins and non pectic sugars complete the dry matter of the lower hydrophobic phase.

► The extract is also made up of a hydrophilic phase. This major fraction contains water-soluble constituents from whole plant: (i) proteins from kernel, (ii) pectins from pith and head, and (iii) hemicelluloses from stalk.

► The raffinate (cake meal) is rich in fibers. It has also a significant content of proteins with thermoplastic properties. It can be manufactured into biodegradable agromaterials by compression moulding. Panels can be used as inter-layer sheets for pallets or for the manufacturing of containers by assembly of panels.



Prediction of the residence time of the solid in the three successive zones of the extruder: example of its evolution with the inlet flow rate of sunflower whole plant (S_S = 75 rpm, and Q_W = 24.5 kg/h).

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