To cite this version:
Evon, Philippe and Vandenbossche, Virginie and Pontalier, Pierre-Yves and Rigal, Luc *Aqueous extraction of oleic sunflower oil from whole plant by twin-screw extruder: feasibility study, influence of screw configuration and operating conditions.* (2007) In: 1st International Congress on Green Process Engineering (GPE 2007), 24 April 2007 - 26 April 2007 (Toulouse, France). (Unpublished)

AQUEOUS EXTRACTION OF OLEIC SUNFLOWER OIL FROM WHOLE PLANT BY TWIN-SCREW EXTRUDER: FEASIBILITY STUDY, INFLUENCE OF SCREW CONFIGURATION AND OPERATING CONDITIONS

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Aqueous extraction process using water alone as medium is an alternative to the solvent oil extraction process from oilseeds. It enables simultaneous recovery of oil and protein. The implementation of a co-rotating twin-screw extruder allows the aqueous extraction of oleic sunflower oil from whole plant.

Screw configuration, screw rotation speed and whole plant input flow rate affect directly the efficiency of liquid/solid separation. Wringing out the mixing is possible because of the natural abundance of fibers in stalk. However, the compression of the vegetable matter is imperfect to allow an expedient separation of the two phases. Lixiviation of oilseeds is also incomplete. The highest oil extraction yield obtained is 64.9% and residual oil content of fibrous cake meal is always higher than 13.1%.

Hydrophobic phase produced is an oil-in-water emulsion. Its stability is ensured by the presence at interface of natural surface-active agents also extracted during the process, phospholipids and proteins.

Hydrophilic extract contains soluble proteins but also hemicelluloses and pectins. Originated respectively from stalk, pith and head, these two molecular families also have some interesting surface-active properties. So the aqueous extraction produces a second hydrophobic phase when it is realised from whole plant. This water-in-oil-in-water emulsion is denser than aqueous phase. Its stability is ensured by the presence at interface of phospholipids, proteins, hemicelluloses and pectins.

Fibrous cake meal is richer in fibers (up to 45.6% of cellulose and lignins against 33.1% in the whole plant) and other insoluble components. It is possible to upgrade it by thermopressing in such a way as to manufacture sound insulation panels.

Aqueous extraction of sunflower oil from whole plant by twin-screw extruder

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Introduction

► Aqueous extraction process is an environmentally cleaner alternative technology to the solvent oil extraction process from oilseeds [1]. It enables the simultaneous production of oil-in-water emulsion (hydrophobic phase) and protein isolate (hydrophilic phase) in the same process.

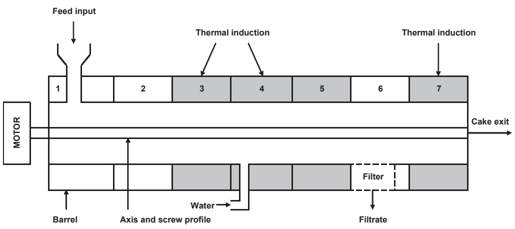
► The implementation of a co-rotating twin-screw extruder allows the aqueous extraction of sunflower oil [2]. Extruder can be considered as a multifunction thermo-mechano-chemical reactor. It conducts a large number of basic operations in a continuous mode and in a single step: trituration of seeds, liquid/solid extraction, liquid/solid separation...

► However, no filtrate is obtained without addition of fibers upstream from the filtration module. One lignocellulosic residue was tested successfully: wheat straw. A new application of twin-screw extruder to conduct aqueous extraction of sunflower oil from whole plant is investigated in this study because of the natural abundance of fibers in sunflower stalk.

Experimental

► **Oleic sunflower whole plant** (15 mm homogenate) (La Toulousaine de Céréales, France):
- Batch n° 1: 26.8% of oil content; 10.7% of protein content; 33.1% of fibers content; 7.8% of moisture content.
- Batch n° 2: 25.4% of oil content; 10.8% of protein content; 33.6% of fibers content; 6.0% of moisture content.

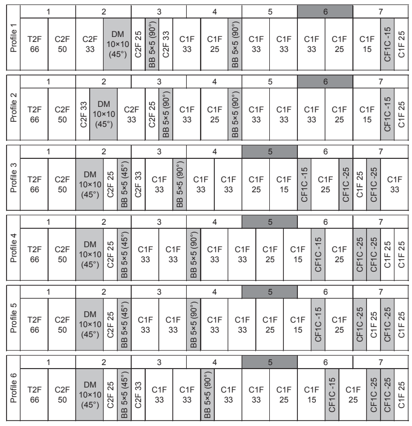
► **Extruder:** co-rotating twin-screw extruder, model BC 45 (Clextral, France).



Schematic modular barrel and screw configuration of twin-screw extruder Clextral BC 45 (France) (θ = 80°C for thermal induction; water introduction in third position for profiles 2 to 6; filter in fifth position for profiles 3 to 6).

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 screw indicate the pitch of T2F, C2F, C1F and CF1C screws and the length of the BB and DM screws.



Results and discussion

► **Oil extraction yield** (% mass)

$$R_C = \frac{(Q_S \times L_S) - (Q_C \times L_C)}{Q_S \times L_S} \times 100$$

► **Protein extraction yield** (% mass)

$$R_P = \frac{(Q_S \times P_S) - (Q_C \times P_C)}{Q_S \times P_S} \times 100$$

► **Specific Mechanical Energy (SME)** (W.h/kg)

$$P = U \times I \times \cos\varphi \times \frac{S_S}{S_{max}} \qquad SME = \frac{P}{Q_S}$$

► A correlation exists between R_P and R_C yields. So, aqueous extraction is regarded as a process primarily aimed at solubilizing proteins which results in the release of the oil [1].

► Bulk density of solid is the biggest in CF1C screw.

► CF1C screw is the most important element of the screw profile. It carries out shearing, mixing and exerts a strong axial compression. It contributes to the liquid/solid separation.

► Globally, moisture of cake meal decreases at the same time as I increases. Thus, the electric current of twin-screw extruder indicates the liquid/solid separation efficiency.

► Profiles with only one CF1C screw (profiles 1 and 2) are to be privileged because foot content of filtrate and energy consumed are lower. Mean residence time of solid is shorter but liquid/solid separation remains efficient. Extraction yields obtained are the best of this study (trials 1-6).

► Extraction yields are better with profile 1 than with profile 2. The limiting factor of aqueous process efficiency is the trituration of seeds rather than the time of contact between solvent and solutes (trials 1-2).

► S_S decrease increases mean residence times of filtrate and cake meal but also foot content of filtrate. Bulk density of solid in CF1C screws is then more important and moisture of cake meal decreases. Liquid/solid separation is so better even with a lower SME value and extraction yields increase (trials 8-10).

► The increase of water flow rate leads to higher extraction yields. The effect in the energy consumed is low and foot content of filtrate decreases (trials 7-8 and 11-12).

► Q_S does not affect residence time distribution of matter for the same water/whole plant ratio. However, the filling of CF1C screw is better for higher Q_S value. Liquid/solid separation and extraction yields are so improved (trials 8-12).

Trial	1	2	3	4	5	6	7	8	9	10	11	12
Operating conditions												
Profile	1	2	3	4	5	6	1	1	1	1	1	1
S_S (rpm)	60	60	60	61	60	60	75	75	60	91	75	75
Q_S (kg/h)	5.0	5.8	6.3	5.9	5.5	5.8	7.5	7.4	7.1	6.9	8.5	8.7
Q_W (kg/h)	20.3	20.0	19.9	20.0	19.8	19.9	19.2	24.4	24.5	24.4	24.6	29.9
Filtrate												
Q_F (kg/h)	15.8	14.7	16.3	13.1	13.9	14.5	11.5	17.6	18.6	17.3	16.3	22.4
Foot content (%)	6.5	8.6	18.3	10.5	9.4	8.2	14.5	9.6	11.0	9.3	12.7	9.5
Foot of the filtrate												
Moisture (%)	68.3	67.0	65.5	65.6	65.9	64.7	63.2	63.6	63.1	66.6	65.1	68.2
L_F (% dry mass)	44.3	46.1	50.5	45.6	48.4	43.7	53.1	49.7	54.5	48.8	54.0	50.8
P_F (% dry mass)	12.8	13.6	15.3	14.3	13.7	14.6	13.4	13.1	16.7	11.5	12.5	12.7
Cake meal (insoluble phase)												
Q_C (kg/h)	9.6	11.1	9.9	12.8	11.5	11.2	15.2	14.2	13.0	14.0	16.8	16.2
Moisture (%)	65.8	65.7	59.7	67.6	66.6	64.0	64.2	64.4	63.7	66.1	64.7	64.1
L_C (% dry mass)	13.1	15.6	15.5	19.9	16.4	18.6	18.0	16.2	14.5	16.5	16.1	15.4
P_C (% dry mass)	6.7	7.4	7.1	7.9	7.7	7.4	9.5	8.8	8.0	8.9	8.7	8.2
Oil extraction yield												
R_C (%)	64.9	58.3	60.5	43.5	54.2	47.8	45.2	53.5	59.7	52.2	53.0	56.7
R_C' (%)	53.2	44.9	27.0	28.7	38.6	35.0	27.2	36.2	35.4	36.3	33.8	40.1
Protein extraction yield												
R_P (%)	54.9	49.9	54.1	43.7	46.4	47.8	31.8	40.6	47.4	39.3	40.5	45.9
R_P' (%)	46.3	39.9	28.5	32.0	35.2	37.0	21.1	29.9	29.9	30.4	30.1	36.1
Energy consumed												
I (A)	14.8	16.0	32.2	21.0	21.3	27.9	12.1	13.3	15.9	10.9	13.5	14.6
P (W)	644.6	702.1	1,405.7	931.1	926.7	1,218.1	657.9	722.6	693.7	716.8	737.4	798.9
SME (W.h/kg)	128.5	120.3	223.4	158.6	167.0	210.9	87.4	98.2	97.9	104.1	86.8	91.8
Residence time distribution												
τ_F (s)	147	-	146	146	140	158	-	98	121	-	-	100
τ_C (s)	261	-	329	317	296	419	-	160	200	-	-	151

S_S is the screw rotation speed. – Q_S, Q_W, Q_F and Q_C are respectively the flow rates of sunflower whole plant, water, filtrate and cake meal. – L_S, L_F and L_C are respectively the lipid contents of sunflower whole plant, foot of the filtrate and cake meal. – P_S, P_F and P_C are respectively the protein contents of sunflower whole plant, foot of the filtrate and cake meal. – R_C' and R_P' also take into account the foot of the filtrate. – I and P are respectively the electric current and the motor power of twin-screw extruder. – τ_F and τ_C are respectively the mean residence times of filtrate and cake meal.

Batch n° 1 (white). Batch n° 2 (grey).

► Clear of its foot, the filtrate reorganizes by centrifugation in three fractions: a higher hydrophobic phase, a hydrophilic phase and a lower hydrophobic phase.

► Lighter hydrophobic phase is an oil-in-water emulsion. Its stability is ensured by the presence at interface of natural surface-active agents also extracted during the process, phospholipids and proteins [2].

► Hydrophilic phase is the dominating fraction. This extract contains soluble proteins but also hemicelluloses and pectins. Originated respectively from stalk, pith and head, these two molecular families also have some interesting surface-active properties.

► Thus, aqueous extraction also produces a second hydrophobic phase when it is realised from whole plant. Denser than the aqueous phase, this oil-in-water emulsion still contains phospholipids and proteins but it is also stabilized by hemicelluloses and pectins.

► Fibrous cake meal is richer in fibers: up to 45.6% for trial 1 against 33.1% in the whole plant. It is possible to upgrade it by thermopressing. Panels obtained have mechanical characteristics comparable with those of other experimental materials. They could be used in conditioning industry. Their hydrophobic character makes them more resistant to water.

Conclusion

► The aqueous extraction of sunflower oil from whole plant is effective by using a co-rotating twin-screw extruder. Wringing out the mixing is possible because of the natural abundance of fibers in sunflower stalk. Screw configuration, screw rotation speed and whole plant input flow rate affect directly the efficiency of liquid/solid separation.

► However, the compression of vegetable matter is imperfect to allow an expedient separation of the two phases. Lixiviation of oilseeds is also incomplete.

► The highest oil extraction yield obtained in this study is 64.9% and residual oil content of fibrous cake meal is always higher than 13.1%.

Acknowledgements

► The authors thank Dr. L. Prat (*LGC, Toulouse, France*) for his competence and theoretical help.

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