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Horizontal centrifuge with screw conveyor (decanter): Optimization of oil/water levels and differential speed during olive oil extraction

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A B S T R A C T

Olive oil extraction using a horizontal centrifuge with a screw conveyor is an essential operation to reduce production costs. However, proper control of the plant is required to maintain a high level of extraction yield and olive oil quality. Rheological characteristics of the olive paste, which change in relation to water content, fruit variety, maturity level and seasonal temperature variations, greatly affect the efficiency of centrifugal extraction. If olive paste is fed to a decanter without automatic control, then non-optimal extraction is performed.

After successfully testing a suitable flow mass sensor in order to set up an automatic system to control the olive paste mass flow rate fed to a decanter centrifuge during olive oil extraction, a feedback control system was tested in the laboratory and built in-line in an industrial processing plant. This allowed trials to be carried out at constant mass flow rate for both the paste and the added water, on a decanter centrifuge with variable differential speed between bowl and screw conveyor (i.e. variable DN) and with regulation capability of oil–water ring levels. Constant quality olives (cv. Coratina) were used for the trials; the correlation was evaluated between oil/water ring levels and DN with respect to the extraction yield, husk fat content and vegetable water fat content.

The "oil recovery efficiency" (η_o) and "separation coefficient" S peaked with maximum residence time, using DN = 13.3 and RING = 284.8, while η_o minimum was achieved at higher DN. More specifically, for DN values higher than about 18 or lesser than 12, η_o becomes independent of RING. Furthermore, η_o and S values are strictly related to the geometry of the decanter centrifuge, whereas the paste dilution ratio determines the preservation quality of the oil extracted, and the maximum oil recovery efficiency represents the remaining objective related to the quantity of extracted oil.

From experimental data some interesting relations were found linking decanter centrifuge parameters; their relationship depends on a complete quadratic interaction model constituted by the input variables that leads to highly correlated polynomials between DN vs. Uopdb ("mass fraction of oil in the fed olive paste" (dry basis)) and η_o optimal vs. Uopdb. These relations allow optimization of DN and RING values such that maximum oil recovery efficiency is achieved. Indeed, knowledge of Uopdb by an on-line method allows the decanter DN and RING operating parameters, to be calculated and modified at once, obtaining optimal maximum oil recovery efficiency.

1. Introduction

Olive oil is the most widely used fat in the diet of Mediterranean countries, thanks especially to its healthy properties, unique aroma and long shelf life, and due to its natural antioxidant content, which make it different from other vegetable oils (Salvador et al., 2003).

Evolution of the oil extraction process has led to the replacement of traditional discontinuous lines, using the pressure system extraction, with continuous ones, using centrifugal extraction. In particular, the horizontal centrifuge with a screw conveyor (i.e. decanter) is widely used in olive oil extraction, especially if large amounts of olives have to be processed in a short time (Ranalli et al., 1997; Piacqadio et al., 1998). However, olive oil extraction by centrifuge is dramatically affected by changes in the rheological characteristics of the olive paste in relation to water content, fruit variety, maturity level and seasonal temperature variations. Therefore, correct control of the process is essential in order to achieve high levels of both extraction yield and olive oil quality (such as content in natural antioxidants and aromatic compounds) (Amirante et al., 1995; Di Renzo and Colelli, 1997; Piacqadio et al., 1998; Ranalli et al., 2001; Altieri, 2010).

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Nomenclature

$R\%$	"percent recovery parameter" (%/s)
DN	differential speed between bowl and screw conveyor of decanter centrifuge in rpm.
RING	water/oil ring level
SS	shear stress (Pa)
K	consistency coefficient (Pa s^n)
SR	shear rate (s^{-1})
n	flow behaviour index

Decanter inlet

Qp	mass flow rate of the fed olive paste (kg/h)
Qw	process water mass flow rate for olive paste dilution (kg/h)
α	"dilution coefficient" as the ratio between the process water mass flow rate and the olive paste mass flow rate fed to the decanter (Qw/Qp)
Uwp	mass fraction of water in the fed olive paste
Uop	mass fraction of oil in the fed olive paste (wet basis)
Uopdb	mass fraction of oil in the fed olive paste (dry basis) (Uopdb = Uop/Usp)
Usp	mass fraction of solids in the fed olive paste

Decanter outlet

Qh	discharged husk mass flow rate (kg/h)
Uwh	mass fraction of water in the discharged husk
Uoh	mass fraction of oil in the discharged husk (wet basis)
Ush	(1 – Uwh – Uoh) mass fraction of solids in the discharged husk
Fo	"oil out flow" as the mass flow rate of the extracted oil (kg/h)
Fvw	"vegetable water" mass out flow rate (kg/h)
Uwvw	mass fraction of water in the discharged vegetable water (Fvw)
Uovw	mass fraction of oil in the discharged vegetable water (Fvw) (wet basis)
Usvw	(1 – Uwvw – Upvw) mass fraction of solids in the discharged vegetable water (Fvw)
Ql	"liquid out flow" as the mass flow rate (Fo + Fvw) at the decanter exit
Uwl	mass fraction of water in the discharged overall liquid (Ql)
Uol	mass fraction of oil in the discharged overall liquid (Ql) (wet basis)
Usl	(1 – Uwl – Uol) mass fraction of solids in the discharged overall liquid (Ql)

Ratio parameters

η_o	"oil recovery efficiency" as the ratio between extracted oil and the overall oil of the olive paste
D	"distribution coefficient" as the ratio between the overall liquid mass flow rate (water + oil) in the husk and overall liquid mass flow rate (water + oil) at the decanter entry
S	"separation coefficient" as (1 – D)
ε	the ratio between discharged husk mass flow rate and mass flow rate of the fed olive paste (Qh/Qp)
γ	the ratio between "vegetable water" mass out flow rate and mass flow rate of the fed olive paste (Fvw/Qp)
λ	the ratio between "liquid out flow" and mass flow rate of the fed olive paste (Ql/Qp = $\gamma + \omega$)
ω	the ratio between "oil out flow" and mass flow rate of the fed olive paste (Fo/Qp)

In the continuous extraction process by decanter centrifuge, adding warm water to the olive paste, during malaxation or extraction, improves the separation of olive oil from water and husk (Amirante et al., 1995).

Other studies underline the need for technologies to be gentle to preserve both the sensory and nutritional value of olive oil (Ranalli et al., 2001; Monteleone et al., 1998; Caponio et al., 2003), as opposed to enhancing extraction yield, reducing processing costs and environmental impact (Roig et al., 2006). Therefore, centrifugal extraction plant manufacturers concentrate their attention on limiting the addition of processing water, which represents the main cause of oxidative damage to olive paste and polyphenols reduction.

With a view to optimizing separation efficiency and extraction performance using a decanter centrifuge, theoretical and empirical studies have been carried out to evaluate the incidence of several process parameters on decanter operation. Such studies have underlined the importance of paste properties and continuous control of parameters in olive oil processing (Amirante and Catalano, 1993, 2000; Amirante et al., 1995; Di Renzo and Colelli, 1997).

Even more research effort has been spent gaining insights into the interaction between the decanter and processing parameters namely: incidence of oil/water ring level thickness, paste mass flow rate, dilution water mass flow rate, screw conveyor torque and conveyor/bowl differential speed DN with respect to extraction yield and fat content in discharged husks (Amirante et al., 1993; Amirante and Catalano, 1993, 2000; Leung, 1998; Corner-Walker, 2000; Corner-Walker and Records, 2000; Catalano et al., 2003; Anlauf, 2007; Daou et al., 2007; Boncinelli et al., 2009; Altieri, 2010).

Therefore, in order to evaluate the relationship involving oil/water ring levels and conveyor/bowl differential speed DN vs. centrifuge extraction yield, in this study an automatic feedback control system was designed and set up to control the paste mass flow rate fed to the decanter centrifuge. Both laboratory and industrial tests were performed.

Subsequently the feedback control system was used in olive oil mill operations to regulate at constant value the olive paste flow rate fed to the decanter centrifuge, also the added water mass flow rate was held at a constant value. A decanter centrifuge was employed with variable differential speed between bowl and screw conveyor (i.e. variable DN) and with regulation capability of oil–water ring levels.

Samples of husks and vegetable water, collected using different processing conditions, were used to evaluate residual fat and water content in order to measure extraction efficiency against DN and oil–water ring levels.

2. Materials and methods

The first step of our research entailed defining the adequate mass flow rate sensor and then designing and building the feedback control system in order to control the mass flow rate of olive paste fed to the decanter centrifuge.

The Corimass G300+ sensor (by Khrone) proved the most suitable as it measures the olive paste mass flow rate by determining