

Simulation of High Quality Fish Oil Production

Monitoring and Control

Winterization Process

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The paper describes a study of monitoring and control of the winterization process within the high quality fish oil production. In order to design and control the stages of this process, among other important parameters, the crystallization temperature is considered crucial. The authors have analysed the employment of an integrated control system used to command this process, with emphasis on the control of the temperature profile during the fractionation stage.

Keywords: quality fish oil, winterization, crystallization temperature, integrated control system

Fats are responsible for performing varied and important functions in the human body, such as providing calories, essential fatty acids, and fat-soluble vitamins. They are considered very important among the ingredients and the sensory aspects of the functional properties of the food.

Fish oil is the lipid fraction that can be extracted from fish or fish by-products. There is a good world market demand for high quality fish meal and oil, and the production can be quite profitable if suitable raw material is available. The difference between fish oil and other oils is mainly the unique variety of fatty acids it contains, including a high level of unsaturated fatty acids. Further, fish oil contains a high level of fatty acids with the first double bond between the third and fourth carbon atom, counted from the terminal methyl group. This family of fatty acids is called omega-3, and is found primarily in oil of marine origin.

In this context, omega-3 fats essential to human overall health represent the main reason why important researches [1-3, 5] have been devoted to evidence the many benefits of these particular fats and oils. Omega-3 comes from both animal and plant sources, most notably from krill oil and fish oil that provide eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). There is robust evidence that fish oil and its component fatty acids, especially EPA plus DHA, are beneficial in maintaining cardiovascular and rheumatoid health in normal adults and reducing the incidence of recurrence of specific health problems [4]. Several authorities have now accepted these benefits; to maintain cardiovascular health, it is recommended an intake of EPA plus DHA between 0.25 g and 0.5 g of per day. Besides that, extensive evidence of the benefits of fish oil consumption on neurological development, brain health and cognitive anti-inflammatory properties surely exists.

Fish oil is commonly refined using the conventional processing steps similar to vegetable oil processing. A production flowchart detailing the stages to transform the raw material into a high quality fish oil [6] contains the main operations performed, i.e. neutralization, bleaching, winterization, and deodorization. Due to the fact that fish oil has a saturated fraction that crystallizes and forms a solid layer during storage, especially at cold temperatures, winterization or chill fractionation is used to remove the

more saturated fraction and, consequently, to increase the amount of omega-3 in clear oil.

In order to obtain high quality oils, the crystallization behaviour of lipids has important implications, especially in industrial processing of products whose physical characteristics (consistency and melting point) are affected by the crystal structure of fat, such as chocolate or margarine. The crystal structure depends on the specific type of triacylglycerol (TAG) present, the composition and distribution of fatty acids, the purity of TAG, and the crystallization conditions (temperature, cooling rate, shear, and solvent) [7-9].

The winterization process consists in fractional crystallization of oils and fats followed by the separation of solids in order to produce high quality oil. During the winterization process it is necessary that the temperature would be very closely regulated and that the oil would be cooled slowly in order to obtain filterable crystals. The cooled oil is kept at this temperature for a certain period of time, prior to separation of solid phase from the liquid oil by filtration of the solid fat slurry. After that, the oil is filtered under very rigidly controlled conditions in order to prevent disintegration of the crystals or clogging of the filtering medium. For example, filtration must be conducted at a low pressure.

To design a winterization process, the rate of oil cooling, the temperature of crystallization and the mobility of triglyceride molecules in the oil mass are crucial. These variables play a significant role, both in separating the solid fats as distinct crystals and in facilitating their filtration from the oil. The most commonly used procedure for winterizing the oil is the De Smet method [10], that requires the following devices: heat exchanger with plates and coil for oil cooling, a crystallization tank for crystals sweeping, filter for waxes separation and mixer for preparing the kieselsgur slurry.

The aim of the analysed automated winterization system is to monitor and control the temperature profile during the fractionation process.

The fractionation process comprises three important stages. In stage 1, the product is heated up to a certain temperature set as a reference parameter and in stage 2, the product is cooled down according to a specified

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temperature profile. Finally, in stage 3 the product emerging from the reactor is filtered through the fractionation filter. Fractionation is the process of solids removing by controlled crystallization and separation techniques, involving the use of either solvents, or of dry processing. Dry fractionation encompasses both winterization and pressing techniques, being the most widely practiced form of fractionation [11, 12]. It relies upon the differences in melting points and triglyceride solubility to separate the oil fractions.

It is a very well-known fact that modelling and simulation are extremely important in chemical engineering [13,14]. Considering the monitoring and control operations, the quality, efficiency and security targets can be reached by using automatic systems that allow, at any time, a good knowledge of the process state by achieving the values of the main parameters that define the respective process. The automatic system for the winterization process temperature control consists of transducers (that measure various process parameters), PID controllers (that receive these measured values and calculate the commands) and the control valves that are actuators receiving and executing the commands from the controllers.

The paper presents the simulation of monitoring and control of the winterization process within the high quality fish oil production plant. The main emphasis is to put in the effect of the temperature upon the performance of the winterization process.

Experimental part

The analysed experimental winterization process comprises the following stages: testing the parameters; initialization; product heating; first crystallization; second crystallization; third crystallization; filtering; obtaining high quality fish oil. The main goal is to perform the temperature control during the fractionation process. This process has three main sequences: (a) heating the product to a temperature set by the operator; (b) cooling the same product to a specified temperature; (c) filtering the product from the reactor.

The automation of the oil winterization plant has been implemented using a Yokogawa Centum VP integrated

system with versatile architecture [15] (fig. 1). Practically a distributed control system (DCS), Centum VP is appropriate for chemical processes automation, covering not only continuous and batch process control, but also manufacturing operations management. There is a single database that contains the application referring to all the involved stations. Also, there is a single configuration software able to handle several projects and generating the whole system. There is no need to create different graphical representations for all human/machine interfaces, only one being sufficient. Moreover, the application database of a plant can be reused to another plant by a project, by a station, by a graphic, or by a control logic.

The Centum VP integrated control system comprises two parts: the graphical part and the logic part. The graphical part consists in Graphic Builder software, that configures the structure of the automated winterization system using the P&ID diagram and the specifications of the project, on the basis of both dynamic and static elements. For the analysed oil winterization plant, the static elements and their codes are the followings: R-32000 chemical reactor, HE-32200 heat exchanger, F-32300 filter, AG 32000 agitator and T-18100 tank. Also, the dynamic elements are: TIC-temperature controllers for heating, transducers, TCV 32212 and XSV 32005 control valves, P 32301 pumping units and engines. Figure 2 displays the connections between all these elements. The logic (programmed) part of the software for simulating the process is configured using functional and control components, logic gates and sequence blocks, as presented in figure 3.

Results and discussions

The sequence of monitored operations is defined in table 1 that presents the specific values of the characteristic parameters implemented in order to perform the winterization process, namely *Min* - minimum values, *Max* - maximum values, *Default* - prescribed implied values, that are assigned to the parameters when an acceptance by default occurs.

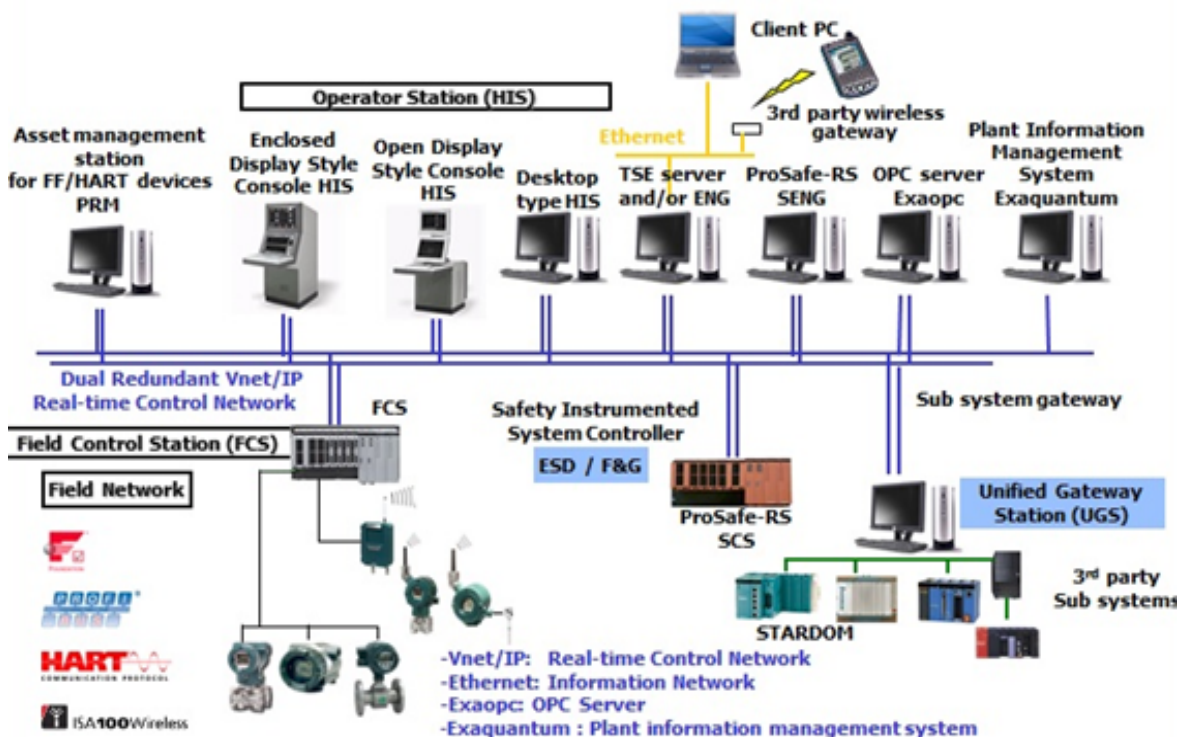


Fig. 1. Centum VP system configuration [15]

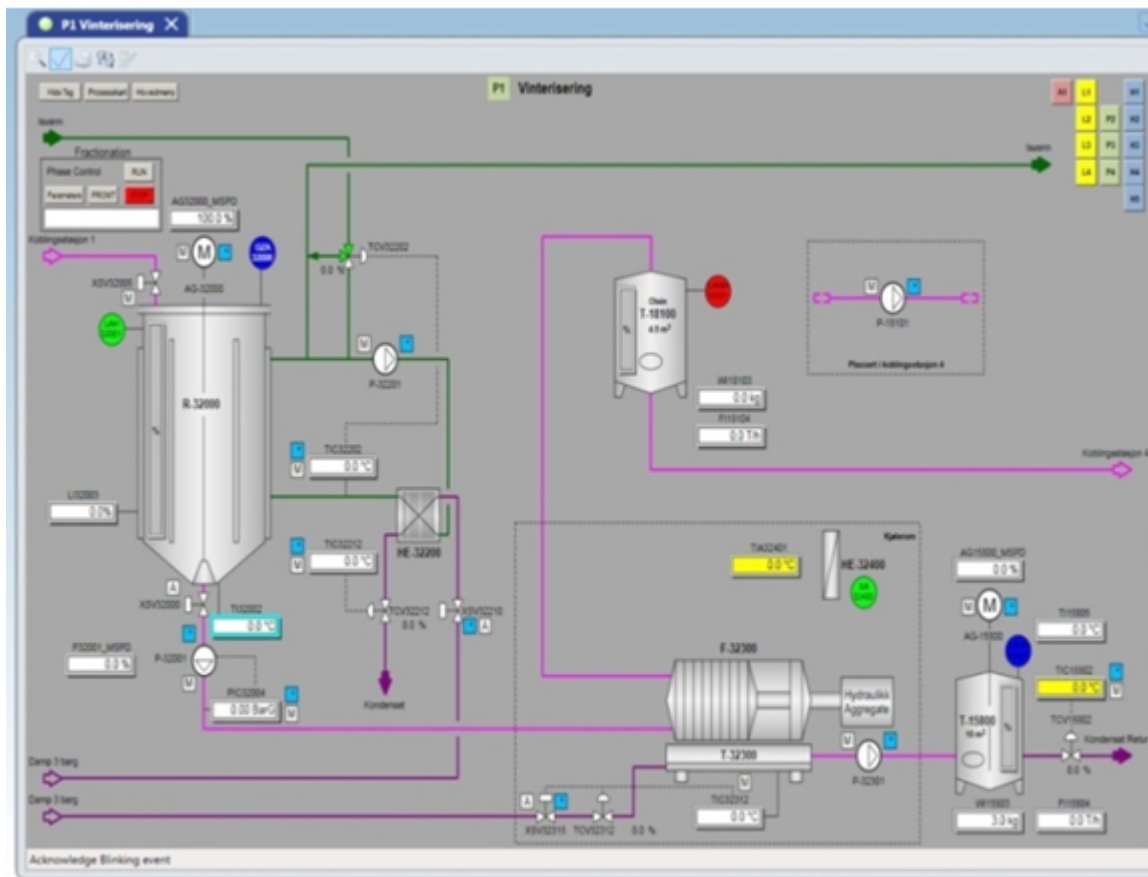


Fig. 2. Graphical interface of the integrated control system that configures the structure of the automated winterization plant

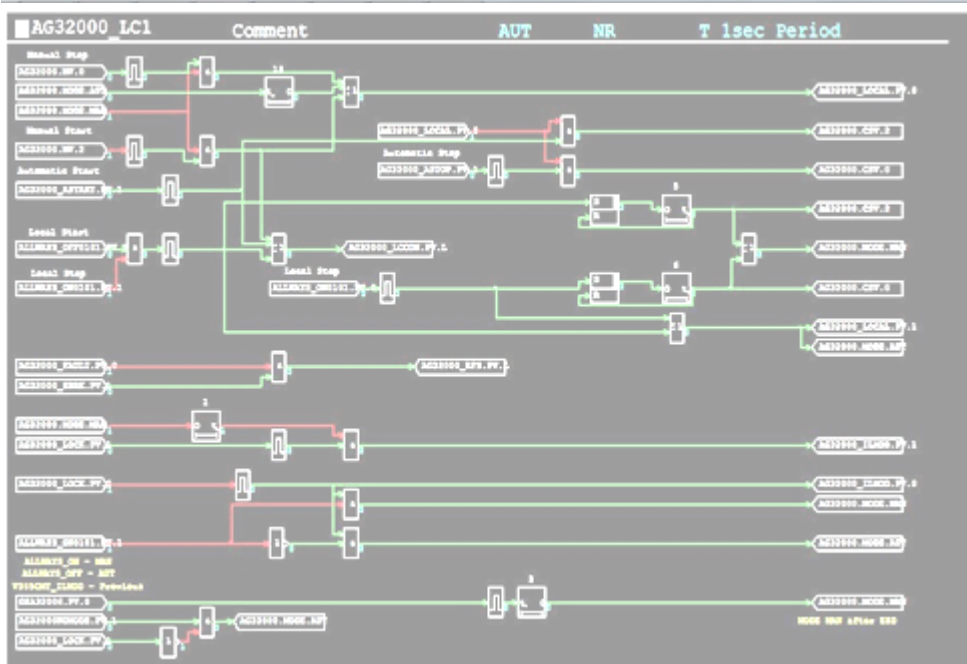


Fig. 3. Programmed part of the integrated control system

Testing the parameters

The following parameters values are verified, as described in table 1:

a) speeds of agitators during heating and, respectively, cooling: S1=100% and S2 =80%;

b) temperatures: T0A=70°C and T0B=50°C - set-point values of water temperature, respectively of product temperature; T1=15°C; T2=7°C; T3=2°C; T4=1°C - limits of product temperature value;

c) set-point values for the control of water temperature cooled in the reactor at different time points: dT1=10°C; dT2= 1°C; dT3= 5°C; dT4=1°C; dT5=5°C; dT6=1°C;

d) predefined periods of time, Time1 = 3h (180 min); Time2 = 3h (180 min); Time3 = 2h (120 min).

Initialization

All TIC-temperature controller modules for heating (TIC 32202, TIC 32212), and the agitator module AG 32000 are set on a *manual* 0% mode. For the product heating stage, one has to perform the following operations:

- the XSV 32005 valve is opened;
- the product content in the reactor has to be at least 5 wt.%;
- the XSV 32005 valve is closed.

Monitoring during product heating

- AG 32000 agitator speed is set at S1 speed (100%);
- TCV 32212 control valve opens;
- AG 32000 agitator starts;
- P 32301 pump starts;
- TCV 32202 valve opens;

No.	Parameter	Description	U.M.	Default		
				Min	Default	Max
1	S1	Speed of agitator during heating	%	70	100	100
2	S2	Speed of agitator during cooling	%	50	80	100
3	T0A	Set-point value of water temperature for heating/cooling	°C	10	70	80
4	T0B	Set-point of product temperature for heating/cooling	°C	10	50	60
5	dT1	Set-point value for the control of water temperature cooled in the reactor	°C	5	10	20
6	T1	First limit of product temperature	°C	5	15	25
7	Time1	First period of crystallization. Timer starts when $dT=dT2$. During Time 1 period, dT set-point has to equalize $dT2$. Time 1 is set in minutes	min	60	180	240
8	dT2	Set-point value for the control of water temperature cooled in the reactor	°C	0	1	5
9	dT3	Set-point value for the control of water temperature cooled in the reactor at the end of Time 1	°C	3	5	10
10	T2	Second limit of product temperature	°C	5	7	20
11	Time2	Second period of crystallization. Timer starts when $dT=dT4$. During Time 2 period, dT set-point has to equal $dT4$. Time 2 is set in minutes.	min	60	180	240
12	dT4	Set-point value for the control of water temperature cooled in the reactor	°C	0	1	5
13	dT5	Set-point value for the control of water temperature cooled in the reactor	°C	1	5	10
14	T3	Third limit of product temperature	°C	0	2	5
15	Time3	Third period of crystallization. Timer starts when $dT=dT6$. During Time 3 period, dT set-point has to equal $dT6$. Time 3 is set in minutes.	min	60	120	240
16	dT6	Set-point value for the control of water temperature cooled in the reactor	°C	0	1	5
17	T4	Fourth and lowest limit of product temperature	°C	0	1	2

Table 1
VALUES OF OPERATING
PARAMETERS USED TO
CONTROL THE
CRYSTALLIZATION
TEMPERATURE

- in order to start the cooling stage, the reactor temperature has to be at least 50°C.

First crystallization

- TIC 32212 temperature controller for heating is set on 'manual' mode - 0%;
- the agitator speed is set at S2 parameter value (80%);
- one has to wait until the reactor temperature equals 25°C;
- the difference between the reactor temperature and the water temperature has to be at most 1°C, in order to start the first crystallization;
- the first crystallization lasts 3 h.

Second crystallization

- after the drainage is confirmed, one has to wait until the water temperature equals 5°C;
- the difference between the reactor temperature and the water temperature has to be at most 5°C, in order to start the second crystallization;
- the second crystallization lasts 3 h.

Third crystallization

- the difference between the reactor temperature and the water temperature has to be at most 1°C, in order to start the third crystallization;
- the duration of the last crystallization is 2h;
- AG 32000 agitator is stopped, followed by TCV32202 control valve;

- P32201 pump is stopped;
- the product is sent to filtration.

Product filtration

- P32001 pump and XSV32000 valve are opened;
- the product is sent to F32300 filter for filtration;
- after the filtration, the remained quantity is deposited in T-32300 tank and then is sent to T- 15800 tank, in order to be used for other purposes.

Obtaining high quality fish oil

- high quality fish oil resulting from the filtration is sent to a 4.5 m³ T-18100 tank;
- consequently, this quantity of oil is sent to terminal 4, to obtain the omega-3 product.

In order to accomplish these specific operations, a set of parameters values (presented in table 1) were calculated to be used as set-points to obtain the desired temperature for the product.

All the parameters can be edited in any moment of the process, even when the sequence is in operation. The temperature is controlled using these parameters, the resulted temperature profile being represented in figure 4. This graphical representation can be continuously displayed during the process, together with the corresponding faceplate, as an useful information for the operator.

It is important to mention that both control and monitoring of the process are easiest due to the fact that

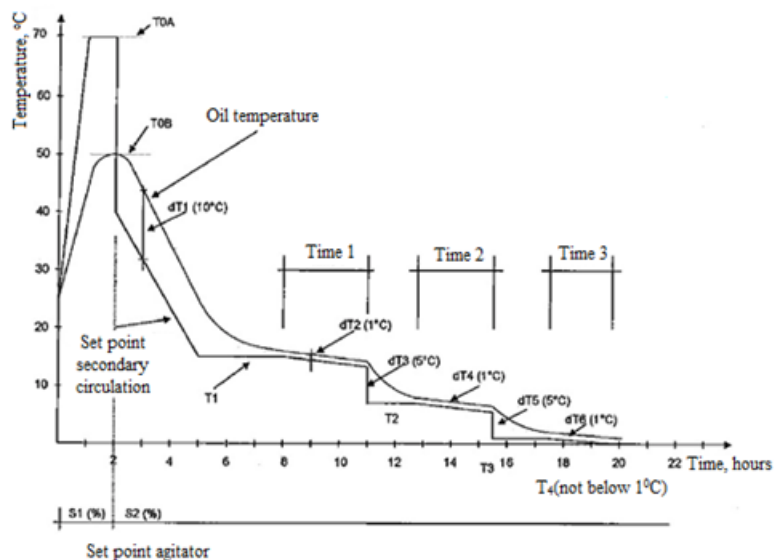


Fig. 4. Oil winterization plant temperature profile

applications of all stations are contained in one single database, and the configuration software that is required to generate the whole system can be used by several projects. For a more productive plant operation, online maintenance of the control application is sometimes required: one can modify the application in real-time, without stopping the controller and without affecting the other applications.

Conclusions

The paper analyses aspects related to simulation of the fish oil winterization process, aiming to put in evidence the effect of the temperature values upon the performance of this process. Consequently, the used automated system monitors the temperature profile by continuously displaying the graphical representations of temperature variations, and controls the temperature values on the basis of calculated set-points of related parameters.

The analysed case study has been implemented using a computer integrated production control system, that offers the facilities of a distributed control system, allowing the graphical interface configuration of an automated control system with performances regarding monitoring and controlling of the crystallization temperature.

A future study would have to consider cases referring to some of the other stages of high quality fish oil production and, possibly, comparative analysis regarding the performances of the DCS in controlling these processes.

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