HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 30. pp. 199 - 206 (2002)

APPLICATION OF FOURIER TRANSFORMATION FOR WASTE MINIMIZATION IN BATCH PLANTS. 1. ANALYSIS OF PRODUCTION RECIPES

N. G. VAKLIEVA-BANCHEVA, E. G. SHOPOVA and B. B. IVANOV

(Institute of Chemical Engineering – Bulgarian Academy of Sciences,
"Acad. G. Bontchev" Street, Bl.103, 1113 Sofia, BULGARIA)

Received: July 23, 2002

In the present study an alternative system oriented approach for determining the environmental impact assessments is proposed. It is based on the application of Fourier transformation for presenting the discontinuous functions of waste-*w* mass rates as continuous ones. Using the Fourier transformation the respective environmental impact indices are presented as functions of time and the environmental impact assessments for the given pollutant and for the entire plant are obtained.
The approach is used for environmental impact analysis of production recipes based on the example of curd processing. The optimal milkfat content is obtained so that the Global BOD generated in the process is minimal. The distribution of the environmental impact level into the production cycle is presented.

Keywords: environmental impact assessment, Fourier transformation

Introduction

Aiming to meet increased environmental regulations, the problems of pollution reduction have taken a significant place in the scientific research in the last few years. The waste decreasing concept has shifted from the "end of pipe" treatment to waste minimization at the sources [1, 2]. Following this trend, a number of systematic methodologies for waste minimization have been proposed and developed during the last decade. Hilaly and Sikdar [3, 4] have introduced the concept of generic pollution balance of a process in order to develop a systematic methodology and the resulting WAR algorithm for waste minimization. By defining a pollution index of a product for a process WAR assesses the waste generation in a given process, provides options for waste reduction and carries out a systematic handling sensitivity analysis of waste minimization tasks on the target process modifications. At the same time, Linninger at al., [5] proposed another systematic approach for batch process conceptual design. According to it a synthesis of utopian process with Zero Avoidable Pollution (ZAP) is carried out first, which is then followed by a guided evaluation to the process with Minimum Avoidable Pollution (MAP). The approach is implemented through a computer-aided tool BatchDesign-Kit [6].

The new development in this direction is a methodology for Minimum Environmental Impact (MEI), developed by Pistikopoulos and others and introduced firstly for continuous processes [7, 8], and further extended for batch plants [9]. The MEI methodology embeds the principles of Life Cycle Analysis within an optimization framework and involves the following steps:

i) definition of a process system boundary;
ii) environmental impact assessment; and
iii) incorporation of environmental impact criteria explicitly as objectives together with economics in different optimization problems.

In step (ii), the environmental impact assessment is carried out using appropriately defined environmental impact indices. These indices are measures for air pollution - Critical Air Mass, $CTAM$ (defined for continuous processes [7, 8] as [(pollutant mass rate in kg waste/h)/(standard limit value in kg waste/kg air)]), for water pollution - Critical Water Mass, $CTWM$, for solid wastes - Solid Mass Disposal, SMD, etc. Similar indices could be defined by using other ecological "indicators" such as BOD, COD, TSS, etc. The integral values of the defined indices over a time period H produce the environmental impact assessments: Environmental Impact for a given pollutant-w - EI_w, and Global Environmental Impact for the entire process - GEI.

However, in batch plants [9], the mass rate of pollutants is not constant with time due to process

Contact information: E-mail: vaklieva@bas.bg

discreetness. This requires the environmental indices to be defined with regard to the mass of pollutant processed at discreet time intervals - t. For example, the index for air pollution $CTAM$ is:

$$CTAM_{tw} = \frac{\text{Mass of pollutant at interval } t \text{ (kg pollutant } w\text{)}}{\text{Standard Limit Value (kg pollutant } w\text{/kg air)}} \quad (1)$$

Thus, to obtain the environmental impact assessments, the process/unit assignments over the time horizon (which is divided in a number of finite time intervals) must be firstly carried out, followed by calculation of the processed mass of the waste-w and the environmental impact indices at each time interval. The environmental impact assessment - EI_{Hw} for a pollutant - w, is obtained by summarizing the respective environmental indices in the time horizon H:

$$EI_{Hw} = \sum_{t=1}^{H} [CTAM_{tw}\ CTWM_{tw}\ SDM_{tw} \ldots] \quad (2)$$

and, the global assessment for the entire process – GEI_H is:

$$GEI_H = \sum_{w=1}^{W} EI_{Hw} \quad (3)$$

The procedure for environmental impact assessment calculation results in the use of binary variables in optimization problems to describe process/unit/waste states at the time intervals.

Taking into account the fact that a great part of batch productions are manufactured cyclically, the aim of this study is to propose an alternative system oriented approach for determining the environmental impact assessments. The approach is based on the application of Fourier transformation for presenting the discontinuous functions of waste-w mass rates as continuous ones. This allows the environmental impact indices to be defined similarly to those for continuous processes, through waste mass rate. Moreover, this presentation demonstrates the distribution of the waste-w mass rate, and/or respective impact indices into the horizon H, and provides opportunities for pollution control in the case of posed environmental limits.

The paper is structured as follows: Application of the Fourier transformation for polluting description from periodic waste sources and determination of the environmental impact indices and assessments by using the transformed functions are presented in the first part. The second part presents a practical application of the proposed approach for environmental impact analysis of production recipes based on the example of curd processing. Comments and discussion of the obtained results are given in the third part.

Fourier Transformation for Pollution Description from Routine Waste Sources

Generally, the manufacture of products in batch plants follows discreet sequences of individual production tasks, which appearance onto the time horizon H depends on the corresponding cycle time – TC, while their duration is specified by the production time – T. The absence of a strong process/unit assignment leads to the existence of a number of production routes with different batch sizes – B. The waste sources also appear discreetly into time and their place in the plant depends on the chosen process/unit assignment.

Commonly, the waste sources in batch plants are considered routine and non-routine. The routine sources are expected to appear in product manufacture. They depend on the chosen production recipes, the type and quality of the raw materials solvents and other used compounds, production tasks and determined process/unit assignment, scheduling, cleaning technology etc. The amount of processed wastes from routine sources and their impact on the environment can be assessed in advance. The non-routine waste sources come as a result of units breakdown, human mistake or other accidental events. The amount of the processed waste cannot be predicted in advance but the appearance of such waste sources can be avoided by increasing system reliability and decreasing its sensitivity with regard to the affect of human factors.

Consequently, the appearance of routine waste source related to a given production task – l of product - i, follows the corresponding cycle time - TC_i into the time horizon. Supposing that the mass rate of the pollutant–w is a constant during processing time - T_{il} then the discreet function - $\Phi_{wil}(t)$ of w–polluting for one production cycle is:

$$\Phi_{wil}(t) = \begin{cases} 0 \text{ for } 0 \le t \le Ts_{il} \\ \dfrac{B_i m_{wil}}{T_{il}} \text{ for } Ts_{il} \le t \le Ts_{il} + T_{il}, \quad 0 \le t \le TC_i, \\ 0 \text{ for } Ts_{il} + T_{il} \le t \le TC_i \end{cases} \quad (4)$$

when:

Ts_{il} is the starting time of task – l with regard to the cycle beginning;

B_i [kg] is the batch size; and

m_{wil} [kg/kg] is the mass of the waste – w processed from the production task – l per a unit target product.

The expression $\dfrac{B_i m_{wil}}{T_{il_i}}$ [kg/h] presents the waste - w mass rate.

The function $\Phi_{wil}(t)$ depicts a cyclic discontinuous function with a period TC_i into the time horizon H, as is shown on *Fig.1*.

It is well known that each discontinuous function with a period $T > 0$ can be approximated with the Fourier series:

$$\Psi(t) = \frac{a_o}{2} + \sum_{k=1}^{\infty} [a_k \sin(k\varphi t) + b_k \cos(k\varphi t)], \quad -T \le t \le T, \quad (5)$$

when k is a series order.

The function confessions are determined as follows:

$$a_0 = \frac{2}{T} \int_0^T \Psi(t) dt, \quad (6)$$

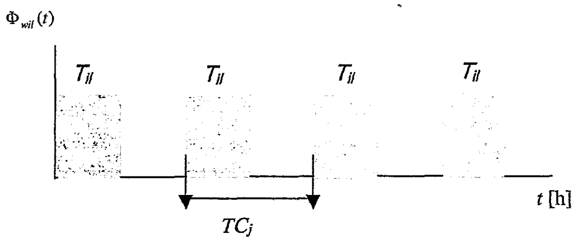


Fig.1 Cyclic discontinuous function of the polluting from the routine waste source

$$a_k = \frac{2}{T}\int_0^T \Psi(t)\sin(k\varphi t)dt\,, \qquad (7)$$

$$b_k = \frac{2}{T}\int_0^T \Psi(t)\cos(k\varphi t)dt\,. \qquad (8)$$

The discreet periodic function $\Phi_{wil}(t)$ can also be approximated with a Fourier series into the horizon H where the determined confessions according to (6)-(8) are:

$$a_{(wil)0} = \frac{2B_i m_{wil}}{TC_i} \qquad (9)$$

$$a_{(wil)k} = \frac{B_i m_{wil}}{k\pi T_{il}}\begin{bmatrix} \cos\left(\frac{k2\pi}{TC_i}Ts_{il}\right)\left[1-\cos\left(\frac{k2\pi}{TC_i}T_{il}\right)\right]+ \\ +\sin\left(\frac{k2\pi}{TC_i}Ts_{il}\right)\sin\left(\frac{k2\pi}{TC_i}T_{il}\right)\end{bmatrix} \qquad (10)$$

$$b_{(wil)k} = \frac{B_i m_{wil}}{k\pi T_{il}}\begin{bmatrix} \sin\left(\frac{k2\pi}{TC_i}Ts_{il}\right)\left[\cos\left(\frac{k2\pi}{TC_i}T_{il}\right)-1\right]+ \\ +\cos\left(\frac{k2\pi}{TC_i}Ts_{il}\right)\sin\left(\frac{k2\pi}{TC_i}T_{il}\right)\end{bmatrix} \qquad (11)$$

The function $\Phi_{wil}(t)$ transformed in the Fourier series into the time horizon H is

$$F_{wil}(t) = \frac{2B_i m_{wil}}{TC_i}\left[\frac{1}{2}+\sum_k \frac{1}{k\varphi_i T_{il}}\left[\begin{matrix}\begin{bmatrix}\cos(k\varphi_i Ts_{il})\cdot \\ \cdot(1-\cos(k\varphi_i T_{il}))+ \\ +\sin(k\varphi_i Ts_{il})\cdot \\ \cdot\sin(k\varphi_i T_{il})\end{bmatrix}\cdot \\ \cdot\sin(k\varphi_i t)+ \\ +\begin{bmatrix}\sin(k\varphi_i Ts_{il})\cdot \\ \cdot(\cos(k\varphi_i T_{il})-1)+ \\ +\cos(k\varphi_i Ts_{il})\cdot \\ \cdot\sin(k\varphi_i T_{il})\end{bmatrix}\cdot \\ \cdot\cos(k\varphi_i t)\end{matrix}\right]\right] \qquad (12)$$

$$for\ 0 \le t \le H$$

where $\frac{2\pi}{TC_i} = \varphi_i$

The new function $F_{wil}(t)$ "wraps up" the emissions from a given routine source into a "shell" which is continuous in the time horizon. It describes adequately the w–waste mass rate from a given routine source because it is presented through w-waste mass balance per a unit target product, and contains such parameters as batch size, cycle time and processing time that characterize the product – i manufacture in the plant. The function $F_{wil}(t)$ allows determination of the w-waste mass rate at any moment t from H.

By using functions $F_{wil}(t)$ the routine sources of the waste-w which belong not only to a given product but also to a system of compatible products can be "wrapped up" into a common "shell" in the time horizon:

$$F_w(t) = \sum_i \sum_l F_{wil}(t), \quad \forall l \in L_i,\ \forall i \in I, \quad for\ 0 \le t \le H \qquad (13)$$

where:

L_i is a number of production tasks of product - i; and

I is a number of products compatible in the horizon H.

The function $F_w(t)$ presents the w-waste mass rate in the time horizon and can be used for the determination of the respective environmental impact indices. If the pollutant-w is emitted into the air, when using *Eq.(13)* the respective environmental indices are expressed as a function of t. For example for air pollution they are:

$$CTAM_w(t) = \frac{1}{\mu_w}\sum_i \sum_l F_{wil}(t), \quad \forall l \in L_i,\ \forall i \in I, \quad for\ 0 \le t \le H \qquad (14)$$

where:

μ_w is the standard limit value for the pollutant-w into the air.

The environmental impact indices can also be presented in accordance with the *Eq.(1)* for a whole horizon H. In this case the processed w-waste mass from one routine source or from a set of routine sources belonging to one or a system of compatible products is obtained through integrating over the time horizon H:

$$(M_{wil})_H = \int_0^H F_{wil}(t)dt \qquad (15)$$

$$(M_w)_H = \sum_i \sum_l \int_0^H F_{wil}(t)dt, \quad \forall l \in L,\ \forall i \in I \qquad (16)$$

Using (16) the environmental impact indices $CTAM_{Hw}$, $CTWM_{Hw}$, SDM_{Hw}, etc. at the whole horizon H are:

Table 1 Content of the standardized whole milk. $BOD = 10$

Composition	content		
1. Water	87 %		
2. Total solids	13 %		
milkfat		3.6 %	
lactose		5 %	
proteins – total		3.25 %	
casein			2.85 %

$$CTAM_{Hw} = \sum_i \sum_l \frac{1}{\mu_w} \int_0^H F_{wil}(t)dt \qquad (17)$$

It is obvious that *Eq.(17)* is integrated over *H Eq.(14)*.

It is important to note that the *Eq.(17)* has an analytical solution at *H* and the Fourier series at $k = 1$ could be used for the purposes of waste minimization problems.

Using (17) the respective environmental assessments - EI_{Hw} for a pollutant -*w*, and for the entire process GEI_H are:

$$EI_{Hw} = [CTAM_{Hw}\ CTWM_{Hw}\ SDM_{Hw}] \qquad (18)$$

$$GEI_H = \sum_w EI_{Hw} \qquad (19)$$

The application of the Fourier transformation, for adequate description of pollution from discreet routine sources of batch plants has been presented. By using it, the periodic discontinuous fiction of the *w*-pollutant mass rate from a given source is approximated with a continuous one in the time horizon. This approximation is extended to the sources that belong not only to one product but also to a system of compatible products in a given horizon. Using the Fourier transformation the respective environmental impact indices are presented as functions of time. Their integrals over the time horizon *H* are used for determination of the environmental impact assessments for the given pollutant and for the entire plant.

Environmental Impact Analysis of Production Recipes on the Example of Curd Production

The biochemical oxygen demand – *BOD*, is a measure of effluent strength in terms of the amount of dissolved oxygen utilized by microorganisms during the oxidation of organic components. The wastewater discharged from dairy plants contains a significant amount of proteins, milkfat, lactose and other organic matters. Some of these pollutants come as a result of dairy processing such as pasteurization, vat-processing draining etc. while the rest are due to losses of raw material, by-product and product, for example spilled and leaked milk or whey, coagulated milk, butter, curds or cheese particles glued to unit walls.

Generally, the *BOD* loading from dairy processing depends on the composition and the amount of processed raw materials – whole and/or skimmed milk. The biochemical oxygen demand of the milk is:

Table 2 Description of the production tasks in curds processing. $CY1(x)^*$ is yield of curds by-product and *x* is milkfat content in skimmed milk

Production tasks	Task Duration	Input/Output		Fractions
Task 1	30 min.	In.	Skim-milk	1
		Out.	Pasteurized Skim-milk	1
Task 2	240 min.	In.	Skim-milk	0.88
		In.	Culture	0.12
		Out.	Curds by-product	$CY1(x)^*$
		Out.	Whey	$1\text{-}CY1(x)$
Task 3	30 min.	In.	Curds by-product	1
		Out.	Curds target product	0.9
		Out.	Drained Whey	0.1

$$BOD_M = 0.89.MF\% + 1.031.MP\% + 0.69.ML\% \qquad (20)$$

where (*MF%*), (*MP%*) and (*ML%*) are the content of the main milk components milkfat, proteins and lactose.

It is accepted in the world practice [10, 11] to standardize the whole milk (*Table 1*) which is the base for determining the milk composition required for products manufacturing and to account *BOD* "processed" in different production tasks.

The contribution of product losses could reach up to 80% of the common *BOD* load. That is why the *BOD* is used as a loss measure during handling and processing [10]. Taking into account that losses cannot be avoided, it is a common practice to assess their impact by using the established levels of the inherent losses.

Purpose of the analysis

Generally, the purpose of the environmental impact analysis of production recipes is to find the optimal conditions for product manufacturing at minimum environmental impact. It is very important to note that this analysis is carried out with regard to 1-kilogram target product processed and the particular process/unit assignment is not taken into account.

Using the proposed approach, the aim of the environmental impact analysis of curd production recipe is:

1. To determine the optimal milkfat content of the used skimmed milk in such a way that the Global Environmental Impact assessment - Global *BOD* is minimal. In the analysis both *BOD* "processed" in production tasks and *BOD* due to accounted inherent losses are considered;
2. To show the distribution of the environmental impact level into the production cycle at different operational modes.

Production recipe and products content

The curd is a lowfat milk product. It contains about 80 % water and 20 % solids – proteins (mainly casein) fat, minerals, microelements and other milk compounds.

Table 3 The product compositions and calculated values of the recovery factors

	Composition of the curd target products				Values of the recovery factors			
	moisture %	*FC* %	*CC* %	*SC* %	*RS*	*RC*	*FDM*	*RF*
A	80	0.3	11.3	20	1.724	0.96	0.015	0.075
B	81.58	1.009	12.28	18.42	1.386	0.96	0.055	0.231

The curd is processed from milk skimmed in the boundaries of $0.05\% \le x \le 1.4\%$ (*x* is % of milkfat) by direct acidification with lactic acid-producing bacteria or acidifiers.

The curd production is a cyclic batch process. Its flow chart and the description of the respective production tasks are presented on *Fig.2* and in *Table 2* [9-11].

The yield of the target product depends on the milkfat and casein content in the skim-milk. The lactose is fully passed into the whey. The Van Slyke equation for yield calculation is used [12]:

$$CY(x) = \frac{[RF.x + RC.MC\%(x)]RS}{SC\%} \quad (21)$$

where:

- x is milkfat content in the skim-milk
- $MC\%(x)$ casein content in the skim-milk presented as a function of milkfat content.
- RC, RF, RS are factors of casein, milkfat and other solids recovery from the milk;
- $SC\%$ is the solids content in the target product.

One is accepted $RC \approx 0.96$, while *RS* is determined as $RS = \frac{SC\%}{CC\% + FC\%}$, where *CC%*, *FC%* are the casein and fat content in the curd. The fat recovery factor *RF* is calculated by using Fat in Dry Matter factor – *FDM* at milkfat $x = 1$ % [12]:

$$FDM = \frac{RF.(x=1\%)}{[RF.(x=1\%) + RC.MC\%(x=1\%)]RS},$$

and (22)

$$FDM = \frac{\text{total fat retained in curds}}{\text{total solids in curds}}.$$

For the purpose of the environmental impact analysis two types of curds – target products data are used. The first one, called Product A contains 0.3 % fat, while the second - Product B contains 1.0 % fat. The product compositions and calculated values of the above factors are presented in *Table 3*.

Each of the above production tasks is source of pollution in curds processing due not only to the process but also to the inherent losses associated with the by-product and target product. Each of the pollutants is characterized with the own *BOD* load.

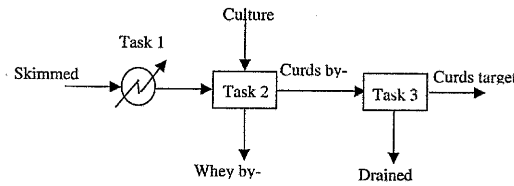


Fig.2 Flow chart of the curd processing. Task 1 Skim-milk pasteurization. Task 2 Acidification. Task 3 Draining Waste sources and pollutant

Task 1 – pasteurization. The pollutant processed in pasteurization is due to coagulated milk glued to the pasteurizer's walls. The *BOD* "generated" from this task depends on the mass of the pasteurized milk. The associated *BOD* at each kilogram processed milk is $BOD_P = 1.5.10^{-3} \frac{kg\ O_2}{kg\ pasteurized\ milk}$.

Task 2 – acidification. The pollution from this task results from spilled whey. It is accounted for as inherent loss. The leak is $WL\,\% = 1.6\,\%$ from the processed whey mass. The *BOD* load of 1-kilogram acid whey is $BOD_W = 32.10^{-3} \frac{kg\ O_2}{kg\ acid\ whey}$.

Task 3 – draining. The polluting from this task is due to:

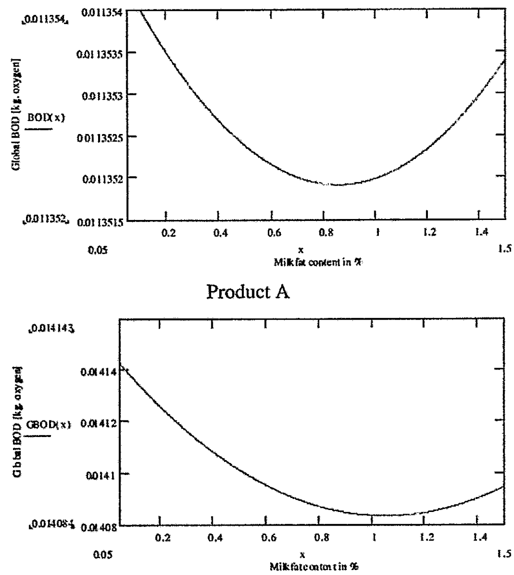
1. Discharging of drained whey which remained in the curd. The amount of the waste depends on its fraction in the curd by-product (see *Table 2*). The *BOD* load of 1-kilogram acid whey is $BOD_W = 32.10^{-3} \frac{kg\ O_2}{kg\ acid\ whey}$.
2. Inherent loss of target product as a result of gluing to the drainer's walls. The leak depends on the curd fat content and is determined as $CL\% = 0.0017.FC\%$, where *FC* % is curd fat content which for products A and B is 0.3 % and 1,009 % respectively. The *BOD* load of 1-kilogram curd depends on the curd yield and the *BOD* of used skimmed milk for it manufacturing - $BOD_C(x) = CY(x).BOD_M(x) \frac{kg\ O_2}{kg\ curds}$.

Consequently, the effluent from curd production will contain the three types of waste processed from its three tasks – routine sources.

Environmental impact indices. Global BOD.

The total amount of *BOD* generated in the horizon *H* measures the curd processing global environmental impact. It is called Global BOD. In order for it to be determined (see section 1) a description of polluting from respective routine sources and their environmental impact indices could be carried out.

Generally, the *BOD* "processed" in the sources, depends on the milkfat content, which affects the processed materials and product and by-products yield.



Product B

Fig.3 The functions $GBOD_{TC}(x)$ for products A and B

To express the milkfat dependence of the environmental impact indices the production tasks mass balance is used to determine the mass of the wastes referred to 1-kilogram target product processed at each routine source - $m(x)_{wl}$ [kg/kg]:

$$m(x)_{w,l} = \begin{bmatrix} \dfrac{0.88}{CY(x)} & 0 & 0 \\ 0 & \dfrac{1-CY(x)\left[1+\dfrac{0.1}{0.9}\right]}{CY(x)}.WL\% & \dfrac{0.1}{0.9} \\ 0 & 0 & 1.CL\% \end{bmatrix}, \quad (23)$$

$$w = 1,2,3;\ l = 1,2,3$$

The batch size is considered equal to 1-kilogram curd. The *BOD* of one kilogram pasteurized milk, whey and curd are:

$$BOD(x)_w = \begin{bmatrix} BOD_P \\ BOD_W \\ BOD_C(x) \end{bmatrix}, \quad w = 1,2,3 \quad (24)$$

To define the respective indices in accordance with *Eq.(17)* time data are required. The duration of the time horizon is very important. Curd production is a cyclic process, consequently the time horizon equals the duration of production cycle determined by the Cycle Time. The cycle time depends on the chosen operational mode. For the purpose of analysis, the two most used operational modes are discussed:

1. Operation with cycles overlapping – Case A, where $TC = \max T_l = 240[\text{min}]$;
2. Operation without cycles overlapping – Case B, where $TC = \sum_{l=1}^{3} T_l = 300[\text{min}]$.

Other time data in [min] for tasks duration and for tasks starting time referred to the cycle beginning for both cases are:

$$T_l = \begin{bmatrix} 30 \\ 240 \\ 30 \end{bmatrix}, \quad Ts_l = \begin{bmatrix} 210 \\ 0 \\ 240 \end{bmatrix}, \quad l = 1,2,3 \quad \text{(25-Case A)}$$

$$T_l = \begin{bmatrix} 30 \\ 240 \\ 30 \end{bmatrix}, \quad Ts_l = \begin{bmatrix} 0 \\ 30 \\ 270 \end{bmatrix}, \quad l = 1,2,3 \quad \text{(25- Case B)}$$

Using (23-25) the Environmental Impact Indices are presented as functions of the milkfat content:

$$BOD_{TC}(x)_w = \sum_{l=1}^{3} BOD(x)_w \int_0^{TC} F_{wl}(x,t)dt \quad (26)$$

where

$$F_{wl}(x,t) = \frac{2B.m(x)_{wl}}{TC}\left[\frac{1}{2} + \sum_k \frac{1}{k\varphi T_l}\left[\begin{bmatrix}\cos(k\varphi Ts_l)\cdot \\ \cdot(1-\cos(k\varphi T_l))+ \\ +\sin(k\varphi Ts_l)\cdot \\ \cdot\sin(k\varphi T_l)\end{bmatrix}.\cdot\sin(k\varphi t) + \begin{bmatrix}\sin(k\varphi Ts_l)\cdot \\ \cdot(\cos(k\varphi T_l)-1)+ \\ +\cos(k\varphi Ts_l)\cdot \\ \cdot\sin(k\varphi T_l)\end{bmatrix}.\cdot\cos(k\varphi t)\right]\right] \quad (27)$$

$$\text{for } 0 \le t \le TC \text{ and } \frac{2\pi}{TC} = \varphi$$

The Global *BOD* - (*GBOD*) assessing the environmental impact of the 1-kilogram curd processing over one production cycle presented as a function of the milkfat content – x is:

$$GBOD(x) = \sum_{w=1}^{3} BOD_{TC}(x)_w \cdot \quad (28)$$

Minimum of function (28)

$$\underset{0.05 \le x \le 1.4}{MIN}\ GBOD(x), \quad (29)$$

corresponds to the milkfat – x in skimmed milk at which the Global BOD at interval $0 \le t \le TC$ is minimal.

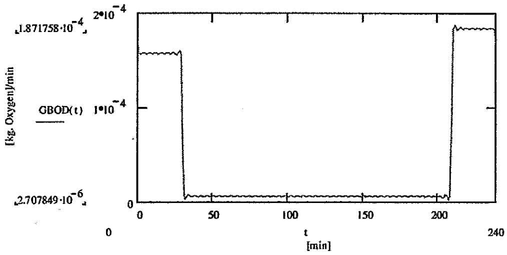
Results:

Based on the Fourier transformation the Global *BOD* for one production cycle is presented as continuous function of the milkfat content. The functions (28) for both products A and B are shown on *Fig.3*. The minimal values of *GBOD* for both products and corresponding optimal milkfat content – x are presented in *Table 4*. The yield of curd from one kilogram milk at the determined milkfat content according to *Eq.(21)*is 0.248 kg for product A and 0.23 kg for product B.

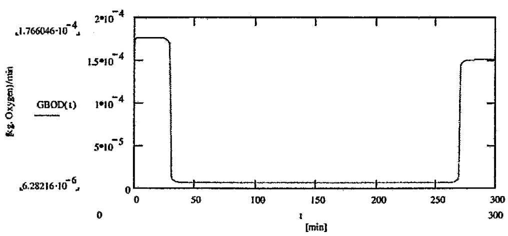
The values of the Impact indices calculated according (26) for the processing routine sources at the

Table 4 The minimal values of *GBOD* for products A and B and corresponding optimal milkfat content – x

Products	*GBOD* [kg O_2]	x milkfat content in %
Product A	1.1352×10^{-2}	0.858
Product B	1.4084×10^{-2}	1.052



Case A



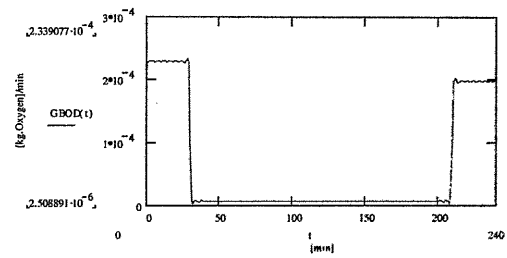
Case B

Fig.4 Distribution of the level of the biological oxygen demand for Product A processing at $x = 0.858$ into the production cycle for both operational modes (Case A and Case B)

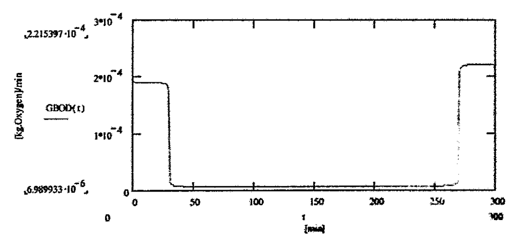
determined optimal milkfat content for both products are summarized in *Table 5*. From the table it is seen that the *BOD* due to accounted inherent losses has a significant contribution to the *GBOD* and constitutes 21,8 % and 33,9 % for products A and B respectively. The increased contribution of Product B results from its higher fat content.

Table 5 The values of the Impact indices according (26) for the processing routine sources at the determined optimal milkfat content

Product	Source	Values of the Environmental impact indices [kg O_2]		
		Pollutant Pasteurization	Pollutant Whey	Pollutant Curds target product
A $x = 0.858$	Task 1	5.32×10^{-3}		
	Task 2		1.495×10^{-3}	
	Task 3		3.556×10^{-3}	9.87×10^{-4}
B $x = 1.052$	Task 1	5.749×10^{-3}		
	Task 2		1.661×10^{-3}	
	Task 3		3.556×10^{-3}	3.118×10^{-3}



Case A



Case B

Fig.5 Distribution of the level of the biological oxygen demand for Product B processing at x=1.052 into the production cycle for both operational modes (Case A and Case B)

Distribution of the environmental impact level into the production cycle.

The distribution of the environmental impact indices in the time interval H can be presented based on *Eq.(14)*.

Using functions (27) the distribution of the level of the biological oxygen demand for curds processing into the production cycle $0 \leq t \leq TC$ can be expressed at the calculated optimal values of milkfat content as:

$$\underset{\substack{x=0.858\\ or\\ x=1.052}}{GBOD_{TC}(x,t)_w} = \sum_{w=1}^{3}\sum_{l=1}^{3} BOD(x)_w . F_{wl}(x,t) \quad (30)$$

Results:

For both operational modes Case A and Case B functions (30) are presented on *Fig.4* for Product A and on *Fig.5* for product B. It is obvious from both figures that the level of the environmental impact during curdsprocessing is greatest in the first and last 30 minutes of the cycle duration. For Case A the overlapping of tasks 2 and 3 at the beginning of the time interval and this of 2 and 1 at its end forms the impact level, while for Case B it is formed from task 1 in its beginning and task 3 in its end. Moreover it can be seen from both figures that the higher fat content of Product B makes the impact level of task 3 dominating compared to Product A where the impact level of task 1 is dominating. The above results could be used to look for opportunities for environmentally efficient control of batch processes.

Conclusions and Comments

The example above illustrates the opportunities of the proposed alternative system oriented approach for determination of environmental impact assessments.

Based on the application of the Fourier transformation, it adequately describes polluting from discreet routine sources.

The approach is used for environmental impact analysis of the curd production recipe. The optimal milkfat content is obtained so that the Global BOD generated in the process is minimal. The distribution of the environmental impact level into the production cycle is presented. The obtained results show that:

1. The minimum value of the Global BOD is reached at different milkfat content depending on the target product fat content ($x = 0.858$ for Product A and $x = 1.052$).
2. The inherent losses have a significant contribution to the *GBOD*. They constitute 21,8 % and 33,9 % for products A and B. Consequently, they must be taken into account in the environmental impact assessment of dairy processing.
3. The operational mode affects the level and distribution of environmental impact into the production cycle, which is very important for environmentally efficient control of batch processes.

The environmental impact analysis of production recipes provides the optimal conditions for product manufacturing at minimum environmental impact which could be used at the scheduling and controlling levels of batch plants.

The proposed system oriented approach based on the Fourier transformation application can find a number of practical applications in different engineering problems.

Acknowledgement

This study is conducted with the financial support of the Bulgarian National Science Fund under the Contract X-1108/01.

SYMBOLS

B	batch sizes [kg];
CC%	casein content in the curd;
CL%	inherent loss of curd;
FC%	fat content in the curd;
FDM	Fat in Dry Matter factor;
H	time horizon [h] ;
I	number of products;
L	number of production tasks;
MC%	casein content in the skim-milk;
RC	factors of casein recovery from the milk;
RF	factors of milkfat recovery from the milk;
RS	factors of other solids recovery from the milk;
SC%	solids content in curd;
T	production time [h] ;
TC	cycle time [h] ;
Ts	starting time of task with regard to the cycle beginning;
WL%	inherent loss of whey;
m	mass of waste processed from the production task per a unit target product [kg/kg] ;
t	time [h] ;
x	milkfat content in skim-milk.

Subscripts:

i	product;
k	a series order;
l	production task;
w	waste.

Greek

μ	the standard limit value for the pollutant.

REFERENCES

1. RITTMEYER R. W.: Chem. Eng. Prog., *1991*, May, 56-62
2. SMITH R. and Petela E.: TCE, *1991*, 31 October, 24-25
3. HILALY A. K. and SIKDAR S. K.: J. Air Waste Manage. Assoc., *1994*, 44, 1303-1308
4. HILALY A. K. and SIKDAR S. K.: Ind. Eng. Chem. Res., *1995*, 34, 2051-2059
5. LINNINGER A. A., SHALIM A. A., STEPHANOPOLOUS E., HAN C. and STEPHANOPOLOUS G.: AIChE Symposium Series, Pollution Prevention via Process and Product Modification, *1994*, 90(303), 46-58
6. LINNINGER A. A., STEPHANOPOLOUS E., SHALIM A. A., HAN C. and STEPHANOPOLOUS G.: Computers&Chem. Eng., *1995*, 19, S7-S13
7. PISTIKOPOULOS E. N., STEFANIS S. K., LIVINGSTON A. G.: AIChE Symposium Series, Pollution Prevention via Process and Product Modification, *1994*, 90(303), 139-150
8. STEFANIS S. K., LIVINGSTON A. G. and PISTIKOPOULOS E. N.: Computers&Chem. Eng., *1995*, 19, S39-S44
9. STEFANIS S. K., LIVINGSTON A. G. and PISTIKOPOULOS E. N.: Computers&Chem. Eng., *1997*, 21, 1073-1094
10. CARAWAN R. E., CHAMBERS J. V. and ZALL R. R.: Spinoff on Dairy Processing Water Management, Extension Special Report No AM-18.B, The North Carolina Agricultural Extension Service, January 1979
11. Overview of Dairy Processing, Cleaner production Assessment in Dairy Processing, COWI Consulting Engineers and Planners AS, Denmark, for UNEP and Danish EPA, 7-11, 2000
12. JOHNSON M.: Dairy Pipeline, *2000*, 12(2), 9-11