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THERMOECONOMIC METHOD FOR ANALYSIS OF SUGAR REFINERIES

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***Abstract* – The matematical model founded on the thermoeconomic method applied for analysis of technological processes on the sugar refineries in Republic of Moldova is present in this paper. The structural scheme of an sugar refinery including Thermal Power Station is elaborated. All mass and energy flows are indicated. Presented mathemetical model can be applied for establishing of thermoeconomic costs of intermediate and final products.**

Keywords: *balance**,** termoeconomic cost, sugar refinery , exergy.*

1. INTRODUCTION

The develoment of a Termoeconomic Analysis Methodology for the sugar refinary is exposed. The scope of this paper is to show an approach to an integral methodology that integrates the energy analysis with the economic balance using Thermoeconomics.

2. NOMENCLATURE

O&M – operating and maintenance capital flow;
∏ - Capital flow rate , \$/s;
Ω - Exergy distruction rate, kW;
Z – Operating and maintenance capital flow, \$/s;
Ex – Exergy flow rate, kW;
c – Thermoeconomic cost, \$/GJ;
d – Production cost, \$/kg, \$/t;
G – Mass flow rate, kg/s;
N_e – Electrical power, kW.

Super indexes

WTB – Washing, Cutting and Transportation of a beet Plant;
EGP– Electric Generation Plant;
DP – Diffusion Plant;
BP – Boiling Plant;
CPP – CO_2 and limy milk Production Plant;
SO - SO_2 Production Plant;
PP – Purification Plant;
CP – Cristallization Plant;
nu – not used;
SGP - Steam Generation Plant;
f – sugar-refinery;
gener – generated;
gr – related to electric energy for National Grid.

Sub indexes

i – input;
sb – sugar beet;
OM – operating and maintenance;
cw – cool water;
EE – electrical energy;
bs– beet shavings;
o - output;
hw – hot water;
cond – condensate;
hs – heating steam;
pc – pressed cake of beet shavings;
dj – diffusion juice;
lm – limy milk;
CO2 – gas CO_2;
SO2 – gas SO_2;
s – sulfur;
fw – filter washings;
ev – evaporating water;
fmc – filter mud cake;
cj – clear juice;
LPS – low pressure steam;
TL – thick liquor;
bf – boiler feedwater;
sbc – steam dissipation on the barometric condenser;
pc – the polluted condensate;
molas – molasses;
sug – sugar;
gn – natural gas;
tw – cooling water (technological water);
gr – related to electric energy for National Grid;
Ca – $CaCO_3$ (limestone);
HPS – high pressure steam;
fuel – solid fuel.

3. THERMOECONOMIC METHOD FOR COST EVALUATION IN THE SUGAR REFINERIES

The sugar production process is divided economically for same interconnected plants which are showing bellow:
washing, cutting and transportation of a beet plant;
diffusion plant;
purification plant;
boiling plant;
crystallization plant;
CO_2 and limy milk production plant;
SO_2 production plant;
steam generation plant;
electricity generation plant (including turbines).
In order to give a technical and also an economical approach to the solution of problem to develop the thermoeconomic cost accounting methodology, in Figure 1 is present an schematic layout that illustrate the typical relationships among different plants.
The general equation to express the money balance for a generic plant is:

$$Z_{OM} + \sum \Pi_i = \sum \Pi_o \tag{1}$$

The exergy flow balance in a generic plant is:

$$\sum Ex_i = \sum Ex_o + \Omega \tag{2}$$

The thermoeconomic cost associated to the input streams will be expressed as:

$$c_i = \frac{\sum \Pi_i}{\sum Ex_i} \tag{3}$$

and for the output streams:

$$c_o = \frac{\sum \Pi_o}{\sum Ex_o} \tag{4}$$

The production cost of any flow of matter (final and intermediate products) will be determined as:

$$d_j = c_o \cdot e_j = \frac{\Pi_{oj}}{G_j} \tag{5}$$

Using the flows relationships illustrated in Figure 1, the set of ecuations that conform the thermoeconomic methodology for the sugar-refinery process, are shown bellow for each interconnected plant.

3.1. Washing, Cutting and Transportation of a beet Plant

Input:

$$\sum \Pi_i^{WTB} = \Pi_{sb} + \Pi_{cw} + \Pi_{EE}^{WTB} + Z_{OM}^{WTB} \tag{6}$$

Output:

$$\sum \Pi_o^{WTB} = \Pi_{bs} \tag{7}$$

$$\sum \Pi_i^{WTB} = \sum \Pi_o^{WTB} \tag{8}$$

Input capital flows:

$$\Pi_{sb} = d_{sb} \cdot G_{sb} \tag{9}$$

$$\Pi_{cw} = d_{cw} \cdot G_{cw} \tag{10}$$

$$\Pi_{EE}^{WTB} = c_o^{EGP} \cdot N_e^{WTB} \tag{11}$$

Thermoeconomic cost:

$$c_o^{WTB} = \frac{\sum \Pi_i^{WTB}}{Ex_{bs}} \tag{12}$$

Output capital flow:

$$\Pi_{bs} = c_o^{WTB} \cdot Ex_{bs} \tag{13}$$

3.2. Diffusion Plant

Input:

$$\sum \Pi_i^{DP} = \Pi_{bs} + \Pi_{hw} + \Pi_{EE}^{DP} + \Pi_{cond}^{BP} + \Pi_{hs}^{DP} + Z_{OM}^{DP} \tag{14}$$

Output:

$$\sum \Pi_o^{DP} = \Pi_{dj} + \Pi_{pc} + \Pi_{cond}^{DP} \tag{15}$$

$$\sum \Pi_i^{DP} = \sum \Pi_0^{DP} \tag{16}$$

Input capital flows:

The connection with the preceding plant is established by mean of equation (13) as input stream;

$$\Pi_{hw} = c_0^{hw} \cdot Ex_{hw} \tag{17}$$

$$\Pi_{EE}^{DP} = c_0^{EGP} \cdot N_e^{DP} \tag{18}$$

$$\Pi_{cond}^{BP} = c_0^{BP} \cdot Ex_{cond}^{BP} \tag{19}$$

$$\Pi_{hs}^{DP} = c_0^{BP} \cdot Ex_{hs}^{DP} \tag{20}$$

Thermoeconomic cost:

$$c_0^{DP} = \frac{\sum \Pi_i^{DP} - \Pi_{pc} - \Pi_{cond}^{DP}}{Ex_{dj}} \tag{21}$$

Due to the fixed sale price of the pressed cake of beet shavings, it is recommended to calculate the cash flow associated to this stream as:

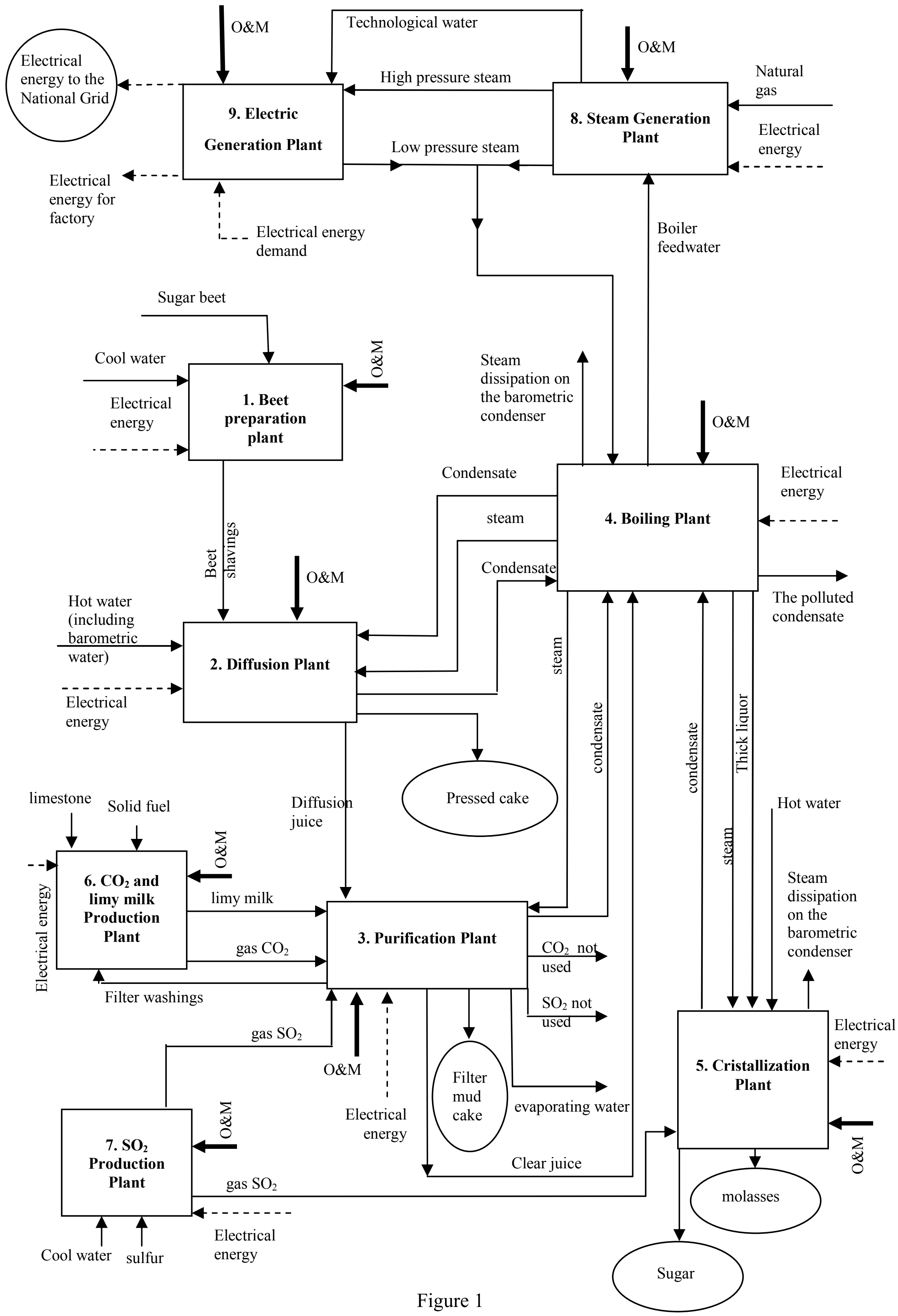
O&M
Technological water
O&M
Electrical energy to the National Grid
High pressure steam
Natural gas
9. Electric Generation Plant
8. Steam Generation Plant
Electrical energy
Low pressure steam
Electrical energy for factory
Electrical energy demand
Boiler feedwater
Sugar beet
Cool water
O&M
1. Beet preparation plant
Steam dissipation on the barometric condenser
Electrical energy
O&M
Condensate
Electrical energy
steam
4. Boiling Plant
Beet shavings
Condensate
O&M
The polluted condensate
Hot water (including barometric water)
steam
2. Diffusion Plant
condensate
Electrical energy
condensate
Thick liquor
Pressed cake
limestone
Solid fuel
Diffusion juice
Hot water
O&M
steam
6. CO_2 and limy milk Production Plant
limy milk
Steam dissipation on the barometric condenser
3. Purification Plant
Electrical energy
gas CO_2
CO_2 not used
Filter washings
SO_2 not used
gas SO_2
Electrical energy
O&M
Filter mud cake
5. Cristallization Plant
evaporating water
Electrical energy
7. SO_2 Production Plant
O&M
Clear juice
O&M
gas SO_2
molasses
Electrical energy
Cool water
sulfur
Sugar

Figure 1

$$\Pi_{pc} = d_{pc} \cdot G_{pc} \quad (22)$$

Output capital flows:

$$\Pi_{cond}^{DP} = d_{cond}^{DP} \cdot G_{cond}^{DP} \quad (23)$$

$$\Pi_{dj} = c_0^{DP} \cdot Ex_{dj} \quad (24)$$

3.3. Purification Plant

Input

$$\sum \Pi_i^{PP} = \Pi_{dj} + \Pi_{CO2} + \Pi_{lm} + \Pi_{EE}^{PP} + \Pi_{SO2}^{PP} + \Pi_{hs}^{PP} + Z_{OM}^{PP} \quad (25)$$

Output

$$\sum \Pi_o^{PP} = \Pi_{fw} + \Pi_{CO2}^{nu} + \Pi_{cond}^{PP} + \Pi_{SO2}^{nu} + \Pi_{ev}^{PP} + \Pi_{fmc} + \Pi_{cj} \quad (26)$$

$$\sum \Pi_i^{PP} = \sum \Pi_0^{PP} \quad (27)$$

Input capital flows:
The connection with the preceding plant is established by mean of equation (24) as input stream.

$$\Pi_{CO2} = c_0^{CPP} \cdot Ex_{CO2} \quad (28)$$

$$\Pi_{lm} = c_0^{CPP} \cdot Ex_{lm} \quad (29)$$

$$\Pi_{SO2}^{PP} = c_0^{SO} \cdot Ex_{SO2}^{PP} \quad (30)$$

$$\Pi_{hs}^{PP} = c_0^{BP} \cdot Ex_{hs}^{PP} \quad (31)$$

$$\Pi_{EE}^{PP} = c_0^{EGP} \cdot N_e^{PP} \quad (32)$$

Thermoeconomic cost:

$$c_0^{PP} = \frac{\sum \Pi_i^{PP} - \Pi_{fw} - \Pi_{cond}^{PP} - \Pi_{CO2}^{nu} - \Pi_{SO2}^{nu} - \Pi_{ev}^{PP} - \Pi_{fmc}}{Ex_{cj}} \quad (33)$$

Knowing the mass flow rates of output products, the capital flow associated will be determined as:

$$\Pi_{fw} = d_{fw} \cdot G_{fw} \quad (34)$$

$$\Pi_{cond}^{PP} = d_{cond}^{PP} \cdot G_{cond}^{PP} \quad (35)$$

$$\Pi_{CO2}^{nu} = d_{CO2}^{PP} \cdot G_{CO2}^{PP} \quad (36)$$

$$\Pi_{SO2}^{nu} = d_{SO2}^{PP} \cdot G_{SO2}^{PP} \quad (37)$$

$$\Pi_{ev}^{PP} = d_{ev}^{PP} \cdot G_{ev}^{PP} \quad (38)$$

$$\Pi_{fmc} = d_{fmc}^{PP} \cdot G_{fmc}^{PP} \quad (39)$$

Output capital flows:

$$\Pi_{cj} = c_0^{PP} \cdot Ex_{cj} \quad (40)$$

3.4. Boiling Plant

Input

$$\sum \Pi_i^{BP} = \Pi_{cj} + \Pi_{LPS} + \Pi_{cond}^{CP} + \Pi_{EE}^{BP} + \Pi_{cond}^{PP} + \Pi_{cond}^{DP} + Z_{OM}^{BP} \quad (41)$$

Output

$$\sum \Pi_o^{BP} = \Pi_{hs}^{PP} + \Pi_{hs}^{DP} + \Pi_{hs}^{CP} + \Pi_{TL} + \Pi_{bf} + \Pi_{sbc}^{BP} + \Pi_{pc} + \Pi_{cond}^{BP} \quad (42)$$

$$\sum \Pi_i^{BP} = \sum \Pi_0^{BP} \quad (43)$$

Input capital flows:
The connection with the preceding plants is established by mean of equations (23, 35, 40) as input streams.

$$\Pi_{LPS} = c_{LPS} \cdot Ex_{LPS}^{BP} \quad (44)$$

$$\Pi_{EE}^{BP} = c_0^{EGP} \cdot N_e^{BP} \quad (45)$$

$$\Pi_{cond}^{CP} = d_{cond}^{CP} \cdot G_{cond}^{CP} \quad (46)$$

Thermoeconomic cost:

$$c_0^{BP} = \frac{\sum \Pi_0^{BP}}{Ex_{hs}^{BP} + Ex_{hs}^{DP} + Ex_{hs}^{CP} + Ex_{TL} + Ex_{bf} + Ex_{sbc} + Ex_{pc} + Ex_{cond}^{BP}} \quad (47)$$

Output capital flows:
The connection with the preceding plants is established by mean of equations (19, 20, 31) as output streams.

$$\Pi_{hs}^{CP} = c_0^{BP} \cdot Ex_{hs}^{CP} \quad (48)$$

$$\Pi_{TL} = c_0^{BP} \cdot Ex_{TL} \quad (49)$$

$$\Pi_{bf} = c_0^{BP} \cdot Ex_{bf} \quad (50)$$

$$\Pi_{sbc}^{BP} = c_0^{BP} \cdot Ex_{sbc} \quad (51)$$

$$\Pi_{pc} = c_0^{BP} \cdot Ex_{pc} \quad (52)$$

3.5. Cristallization Plant

Input:

$$\sum \Pi_i^{CP} = \Pi_{TL} + \Pi_{hs}^{CP} + \Pi_{hw} + \Pi_{EE}^{CP} + \Pi_{SO2}^{CP} + Z_{OM}^{CP} \quad (53)$$

Output:

$$\sum \Pi_o^{CP} = \Pi_{cond}^{CP} + \Pi_{sbc}^{CP} + \Pi_{molas} + \Pi_{sug} \quad (54)$$

$$\sum \Pi_i^{CP} = \sum \Pi_0^{CP} \quad (55)$$

Input capital flows:

The connection with the preceding plants is established by mean of equations (17, 48, 49) as output streams.

$$\Pi_{SO2}^{CP} = c_0^{SO} \cdot Ex_{SO2}^{CP} \quad (56)$$

$$\Pi_{EE}^{CP} = c_0^{EGP} \cdot N_e^{CP} \quad (57)$$

Thermoeconomic cost:

$$c_0^{CP} = \frac{\sum \Pi_i^{CP} - \Pi_{cond}^{CP} - \Pi_{sbc}^{CP} - \Pi_{molas}}{Ex_{sug}} \quad (58)$$

Output capital flows:
The connection with the preceding plant is established by mean of equation (46) as output stream.

$$\Pi_{sbc}^{CP} = c_0^{CP} \cdot Ex_{sbc} \quad (59)$$

Due to the fixed sale price of final molasses, the cash flow associated to this stream should be calculated as:

$$\Pi_{molas} = d_{molas} \cdot G_{molas} \quad (60)$$

3.6. CO_2 and limy milk Production Plant

Input:

$$\sum \Pi_i^{CPP} = \Pi_{Ca} + \Pi_{fuel} + \Pi_{EE}^{CPP} + \Pi_{fw} + Z_{OM}^{CPP} \quad (61)$$

Output:

$$\sum \Pi_o^{CPP} = \Pi_{lm} + \Pi_{CO2} \quad (62)$$

$$\sum \Pi_i^{CPP} = \sum \Pi_0^{CPP} \quad (63)$$

Input capital flows:

$$\Pi_{Ca} = d_{Ca} \cdot G_{Ca} \quad (64)$$

$$\Pi_{fuel} = d_{fuel} \cdot G_{fuel} \quad (65)$$

$$\Pi_{EE}^{CPP} = c_0^{EGP} \cdot N_e^{CPP} \quad (66)$$

The connection with the preceding plant is established by mean of equation (34) as input stream.
Thermoeconomic cost:

$$c_0^{CPP} = \frac{\sum \Pi_i^{CPP}}{Ex_{lm} + Ex_{CO2}} \quad (67)$$

Output capital flows:

The connection with the preceding plants is established by mean of equations (28, 29) as output streams.

3.7. SO_2 Production Plant

Input:

$$\sum \Pi_i^{SO} = \Pi_{cw} + \Pi_{EE}^{SO} + \Pi_s + Z_{OM}^{SO} \quad (68)$$

Output:

$$\sum \Pi_o^{SO} = \Pi_{SO2}^{PP} + \Pi_{SO2}^{CP} \quad (69)$$

$$\sum \Pi_i^{SO} = \sum \Pi_0^{SO} \quad (70)$$

Input capital flows:
The connection with the preceding plants is established by mean of equation (10) as input stream.

$$\Pi_{EE}^{SO} = c_0^{SPE} \cdot N_e^{SO} \quad (71)$$

$$\Pi_s = d_s \cdot G_s \quad (72)$$

Thermoeconomic cost:

$$c_0^{SO} = \frac{\sum \Pi_0^{SO}}{Ex_{SO2}^{PP} + Ex_{SO2}^{CP}} \quad (73)$$

Output capital flows:
The connection with the preceding plants is established by mean of equations (30, 56) as output streams.

3.8. Steam Generation Plant

Input:

$$\sum \Pi_i^{SGP} = \Pi_{gn} + \Pi_{bf} + \Pi_{EE}^{SGP} + Z_{OM}^{SGP} \quad (74)$$

Output:

$$\sum \Pi_o^{SGP} = \Pi_{HPS} + \Pi_{LPS}^{SGP} + \Pi_{tw} \quad (75)$$

$$\sum \Pi_i^{SGP} = \sum \Pi_0^{SGP} \quad (76)$$

Input capital flows:

$$\Pi_{gn} = d_{gn} \cdot G_{gn} \quad (77)$$

The connection with the preceding plant is established by mean of equation (50) as input stream.

$$\Pi_{EE}^{SGP} = c_0^{EGP} \cdot N_e^{SGP} \quad (78)$$

Thermoeconomic cost:

$$c_0^{SGP} = \frac{\sum \Pi_i^{SGP}}{Ex_{HPS} + Ex_{LPS} + Ex_{tw}} \quad (79)$$

Output capital flows:

$$\Pi_{LPS}^{SGP} = c_0^{SGP} \cdot Ex_{LPS}^{SGP} \tag{80}$$

$$\Pi_{HPS} = c_0^{SGP} \cdot Ex_{HPS} \tag{81}$$

$$\Pi_{tw} = d_{tw} \cdot G_{tw} \tag{82}$$

3.9. Electric Generation Plant

Input:

$$\sum \Pi_i^{EGP} = \Pi_{HPS} + \Pi_{tw} + \Pi_{EE}^{EGP} + Z_{OM}^{EGP} \tag{83}$$

Output:

$$\sum \Pi_o^{EGP} = \Pi_{LPS} + \Pi_{gr} + \Pi_{EE}^{f} \tag{84}$$

$$\sum \Pi_i^{EGP} = \sum \Pi_0^{EGP} \tag{85}$$

Input capital flows:
The connection with the preceding plant is established by mean of equations (81, 82) as input streams.

$$\Pi_{EE}^{EGP} = c_0^{EGP} \cdot N_e^{EGP} \tag{86}$$

Thermoeconomic cost:

$$c_0^{EGP} = \frac{\sum \Pi_i^{EGP} - \Pi_{gr}}{\sum_{i=1}^{9} N_{ei} + Ex_{LPS}} \tag{87}$$

where:

$$\sum_{i=1}^{9} N_{ei} = N_e^{WTB} + N_e^{DP} + N_e^{PP} + N_e^{BP} + N_e^{CP} + N_e^{CPP} + N_e^{SO} + N_e^{SGP} + N_e^{EGP} \tag{88}$$

$$N_e^{gr} = N_{eEE}^{gener} - \sum_{i=1}^{9} N_{ei} \tag{89}$$

Output capital flows:

$$\Pi_{gr} = c_{EE}^{gr} \cdot N_e^{gr} \tag{90}$$

$$\Pi_{LPS} = c_0^{EGP} \cdot Ex_{LPS} \tag{91}$$

$$\Pi_{EE}^{f} = c_0^{EGP} \cdot \sum_{i=1}^{9} N_{ei} \tag{92}$$

Low pressure steam is only supplied to the boiling plant, but is provided by the steam generation plant (through a pressure reducing valve with a spray cooling chamber), and as exhaust steam of the back pressure turbines from the electric generation plant. Thus an average thermoeconomic cost should be defined as:

$$c_{LPS} = \frac{\Pi_{LPS}^{EGP} + \Pi_{LPS}^{SGP}}{Ex_{LPS}^{EGP} + Ex_{LPS}^{SGP}} \tag{93}$$

4. CONCLUSIONS

The proposed thermoeconomic method for cost evaluation is an approach to determine the intermediate product costs, is a useful tool available to the engineer to evaluate technical improvements for the sugar industry. This method allows a general common point of view between the engineer and the economist.

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