SPECIFICATION OF SUGAR PRODUCTION PROCESSES CONNECTED TO THE ACTUATORS INTENDED TO USE FOR BENCHMARK DEFINITION

- *manuscript revision 2.0* –
- ***for internal use only*** -

Piotr WASIEWICZ

Warsaw University of Technology, Faculty of Mechatronics, Institute of Automatic Control and Robotics, Chodkiewicza 8, 02-525 Warszawa, Poland, pwasiew@mchtr.pw.edu.pl

Abstract. This paper is the second one from the series of papers, which are important for benchmark definition in the field on industrial applied actuator diagnosis. The first one ("*Specification of actuators intended to use for benchmark definition*"[1]) gives detailed information concerning the actuators chosen for benchmark in the polish sugar factory Cukrownia Lublin S.A. This paper however describes the parts of technological processes (first two sections of evaporation station and boiler drum in the fourth boiler house) connected to these actuators. Both papers are intended as working background suitable for all the DAMADICS[*)] project members joining the actuator diagnosis challenge.
Keywords: actuators, fault detection, fault isolation, evaporation process, boiler drum

1. THE ACTUATORS CHOSEN FOR RESEARCH [*]

Three actuators have been chosen for research purposes in the framework of DAMADICS project. Two actuators connected with evaporation station (Fig.4):

- first one situated on the inflow of thin juice into the evaporation station (LC51_03-juice level control loop in the first evaporator)
- and the second one situated on the outlet of thick juice from the fifth section of evaporation station (FC57_03-juice flow control loop)

The third actuator connected with the fourth boiler house (Fig.6) is situated on the water inflow into boiler drum (LC74_20-water level control loop in boiler drum)

Each actuator has been equipped with the similar measuring devices shown on Fig. 1.

Detailed information about all mentioned above actuators has been described in [1].

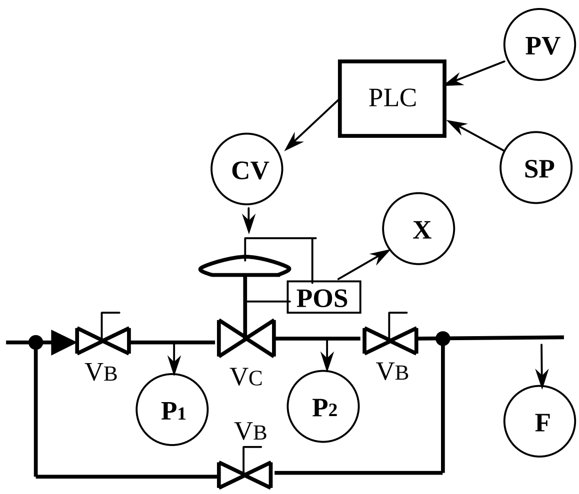


Fig.1. The diagram of actuator with measured variables (in the case of LC51_03 & FC57_03 the fluid is the juice and in the case of LC74_20 the fluid is the water). Symbols: V_C - control valve, V_B - bypass valve, POS - positioner, PLC - programmable logic controller, P_1 - fluid pressure before valve, P_2 - fluid pressure behind valve, F - fluid flow, CV - control variable (controller output signal), X - valve head position, PV - process variable, SP - set point.

[*]) This work has been supported by EU FP5 grant DAMADICS entitled: "Development and Application of Methods for Actuator Diagnosis in Industrial Control Systems".

2. ACTUATOR DIAGNOSIS USING MODEL BASED METHODS

The paper includes data necessary for fault diagnosis of actuators considered as a parts of the whole control loops, i.e. including connection with the process.

As an example of such kind of methods one can mention GOS structure [3]. The diagram of GOS method for actuator diagnosis has been shown on Fig. 2. All process outputs and inputs excluding one input are delivered to all observers (i.e. i'th input is not connected with i'th observer). In this way observer is sensitive for faults of all actuators apart from this one.

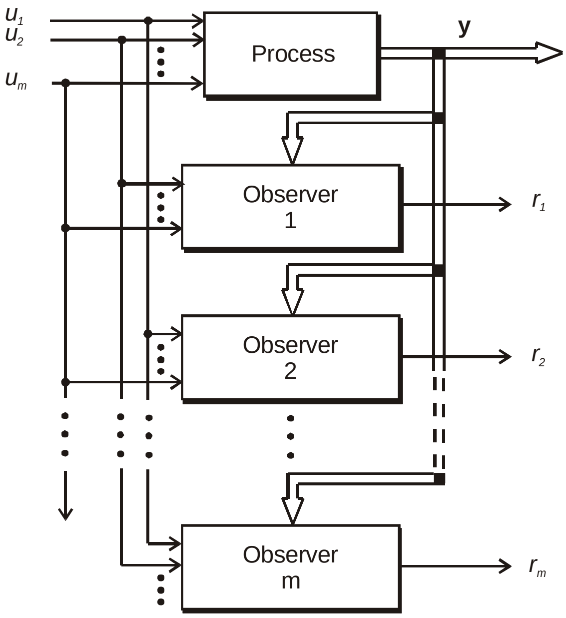


Fig.2. GOS diagram for actuator diagnosis

These methods require the possession of knowledge of mathematical process models, which usually causes grate problems.

The process of water evaporation from beet juice in the I section of evaporation station (in the scope concerning the first considered actuator) will be described below. The evaporation process in the V section (second considered actuator) will not be discuss because of its complexity and poor measurements.

The water accumulation in steam boiler because this process seems to be the simplest for modelling. However it is to emphasize that in the boiler drum unfavourable phenomena (so-called "water swell") appears, which makes that fluid balance became more complicated. However, information announced in the paper can be also useful in another diagnosis methods based on partial process models.

3. EVAPORATION PROCESS

3.1. EVAPORATION STATION - GENERAL DESCRIPTION

The main technological task of evaporation station is to thicken the beet juice being just after the filtering and cleaning processes. The thin juice should be condensed from the density of Bx=14% till Bx=70%. The evaporation station consists of seven evaporators grouped in five sections (sections I,IV,V consist of one evaporator each and sections II and III consists of two evaporators each). The first five evaporators work with natural juice circulation and the last two have another construction and work with juice circulation forced by pumps. The diagram of the I-evaporator (Robert's type) has been shown on Fig. 3.

The juice condensation process is performed using steam and vapour, which are the same quantities from physical point of view but they have different sources. Steam is produced by water-steam-boiler and is mainly delivered to the I section of evaporation station. Whereas, vapour as recyclable medium, is produced in each evaporator and heat accumulator. The vapour is used as heating medium in many technological stations (e.g. steam heaters, consecutive evaporators, diffusers, syrup boilers etc.). Additional task of evaporation station is to produce the condensate, which is delivered next to the steam boiler.

3.2. THE RELATIONS AND DEPENDENCIES BETWEEN VARIABLES IN EVAPORATION STATION

Attempt at description of various phenomena, which occur in evaporation station reveals the complexity of problems.

The simplified, static mathematical model of evaporation station, well known in literature [2], has been worked out by Claassen. Simplified balance of masses for evaporation station can be described by means of the following equations:

$$M_{thk} = M_{thn} - W \quad (1)$$

$$W = E_I + 2E_{II} + 3E_{III} + ... + nE_n \quad (2)$$

$$W = M_{thn}(1 - \frac{Bx_{thn}}{Bx_{thk}}) \quad (3)$$

where:

M_{thn} – quantity of thin juice

M_{thk} – quantity of thick juice

W – quantity of evaporated water in

E_n – quantity of vapour piped away from n'th (n = I, II ...V) section of evaporation station to another heat receiver

$n = I, II ...V$ – number of evaporation sections

Bx_{thn} – density of thin juice

Bx_{thn} – density of thik juice

Mentioned above Claassen's balance passes over the difference of enthalpy of vapour being under various pressures. It also omits the heat losses into environment. Thus, it is necessary to include in the static model of evaporation station the parameters describing the physical state of juice and vapour in consecutive sections. The pressure in vapour chambers, which is dependent on temperature and intensity of vapour receipt from given evaporation section is here of greatest importance. The problem is that the vapour is not only delivered to the next section but also to many heat receivers. In this respect evaporator model involves with processes of almost whole sugar factory and can not be considered separately.

The principle of heat penetration in heating chamber of evaporator defines the following equation:

$$Q = k\ F\ \Delta t \quad (4)$$

where:

Q – quantity of penetrating heat per time unit

k – heat penetrating coefficient $[W/(m^2 K)]$

Δt – usable difference of temperature of condensing vapour and boiling juice $[K]$

F – heating surface of heating chamber $[m^2]$

The value of k coefficient depends on evaporator construction, juice level, heat chamber venting as well as temperature difference. So, assumption its constant value in the equation (5) is a simplification.

The energy balance of evaporation process in particular evaporator can be calculated basing

$$M_s(i_s - i_c)\left(1 - \frac{Q_l}{100}\right) = M_j\ i_j - M_{j-1}\ i_{j-1} + M_v\ i_v \quad (6)$$

where:

M_s – quantity of inflowing steam $[kg]$

i_s – steam enthalpy $[kJ/kg]$

i_c – condensate enthalpy $[kJ/kg]$

i_j, i_{j-1} – enthalpy of juice inflow/outflow $[\frac{kJ}{kg}]$

M_j, M_{j-1} – quantity of juice inflow and outflow $[kg]$

$M_v = M_{j-1} - M_j$ – quantity of outflowing vapour $[kg]$

i_v – vapour enthalpy $[kJ/kg]$

Q_l – heat looses (2 – 4%)

on the following equation:

The juice enthalpy depends on its temperature, density and cleanness. Moreover, temperature of boiling juice is a complex function of not only pressure but also juice density as well as juice level (so-called, increased boiling temperature).

This balance is thus too primitive but it can be a starting point for constructing the dynamic model (also simplified).

3.3. HEAT BALANCE OF A PART OF EVAPORATION STATION

The average values of juice density as well as another process data concerning the first two sections of evaporation station (I, IIA and IIB evaporators) have been shown on Fig. 5. All these values have been measured and calculated during sugar campaign'1999 to prepare the heat-balance of evaporation station for economic purposes. This data are confidential and can be used as approximate values only for DAMADICS's research purposes.

Table 1. Specifications of the juice pipelines and actuator on the inflow of thin juice into the I section of evaporation station.

Item	Parameter	Symbol	Value	Units
1.	Flow irregularity coefficient	k	1,2	
2.	Liquid quantity	Q1	130,90	%nb *)
3.	Liquid quantity	Q2	392,70	t/h
4.	Liquid density	G	986,0	kg/m3
5.	Liquid quantity	Q3	398,28	m3/h
6.	Min. juice velocity in pipeline	Wmin	1,8	m/s
7.	Max. juice velocity in pipeline	Wmax	2,2	m/s
8.	Pipeline diameter for Wmin, calculated	Dmin	0,28	m
9.	Pipeline diameter for Wmax, calculated	Dmax	0,253	m
10.	Pipeline diameter, established	DN	200	mm
11.	Velocity for established diameter		3,52	m/s
12.	Pressure decrease on control valve		50	kPa
13.	Valve Kv, calculated	Kv	559	
14.	Valve Kv, existing	Kv	550	
15.	Valve diameter	Dn	200	mm
16.	Valve type		20.521	

*) quantity in % with reference to sugar beets used in manufacturing process

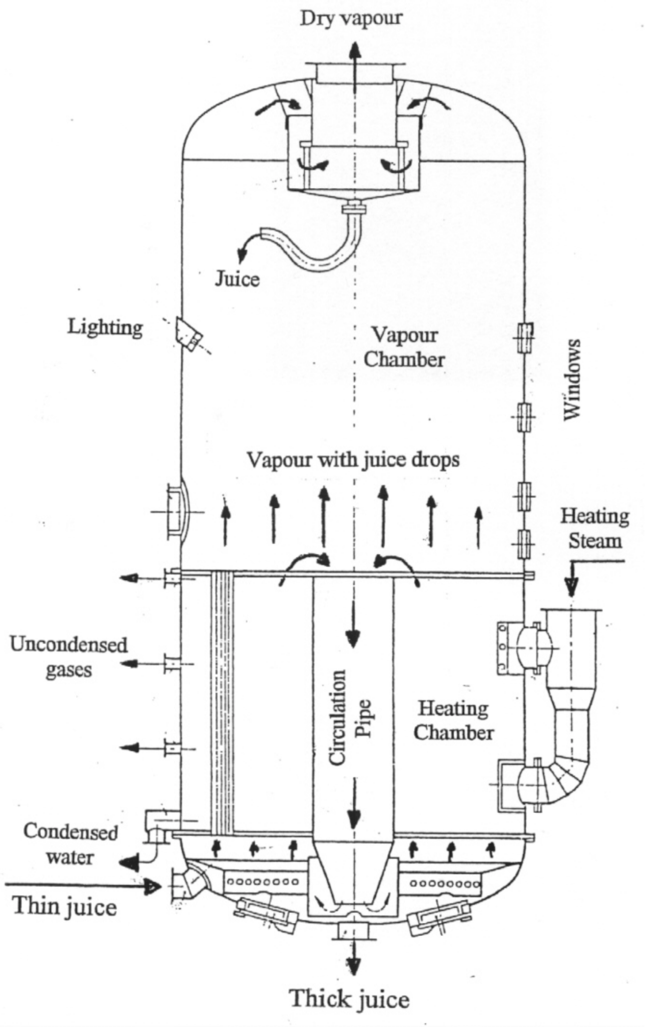


Fig. 3. The diagram of the I-evaporator (Robert's type, with natural juice circulation shown by arrows).

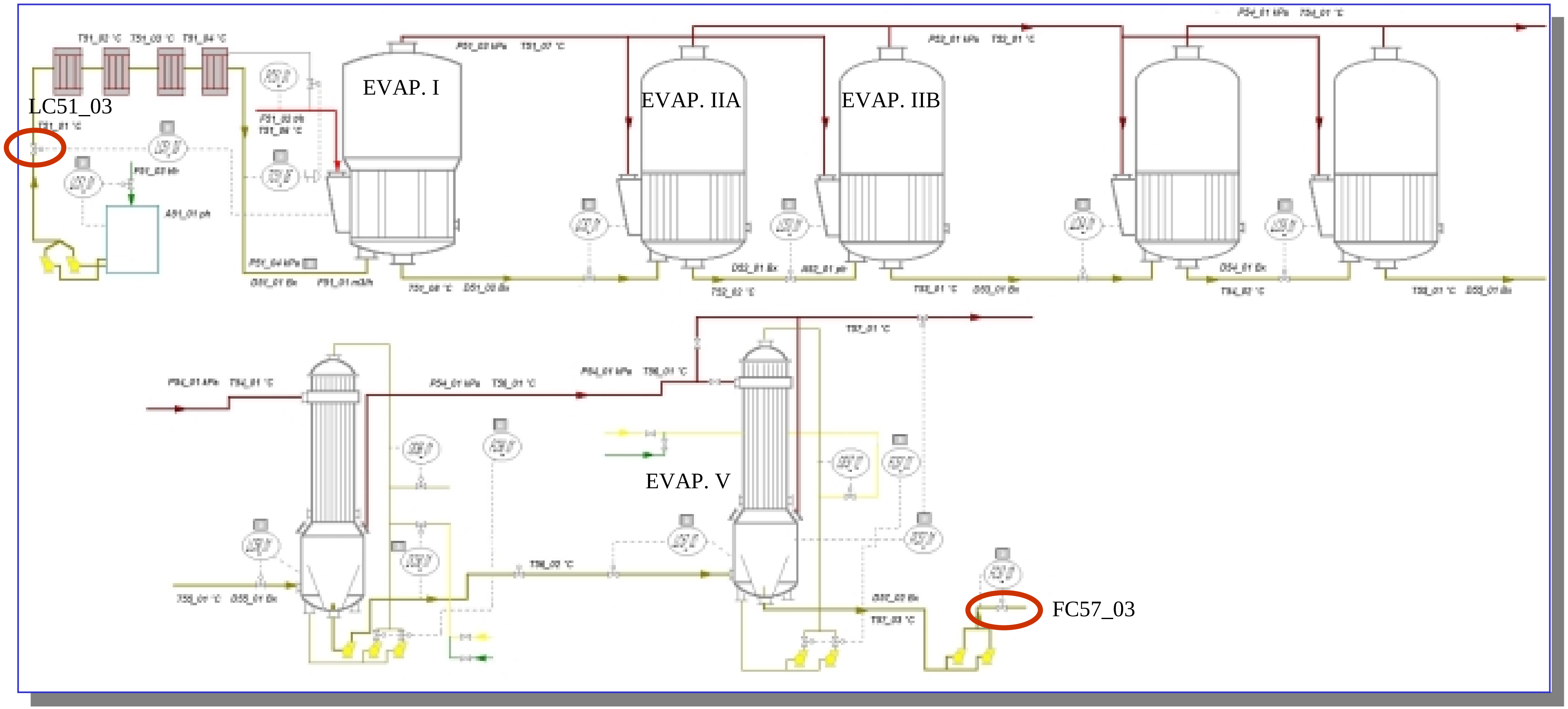
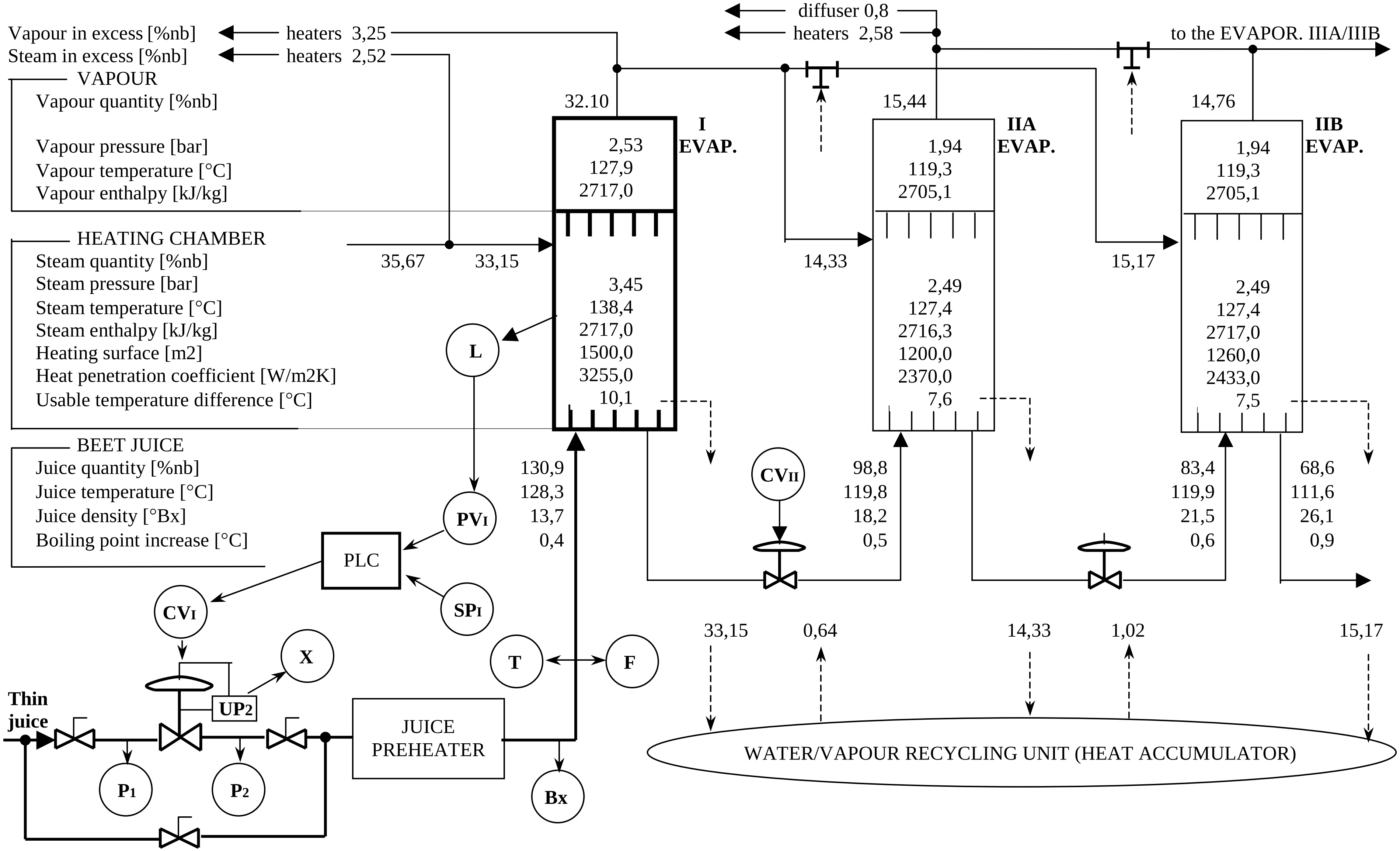


Fig. 4. The diagram of evaporation station of sugar factory Cukrownia Lublin S.A. Location of two chosen actuators for DAMADICS benchmark.
LC51_03 - actuator in the control loop of thin juice level in the first evaporator (EVAP. I - first section of evaporation station)
FC57_03 - actuator in the control loop of thick juice flow on the outlet from the seventh evaporator (EVAP. V - fifth section of evaporation station)

Fig.5. Heat balance of the I, IIA, IIB sections of evaporation station at sugar factory CUKROWNIA "LUBLIN" S.A. (processing of 6.000 t/d)



4. WATER ACCUMULATION PROCESS IN BOILER DRUM

4.1. STEAM BOILER DESCRIPTION

The boiler house of sugar factory CUKROWNIA LUBLIN S.A. is composed of four technological complexes predestined for getting up steam. An coal grate furnace having two grates, boiler drum and initial steam superheater belong to each complex - OSR 32/25x400 type. The steam boiler symbol consists of the following three numbers: the first one - maximal durable capacity in *tons* of steam *per hour*, the second one - steam pressure in *at* and the third one - temperature of superheating steam.

The actuator on the water inflow into the fourth boiler drum will be one of the objects for DAMADICS research purposes. The diagram of steam boiler has been shown on Fig. 4. Its parameters ha been collected in the Tab. 2.

The thickness of coal coat is controlled manually by boiler operator. The feed of each grate (SC74_10/SC74_11 - left/right furnace side) and the air inflow through coal in each grate (PC74_20/PC74_21 - left/right furnace side) are controlled in function of steam pressure in boiler drum.

The automatic control system of water level in boiler drum (LC74_20) with influence on water inflow is of grate importance in each steam boiler. This control system has two structures: the simple one using the measured water level only and the more complex one using additional water inflow (F74_00) and steam outflow (FC74_20). The selection of respective structure can be made by means of switch (S74_01).

The values of content of oxygen as well as carbon dioxide in combustion gases are laboratory evaluated.

4.2. FLOW BALANCE OF STEAM BOILER

The static flow balance of steam boiler can be described by the equation (7).

About dynamic properties one can find in literature information, that the boiler drum can be considered as n-order lag element (n=3-7). It is also to stress the phenomena so-called "water swell", which occurs in the boiler drum and complicates the balance. This phenomena lies in

$$k \, \Delta L = Q_w - Q_s \qquad (7)$$

where :

$\Delta L -$ change of water level

$k -$ coefficient connected to drum geometry

$Q_w -$ quantity of water inflow

$Q_w -$ quantity of steam outflow

temporary decreasing of the steam-water-mixture level when the steam outflow decreases. This is because of increasing of water evaporation in the boiler drum when pressure increases and temperature is constant.

4.3. HEAT BALANCE OF STEAM BOILER

The heat balance of steam boiler can be described by the following equation:

$$B \, W_c \, \frac{\eta}{100} = D \, (\, i_s - i_w \,) \qquad (8)$$

where :

$B -$ quantity of b*urned* c*oal* $[kg/h]$

$D -$ quantity of *generated steam* $[kg/h]$

$i_s -$ s*uperheating* steam enthalpy $[kJ/kg]$

$i_c -$ w*ater* enthalpy $[kJ/kg]$

$\eta -$ b*oiler* d*rum* efficiency $[\%]$

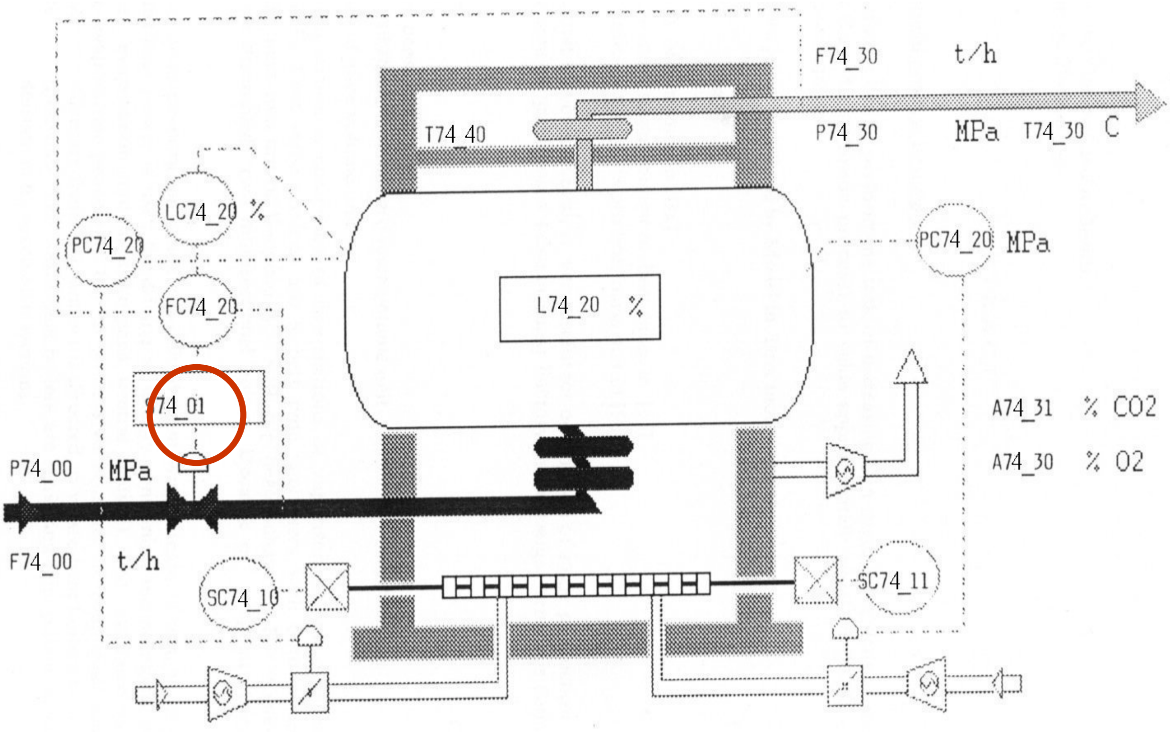


Fig.6. The diagram of the fourth steam boiler at the boiler house of sugar factory CUKROWNIA LUBLIN S.A.. LC74_20 - actuator in the control loop of water level in boiler drum.

Table 2. Specifications of the steam boiler OSR 32/25x400.

Item	Parameter	Value	Units
1	Normal capacity	25 (30)	t/h
2	Maximal capacity	32 (40)	t/h
3	Working pressure	25	at
4	Pressure behind super-heater	23	at
5	Superheated steam temperature	400	°C
6	Supply water temperature	105	°C
7	Drum boiler water capacity	25	m3
8	Grate surface	28,8	m2
9	Fuel (coal) consumption (W=5400kcal/kg) *)	3860-5080	kg/h
10	CO2 content behind boiler	11,5	%
11	Quantity of fumes behind boiler *)	630-810	Nm3/min
12	Temperature of fumes behind boiler *)	180-190	°C
13	Necessary draught behind boiler *)	50-60	Mm H2O
14	Boiler efficiency *)	80-78	%

*) in the cases of normal and maximal capacity, appropriate.

5. LIST OF PROCESS VARIABLES ACQUISED FOR DAMADICS PURPOSES

To get the list of process variables, please refer to:

http://diag.mchtr.pw.edu.pl/damadics

'Benchmark / Real Data Benchmark' Section, Data File Description.

6. REFERENCES

1. Bartys M.: *Specification of the actuators intended to use for benchmark definition*, for internal use of DAMADICS participants.
2. Lekawski W.: *Modernization of heat economy of sugar factory-in Polish*, STC, Warsaw, 1986.
3. Frank P.M.: *Fault Diagnosis in Dynamic Systems Using Analytical and Knowledge -based Redundancy - A Survey and Some New Results,* Automatica, Vol. 26, pp. 459-474, 1990.
4. Rakowski J.: *Automation of the heat-power equipment -in Polish,* WNT, Warsaw, 1976.
5. Withers R, et all: H*eat economy of sugar factory*. XIX Technical Conference BSC, Folkenstone, 1968.
6. Zagrodzki S.: *Heat economy of sugar factory-in Polish,* WNT, Warsaw, 1979.