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INDUSTRIAL WATER USAGE NETWORKS DESIGN PROCEDURE

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The paper addresses some important results as to optimal design of water usage networks. The aim was to minimize freshwater consumption by water re-use at minimum total flow-rate of water streams among processes and small number of process interconnections. The design approach was based on mixed-integer nonlinear multi-objective programming problem of superstructure optimization. The superstructure includes all possible structures and consists of mass balances of mixers, splitters, water users and partial treatment processes. The general solution algorithm of optimization was outlined. The optimal network design procedure is described. The examples presented show that the approach is robust technique for the synthesis of water usage networks.

***Keywords**: water usage network, design, wastewater, optimization, mathematical programming model.*

Wastewater Reduction via Process Integration

The current philosophy of environmental protection in industry is to eliminate or to reduce wastes "at heart" of technology (in contrast to traditional end-of-pipe processing). There are several ways to achieve this goal, for example:

- to use another ("environment friendly") technology;
- to apply new processes (e.g. to use apparatus of high performance, to replace water cooling with air-cooling)

Meanwhile, the application of these means is both expensive and time-consuming. The easiest (and relatively cheap) way to deal with wastes in chemical and allied industries is to integrate processes and apparatus. In case of "grassroot" design the integration costs almost nothing. In case of "revamp" (retrofit) scenario the process optimization by integration is also relatively low-cost. The major financial placements are due to modification of the structure of existing system (e.g. new pipes routing). Also, some parameters shall be changed such as pumps rate.

There are two general strategies of optimal synthesis of total integrated plants:

1. "Hierarchical" (insight-based) approach [1-3].
2. "Simultaneous" (superstructure) approach [4-6].

The "simultaneous" approach provides systematic framework for designing optimal plant while the "hierarchical" approach lacks generality and is not fully systematic. Unfortunately, practical application of the simultaneous strategy is quite difficult at present [7] since there is no effective optimization technique that is able to solve huge optimization problems (nonlinear programming problem or mixed-integer nonlinear programming problem). Furthermore, it seems uncertain whether fully automated method such as simultaneous one is flexible enough to manage with the realworld industrial cases.

The existing simultaneous process integration approaches are able to design some subsystems with the help of systematic procedures. Such subsystems are as follows: heat exchanger networks (HENs), mass exchangers networks (MENs), water networks (WNs), utility subsystems, distillation trains and so on – see e.g. [8-10]. In this paper we will concentrate upon water networks.

Chemical and allied industries are major water consumers. Through stringent environmental protection standards the use of water in industrial processes is going to be more expensive. Consequently, the problem of reducing freshwater usage becomes of vital importance.

The problem of minimizing water usage by process integration is termed "water network design". The water network consists of water using processes such as extraction, distillation, filtration, cooling and steam system, and water treatment processes. Traditionally, such network has the parallel structure where freshwater is fed to water using processes and, then, sent to central treatment station. Such parallel structure with central water treatment station consumes a lot of freshwater and also accounts for the high price of water treatment. By including water reuse and redistributing water treatment operations we can reach even zero water discharge.

Water networks design procedure: the mathematical apparatus

The original mathematical optimization problem definitions were proposed in [5, 11], as well as in [12-17], and others. All these applications contain superstructure-based optimization models of the water usage network. Fig. 1 is given here to illustrate the superstructure, which includes the water usage process and the process of partial water treatment.

Available models are different. They differ from each other by the type of optimization problem (for example, the presence or absence of integer variables), as well as by the type of goal functions. For instance, most models presented [12-14] do not take into account water losses, and several sources of fresh water.

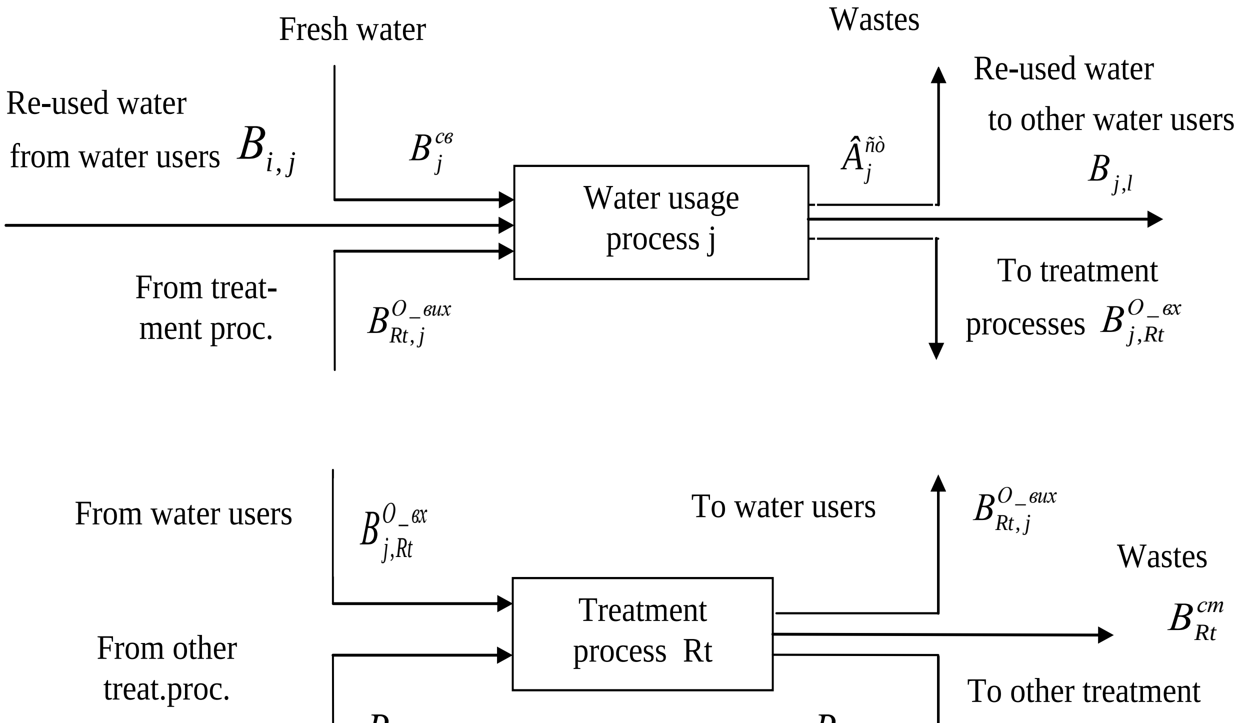

Fig. 1. The section of the superstructure for water usage network design.

An effective model for water usage networks design [12] is suitable for designing water networks with partial treatment of water flows, taking into account the mutual influence between water network units. Minimum fresh water consumption, minimum waste water and minimum pollutant load can be achieved. However, there are some disadvantages of this model:

- it doesn't include water treatment processes;

- it ignores water losses;
- there are no fixed flow-rates at the inlet of water users;
- several sources of fresh water are not included.

For future reference we decided to apply an optimization model which is the combination of the main mathematical apparatus from [5, 11] (proposed by the current authors earlier) and above-mentioned mathematical tools [12].

The task of optimization for the synthesis of water usage networks includes several objective functions. The most common performance index for water usage networks applied in the literature is cost of fresh water consumed in the network (1). In order to account for operation and investment cost we also consider minimization of total streams flow-rates of “contaminated” water in interconnections with water using processes (2). Minimization of mass load of contaminant for the treatment processes (3) and number of interconnections (4) are the next objectives.

$$Min \quad \sum_{j \in P} B^{CB}_{d,j} \tag{1}$$

where: $B^{CB}_{d,j}$ is flow-rate of fresh water at the inlet of the process *j* from the freshwater source *d*. One should notice that in case of a single fresh water source (as it shown in (1)) the goal function is simply the usage of fresh water.

$$Min \quad \sum_{Rt \in O} (\lambda_{Rt} \cdot \sum_{j \in \Pi} B^{O\_\text{вих}}_{Rt,j}). \tag{2}$$

where: λ_{Rt} *is* unit cost of water treatment (weighting factor for the treatment process *Rt*);
$B^{\hat{I}\_\hat{a}\grave{e}\tilde{o}}_{Rt,j}$ is water flow-rate from to the treatment process *Rt* water user *j*.

$$Min \quad \sum_{Rt \in O} (\sum_{j \in \Pi} B^{O\_\text{вих}}_{Rt,j} \cdot \sum ((K^{Bx}_{Rt,s} - K^{Bux}_{Rt,s}) \cdot \lambda_{Rt,s}. \tag{3}$$

where: $\lambda_{Rt,s}$ is weighting factor for the contaminant *s* in treatment process *Rt* (the value of weighting factor is determined by influence of the contaminant on capital costs and operating costs), $\sum_{s \in K} \lambda_{Rt,s} = 1$; $K^{Bx,a}_{Rt,s}$ is limiting concentration of contaminant *s* at the inlet of treatment process *Rt*; $K^{Bux,a}_{Rt,s}$ is limiting concentration of contaminant *s* at the outlet of treatment process *Rt*.

$$Min \quad \sum_{i \in \Pi} \sum_{j \in \Pi} y_{i,j} + \sum_{Rt \in O} \sum_{j \in \Pi} y^{O\_\text{вих}}_{Rt,j} + \sum_{j \in \Pi} \sum_{Rt \in O} y^{O\_\text{вх}}_{j,Rt} + \sum_{Rm \in O} \sum_{Rt \in O} y^{O}_{Rm,Rt} + \sum_{j \in \Pi} y^{\text{ст}}_{j} + \sum_{Rt \in O} y^{O\_\text{ст}}_{Rt} \tag{4}$$

where: $y_{i,j}$ is current value of the water flow-rate from the water user *i* to the water user *j*; $y^{O\_\text{вх}}_{j,Rt}$ is current value of the water flow-rate from the water user *j* to treatment process *Rt*; $y^{O\_\text{вих}}_{Rt,j}$ is current value of the water flow-rate from treatment process *Rt* to the water user *j*; $y^{O}{}_{Rm,Rt}$ is current value of the water flow-rate from treatment process *Rm* to treatment process *Rt*.

Optimization problem constraints:

Process water streams mass balance:

$$\forall j: \quad \sum_{d\in Д} B^{св}_{d,j} + \sum_{\substack{i\in П \\ i\neq j}} B_{i,j} + \sum_{Rt\in O} B^{O\_вих}_{Rt,j} = B^{ст}_{j} + \sum_{\substack{k\in П \\ k\neq j}} B_{j,k} + \sum_{Rt\in O} B^{O\_вх}_{j,Rt} + B^{Вт}_{j}, \tag{5}$$

where: $B^{ст}_{j}$ is flow-rate of wastewater at the outlet of water user *j*; $B^{св}_{j}$ is flow-rate of fresh water at the inlet of water user *j*; $B_{j,l}$ is flow-rate of wastewater from the outlet of water user *j* to the inlet of water user *l*; $B^{O\_вх}_{j,Rt}$ is flow-rate of wastewater from the outlet of water user *j* to the treatment process *Rt*; $B^{O\_вих}_{Rt,j}$ is flow-rate of partially treated wastewater from the outlet of treatment process *Rt* to the outlet of water user *j*.

Water usage: balance of contaminants:

$$\forall j,s: \quad \sum_{\substack{d\in Д \\ i\neq j}} (B^{св}_{d,j}\cdot K^{св}_{d,s}) + \sum_{i\in П} (B_{i,j}\cdot K^{Вих}_{i,s}) + \sum_{Rt\in O} B^{O\_вих}_{Rt,j}\cdot K^{Вих}_{Rt,s} = (\sum_{\substack{d\in Д \\ k\neq j}} B^{св}_{d,j} + \sum_{i\in П} B_{i,j} + \sum_{Rt\in O} B^{O\_вих}_{Rt,j})\cdot K^{Вх}_{j,s} \tag{6}$$

$$\forall j,s: (\sum_{d\in Д} B^{св}_{d,j} + \sum_{\substack{i\in П \\ i\neq j}} B_{i,j} + \sum_{Rt\in O} B^{O\_вих}_{Rt,j})\cdot K^{Вх}_{j,s} + M_{j,s} = (\sum_{d\in Д} B^{св}_{d,j} + \sum_{\substack{i\in П \\ i\neq j}} B_{i,j} + \sum_{Rt\in O} B^{O\_вих}_{Rt,j})\cdot K^{Вих}_{j,s}. \tag{7}$$

Water usage: contaminants limiting conditions:

$$\forall j,s: K^{Вх}_{j,s} \leq K^{Вх,Макс}_{j,s}, \tag{8}$$

$$\forall j,s: \; K^{Вих}_{j,s} \leq K^{Вих,Макс}_{j,s}. \tag{9}$$

Treated water streams mass balance:

$$\forall Rt: \quad \sum_{j\in П} B^{O\_вх}_{j,Rt} + \sum_{\substack{Rm\in O \\ Rt\neq Rm}} B_{Rm,Rt} = \sum_{j\in П} B^{O\_вих}_{Rt,j} + \sum_{\substack{Rn\in O \\ Rt\neq Rn}} B_{Rt,Rn} + B^{ст}_{Rt}. \tag{10}$$

Water: balance of contaminants:

$$\forall Rt,s: \quad \sum_{j\in П} B^{O\_вх}_{j,Rt}\cdot K^{Вих}_{j,s} + \sum_{\substack{Rm\in O \\ Rt\neq Rm}} B_{Rm,Rt}\cdot K^{Вих}_{Rm,s} = (\sum_{j\in П} B^{O\_вх}_{j,Rt} + \sum_{\substack{Rm\in O \\ Rt\neq Rm}} B_{Rm,Rt})\cdot K^{Вх}_{Rt,s}. \tag{11}$$

$$\forall s: \quad \sum_{j\in П} B^{ст}_{j}\cdot K^{Вих}_{j,s} + \sum_{Rt\in O} B^{ст}_{Rt}\cdot K^{Вих}_{Rt,s} = (\sum_{j\in П} B^{ст}_{j} + \sum_{Rt\in O} B^{ст}_{Rt})\cdot K^{ст}_{s} \tag{12}$$

Modeling treatment processes performance:

$$\forall Rt,s: \qquad К_{Rt,s}^{Вих} = К_{Rt0,s}^{Вих}, \tag{13}$$

or

$$\forall Rt,s: \qquad ВВ_{Rt,s} = \frac{К_{Rt,s}^{Вх} - К_{Rt,s}^{Вих}}{К_{Rt,s}^{Вх}}, \tag{14}$$

$$\forall Rt,s: \qquad ВВ_{Rt,s} = в_{Rt0,s}, \tag{15}$$

$$\forall Rt,s: \qquad К_{Rt,s}^{Вих} \le к_{Rt,s}^{Вих,а}, \tag{16}$$

$$\forall Rt,s: \qquad К_{Rt,s}^{Вх} \le к_{Rt,s}^{Вх,а}. \tag{17}$$

$$\forall s: \qquad К_{Rt,s}^{Вх} = К_{Rt,s}^{Вх,опт}, \tag{18}$$

where: $К_s^{ст}$ is concentration of contaminant *s* in the wastewater; $К_s^{ст\_Макс}$ is guideline value of contaminant *s* concentration in the wastewater; $К_{j,s}^{Вх}$ is concentration of contaminant *s* at the inlet of water user *j*; $К_{j,s}^{Вих}$ is concentration of contaminant *s* at the outlet of water user *j*; $К_{j,s}^{Вх,Max}$ is guideline value of contaminant *s* concentration at the inlet of water user *j;* $К_{j,s}^{Вих,Max}$ is guideline value of contaminant *s* concentration at the outlet of water user *j*; $К_{Rt,s}^{Вх}$ is concentration of contaminant *s* at the inlet of treatment process *Rt*; $К_{Rt,s}^{Вих}$ is concentration of contaminant *s* at the outlet of treatment process *Rt*; $К_{Rt,s}^{Вх,опт}$ is optimal concentration of contaminant *s* at the inlet of treatment process *Rt*; $К_{Rt0,s}^{Вих}$ is predefined value of contaminant *s* concentration at the outlet of treatment process *Rt*; $В_{i,j}$ is flow-rate of wastewater from the outlet of water user *i* to the inlet of water user *j*; $В_{Rm,Rt}$ is flow-rate of partially treated water from the outlet of water treatment process *Rm* to the inlet of water treatment process *Rt*; $В_{Rt}^{ст}$ is flow-rate of wastewater at the outlet of water treatment process *Rt*; $М_{j,s}$ is mass load of contaminant *s* at the outlet of water treatment process *Rt*; $ВВ_{Rt}$ is guideline value of remove ratio of contaminant *s* (for the treatment process *Rt*); $вв_{Rt,s}$ is current value of remove ratio of contaminant *s* (for the treatment process *Rt*);

Additional constraints:

$$\forall j: \quad \sum_{d \in Д} В_{d,j}^{св} + \sum_{i \in П} В_{i,j} + \sum_{Rt \in О} В_{Rt,j}^{О\_вих} = В_j^{Вит}, i \ne j \tag{19}$$

$$\forall j: \quad B_j^{Вит} \le B_j^{Вит\_Макс}, \tag{20}$$

$$\forall j: \quad B_j^{Вит} \ge B_j^{Вит\_Мін}. \tag{21}$$

$$\forall d: \quad \sum_{j \in П} B_{d,j}^{св} - B_d^{Макс} = 0. \tag{22}$$

$$\begin{aligned} \forall Rt: &\quad B_{Rt}^{ст} - y_{Rt}^{O\_ст} \cdot U \le 0, \;\; Rt \in O, \\ \forall j: &\quad B_j^{ст} - y_j^{ст} \cdot U \le 0, \quad j \in П. \end{aligned} \tag{23}$$

where: U is limiting value of water re-use flow-rate: $B_j^{Втр}$ is water losses in water usage process *j*; $B_j^{Вит}$ is flow-rate of fresh water at the inlet of water user *j*; $B_j^{Вит\_МАКС}$ is limiting (maximal) flow-rate of fresh water at the inlet of water user *j*; $B_j^{Вит\_МІН}$ is limiting (minimal) flow-rate of fresh water at the inlet of water user *j*; $B_d^{МАКС}$ is volume of water supply for freshwater source *d*;

Having found the solution to this problem, we can obtain the optimal structure of the water usage network. However, it is apparent that in order to effectively solve such a complex optimization problem special methods of solution are required.

Water networks design procedure: the choice of means of implementation

Despite the successful performance in water network design methods there are still problems with their industrial applications. This is due to the fact that existing approaches are aimed at designing the network for fixed (nominal point) data. However, the data they require are highly uncertain in industrial practice. Hence, the network, which is considered optimal for nominal point and current cost parameters, may be expensive or difficult to control and operate under varying conditions in industry. Previously the three-stage procedure to circumvent the problems described above [18] was presented:

1. data preparation by statistical analysis.
2. design of water network using existing approaches, and finally;
3. networks evaluation.

In this contribution we concentrated on the step 2.

The goal functions (1) - (4) coupled with constraints (5) - (23) represents a large mixed-integer nonlinear multi-objective programming problem. In order to solve this optimization problem, the sequential approach (concessions method) was used. The first step is to optimize the fresh water consumption. On the second step (based on the results of the first step), the amount of partially treated water is minimized. In the third step, the pollutant's load on the treatment processes is minimized (per feedback of previous steps).

Calculations were made in MS Excel Solver software.

Case studies

To date we solved the water network synthesis problem for several data sets from the literature as well as for practical case studies. A few case studies of water networks optimization are provided below.

Case Study 1. The pulp-and-paper industry water usage network.

Limiting technological data are presented in table 1. Note that this example considers only one contaminant – chemical oxygen demand.

The possible structure of water network corresponding to the results of the design procedure is presented in fig. 2

Table 1. Water usage units (limiting data)

#	Process	Mass load kg/h	C_{in}, mg O_2/ dm^3	C_{out}, mg O_2/ dm^3	Freshwater flow-rate, m^3/h
1	Pulping	24800,0	500	5000	5511,1
2	Bleach wash	50,0	100	400	166,7
3	Papermaking machine (I)	-18225,0	5000	500	4050,0
4	Papermaking machine (II)	-6480,0	5000	200	1350,0
5	Fiber washing	3,3	20	100	41,6
6	Blanket washing	21,7	100	500	54,2
7	Drum washing	37,5	300	600	125,0
8	Mercerization	10,0	100	220	83,3
9	Degumming	4,8	200	2500	2,1
10	Desizing	35,4	300	3700	10,4
	Total				11394,4

In the optimized network the amount of wastewater has decreased by 56.18%.

Case Study 2. The pharmaceutical industry water usage network.

Technological input data are presented in tables 2-4. There are sixteen water usage units and four groups of contaminants in the system (table 2).

Table 3. Freshwater source data

#	Name of source	Maximum concentrations of contaminants			
		total suspended solids, mg/dm^3	general hardness, mg-eq/m^3	chemical oxygen demand, mg O_2/dm^3	salts, mg/dm^3
1	Tap water	1,40	4,10	6,40	167,93

Limit values of concentration of contaminants were determined from mass balances or by observation. Instead of reuse costs proportional values (distances between water units) are used (table 4).

Table 2. Water usage units (limiting data)

#	Water usage unit	Freshwater flow-rate, m^3/h	Water losses, m^3/h	Maximum inlet concentration				Maximum outlet concentration			
				total suspended solids, mg/dm^3	general hardness, $mg\text{-}eq/m^3$	chemical oxygen demand,	salts, mg/dm^3	total suspended solids, mg/dm^3	general hardness, $mg\text{-}eq/m^3$	chemical oxygen demand, mg O_2/ dm^3	salts, mg/dm^3
1	Heat exchanger	20,83	1,67	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
2	Heat exchanger	20,83	1,67	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
3	Heat exchanger	20,83	1,67	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
4	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
5	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
6	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
7	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
8	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
9	Heat exchanger	15,83	1,27	23,6	4,50	55,0	900,0	30,0	5,00	70,0	1200,0
10	Water preparation (distillation) unit	31,50	6,30	1,45	4,100	6,41	168,0	1,5	5,95	7,53	188,0
11	Chemical “A” bottles washing machines	27,36	2,00	1,48	4,185	7,38	170,0	19,62	5,66	8,30	175,28
12		27,36	2,00	1,48	4,185	7,38	170,0	19,62	5,66	8,30	175,28
13		27,36	2,00	1,48	4,185	7,38	170,0	19,62	5,66	8,30	175,28
14	Chemical “B” bottles washing machines	21,96	1,00	1,48	4,185	7,38	170,0	20,67	5,20	8,36	171,50
15		21,96	1,00	1,48	4,185	7,38	170,0	20,67	5,20	8,36	171,50
16	Steam-boiler (with ion-exchange filter)	112,5	112,5	1,40	4,15	6,41	167,93	-	-	-	-

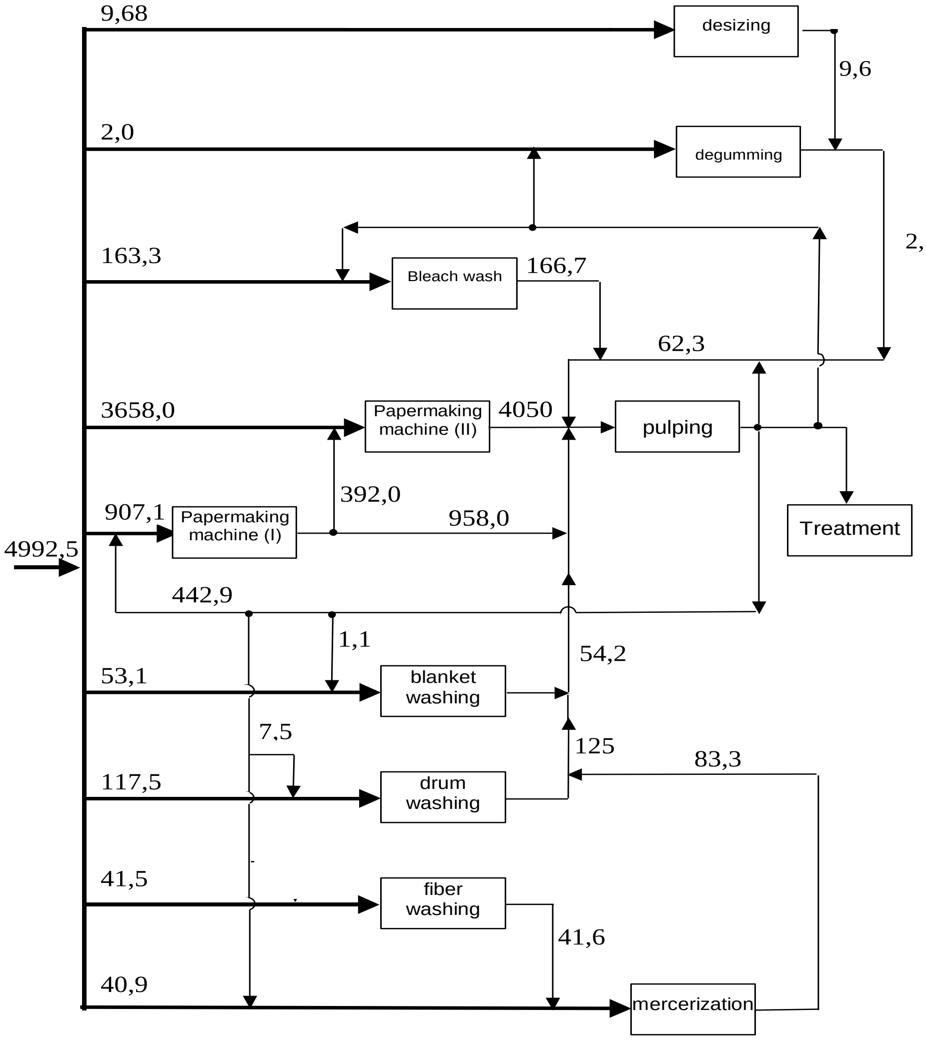

Fig. 2. Possible structure of water network of pulp and paper plant

Table 4. Distances between water usage units, m

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	20	23	26	18	20	100	17,4	16,3	15	40,5	38	36	34	32,5	30
2		0	3	6	20	21,5	120	37,2	36,2	35	55	53	52	50	52,5	50
3			0	3	23	24,5	123	40,4	39,2	38	58	56	55	53	55,5	53
4				0	26	27,5	126	43,4	42,2	41	61	59	58	56	58,5	56
5					0	2	118	20	19	18	38	36	35	32	34	32
6						0	120	19	18	18	35	32	32	32	35	34
7							0	119	120	119	134	135	135	138	138	140
8								0	1,2	2,4	15	15	18	20	22	24
9									0	1,2	17	15	17	18	20	22
10										0	20	18	17	15	16	17
11											0	2,5	5	7,5	10	12,5
12												0	2,5	5	7,5	10
13													0	2,5	5	7,5
14														0	2,5	5
15															0	2,5
16																0

The possible structure of water network of the pharmaceutical plant is presented in fig. 3. To increase the reliability of network in this case the re-used water tanks were applied.

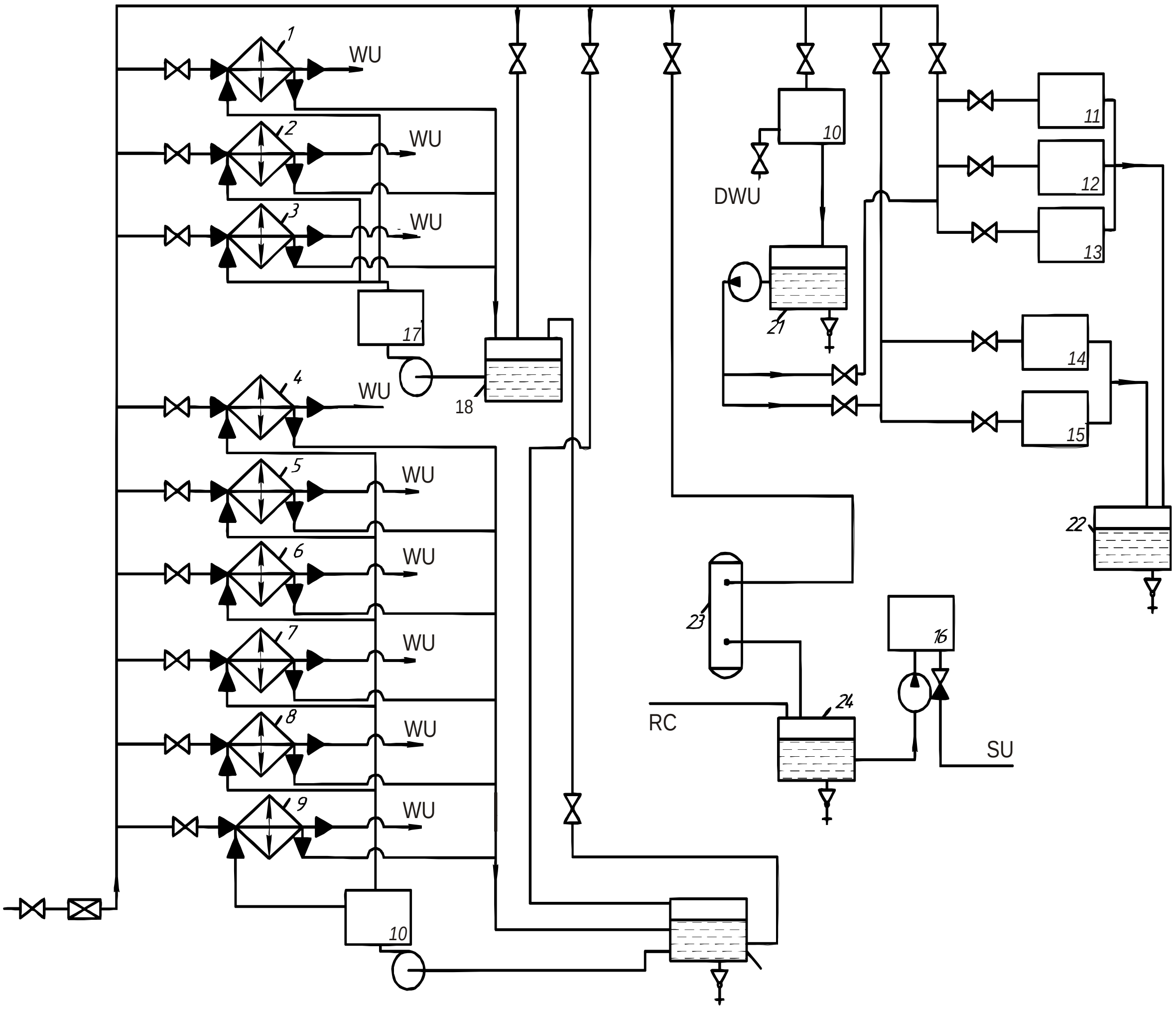

Fig. 3. Possible structure of water network of pharmaceutical plant:
1–9 – heat exchangers; 10 – Water preparation (distillation) unit; 11–13 – Chemical "A" bottles washing machines; 14, 15 – Chemical "B" bottles washing machines; 16 –Steam-boiler; 17, 19 – Heaters; 18, 20–22 – Re-used water tank; 23 – ion-exchange filter; 24 – Condensate tank; RC – return the condensate from steam users; SU –to steam users; WU – to water users; DWU – to distilled water users.

In the optimized network the amount of wastewater has decreased from 10835 m^3/day to 8509 m^3/day (21%.)

Summary

Simultaneous procedure for designing optimal water usage network has been developed above. The present authors strongly believe that optimization-based methods of designing usage networks together with computer software are very promising. Appearingly, simultaneous approaches will not be fully automated in order to allow the designer to have control over the process being designed. Also, they need some sequential strategy in generally simultaneous framework. Such the inference can be drawn from analysis of suggested current approaches and industrial needs. Further research should combine different procedures to create a common one, which will consider the interaction of subsystems (such as HENs, MENs, WNs and so on) in the integrated total chemical site.

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ПРОЦЕДУРА ПРОЕКТУВАННЯ СХЕМ ПРОМИСЛОВОГО ВОДОСПОЖИВАННЯ.

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У роботі розглядаються деякі результати досліджень щодо створення процедур оптимального проектування промислових схем водоспоживання відповідно до парадигми «інтегрування процесів». Мета досліджень – досягнення обґрунтованого мінімуму обсягів споживання свіжої води технологічною схемою шляхом впровадження повторно-бататоразового водоспоживання за умов оптимальної кількості технологічних взаємозв’язків між процесами водоспоживання та водоочищення.

Проаналізовано доцільність використання у випадку підсистем водоспоживання існуючих «ієрархічних» та «послідовних» концепцій проектування хіміко-технологічних систем на принципах інтегрування процесів. За результатами аналізу обрано підхід, заснований на вирішенні математичної задачі оптимізації (вказаний “одночасний”, або ж “надструкурний” підхід носить у вітчизняній літературі також назву методу структурних параметрів).

У роботі представлено загальний алгоритм вирішення задачі оптимізації, який включає етапи попереднього аналізу та підготування вихідних даних, синтезу структури схеми водоспоживання, підготування до промислової імплементації. Описано розроблену на основі вказаного алгоритму процедуру оптимального проектування схем водоспоживання.

У межах задач дослідження, у роботі обґрунтовано вибір математичного апарату. Пропонована у роботі процедура проектування схем промислового водоспоживання базується на вирішенні задачі змішано-цілочисельного умовного нелінійного багатоцільового програмування, складеної на основі узагальненої схеми системи водоспоживання (“надструктури водоспоживання”). Узагальнена схема включає всі можливі варіанти структури схеми водоспоживання і виходить із матеріальних балансів складових частин технологічної схеми водоспоживання: змішувачів та дільників потоків, процесів водоспоживання та процесів часткового очищення води.

Наведені характерні приклади оптимізації систем водоспоживання покликані продемонструвати ефективність пропонованої обчислювальної процедури для оптимального синтезу схем водоспоживання.

***Ключові слова**: схема водоспоживання, проектування, стічні води, оптимізація, задача математичного програмування.*

ПРОЦЕДУРА ПРОЕКТИРОВАНИЯ СХЕМ ПРОМЫШЛЕННОГО ВОДОПОТРЕБЛЕНИЯ.

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В работе рассматриваются некоторые результаты исследований относительно оптимального проектирования схем водопотребления. Цель исследований – минимизация потребления свежей воды путем внедрения повторно-многократного водопотребления в условиях оптимального количества технологических взаимосвязей между процессами водопотребления и водоочистки. Подход к проектированию основан на решении математической задачи смешанно-целочисленного нелинейного многоцелевого программирования. Задача оптимизации базируется на обобщенной схеме системы водопотребления. Обобщенная схема включает все возможные варианты структуры и включает и исходит из материальных балансов смесителей и делителей потоков, водопотребителей и процессов частичной очистки воды. Представлен общий алгоритм решения задачи оптимизации. Описана процедура оптимального проектирования схем водопотребления. Приведенные примеры показывают, что подход является эффективной техникой для оптимального синтеза схем водопотребления.

***Ключевые слова**: схема водопотребления, проектирование, сточные воды, оптимизация, задача математического программирования.*

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