Information model of the structure of the heat and power system of pulp and paper production and a systematic approach to its improvement

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Abstract. The stages of the system analysis of an industrial energy system with a complex structure are considered by the example of pulp and paper production. The software of the structural and thermodynamic stages of the analysis is presented. The results of thermodynamic calculations of the elements of the energy system by the optimal sequence are given. A variant of the system modernization using a heat pump is presented.

1 Introduction

Pulp production is one of the largest industrial consumers of thermal energy. Pulp and paper production is a complex structure with many elements that interact with each other and with the environment. The interaction of elements is often of a reverse nature, which leads to recycling and numerous iterations in the calculations of the system and in the selection of measures for the modernization of production [1 – 3].

To reduce the number of iterations in the calculation of the scheme, it is proposed to use the method of structural modeling and the development of an information model of production based on it. This approach simplifies the structure of multi-element production schemes and can be the basis for conducting thermodynamic calculations of the system. The structural modeling method formed the basis of the developed software [4 – 7], which can be used when conducting a system analysis of production and making decisions on the return of waste energy flows to the technological circuit.

2 Stage of structural analysis

The object is the heat technology scheme of pulp and paper production at JSC “Polygraphboard”, Balakhna (Russia), including 110 elements, 193 streams [7]. All elements and threads are represented as an oriented graph. The scheme is decomposed by weak links (flows that are not included in the closed contours of the scheme) into separate blocks. Let us dwell on one of the blocks selected as a result of decomposition (fragment - Figure 1). This unit is also the most energy-intensive sector of pulp and paper production. The stages of the program are considered (Figure 2, Figure 3). The scheme is represented as a matrix (Figure 2 (a)); the number in the matrix is the stream number. The matrix is multiplied according to the rules of Boolean algebra (Figure 2 (a)). At certain stages of the matrix multiplication, there are closed sequences – cycles (Figure 2 (b)). Next is the minimum number of streams, the conditional discontinuity of which will allow to carry out a sequential thermodynamic calculation of the circuit with a minimum of iterations (Figure 2 (c, d)), (Figure 2 (e, f)).

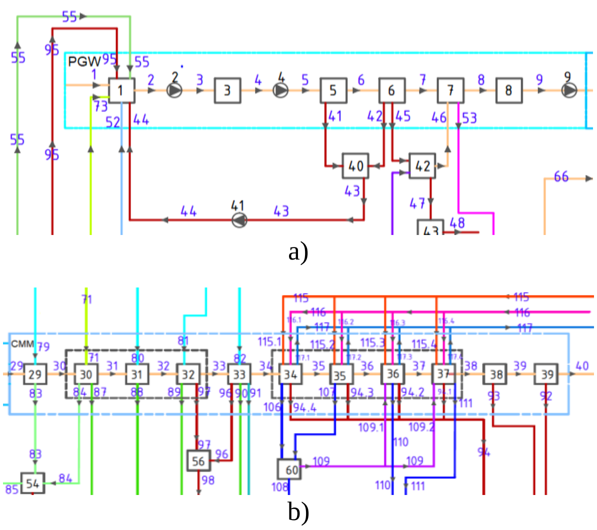

Fig. 1. Fragments of the section (a, b) of the information scheme of the block of the cardboard machine: PGW – pre-grinding workshop; CMM – cardboard making machine; numbers in squares - numbers of positions of system elements; the numbers on the arrows are the position numbers of the system streams.

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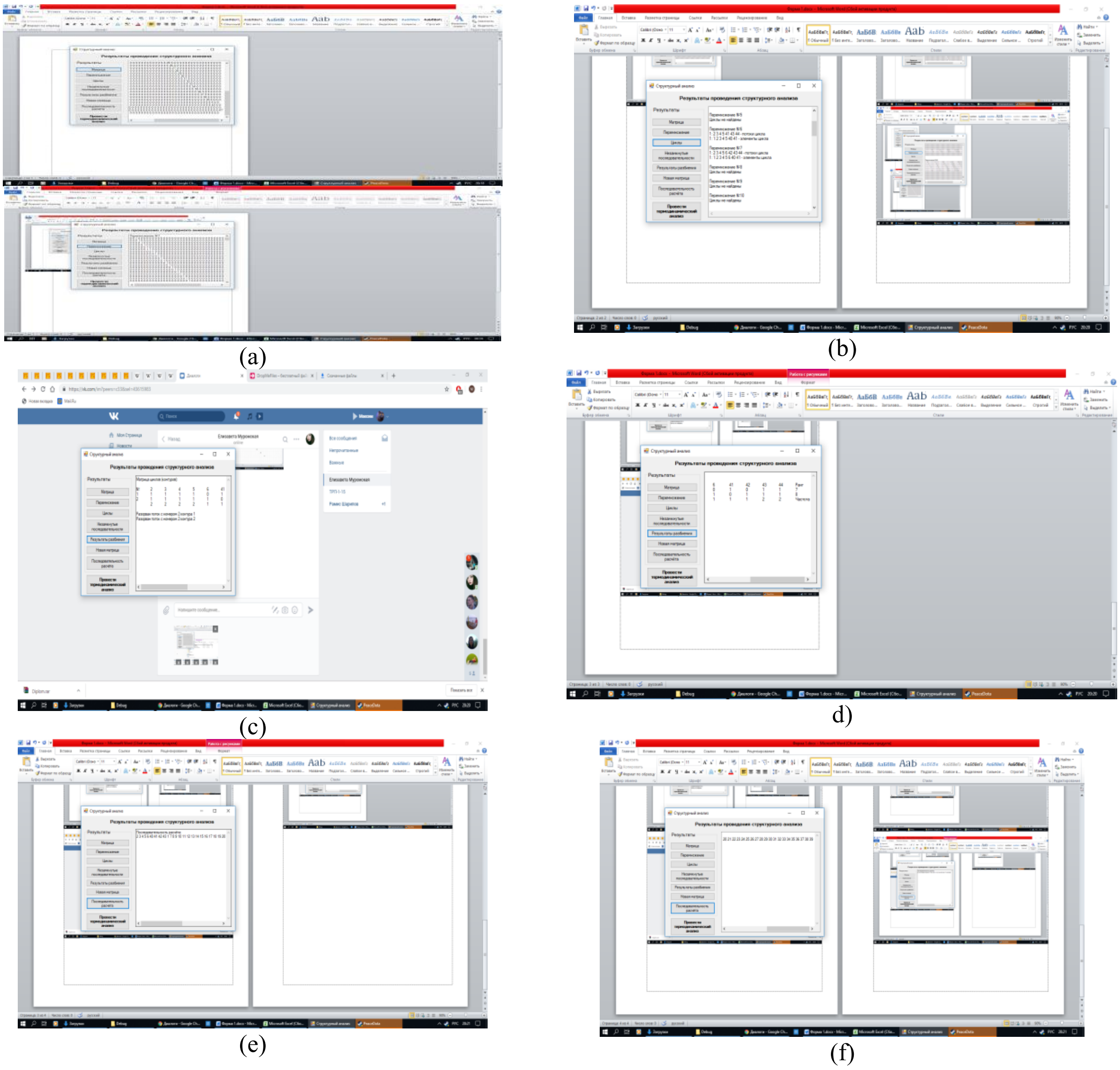


Fig. 2. Stages of the program for the structural analysis of complex schemes (a, b, c, d).

3 Stage thermodynamic analysis

The software provides for the possibility of carrying out thermodynamic calculations based on the found sequence and determining the efficiency of the apparatus (Figure 4). Let us enter the flow parameters when entering the scheme matrix at the structural analysis stage and entering formulas for the scheme elements (Figure 4 (a)). Also provides for the calculation of performance indicators of the elements of the system (Figure 4 (b)); explanation of symbols in the Figure 3 (b).

The obtained parameters of the flows of the block of the cardboard machine in the form of the initial data and the results of the thermodynamic calculation are presented in table 1. The values of thermal and exergic power are determined by temperature, flow rate, pressure for each flow. The greatest exergetic power among the outlets is at the condensate stream 113 and at the air stream 117.

Further, the possibility of returning the energy of these flows to this scheme is considered. For this purpose, a thermal and exergy calculation of the elements included in the block is carried out [8 - 11]. The results of the exergic calculation are shown in table 2.

From table 2 it is seen that for those devices in which there is no heat and mass transfer, the efficiency is high, therefore, there is no need to make their modernization. And at devices 33 - 37, the efficiency is much lower. Therefore, it is necessary to carry out the modernization of these devices, namely, to realize the return of the energy of the streams of the greatest exergy potential to these devices [12, 13].

4 Conclusions

Condensate flow 13 was previously used in the scheme under consideration in the system for collecting and returning condensate, therefore it is not considered in the

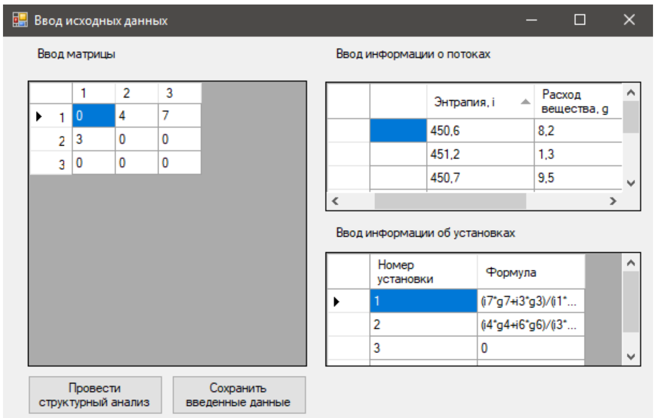
Структурный анализ	structural analysis
Результаты проведения структурного анализа	results of structural analysis
Матрица	matrix
Перемножение	multiplication
Циклы	cycles
Незамкнутые последовательности	open sequences
Результаты разбиения	split results
Новая матрица	new matrix
Последовательность расчёта	calculation sequence
Провести термодинамический анализ	apply thermodynamic analysis
Циклы не найдены	cycles not found
потоки цикла	streams of cycle
элементы цикла	elements of cycle
Матрица циклов (контуров):	matrix of cycles
Разорван поток с номером 2 контура 1	stream number 2 of circuit 1 is broken
Ранг	rank
Частота	frequency

a)

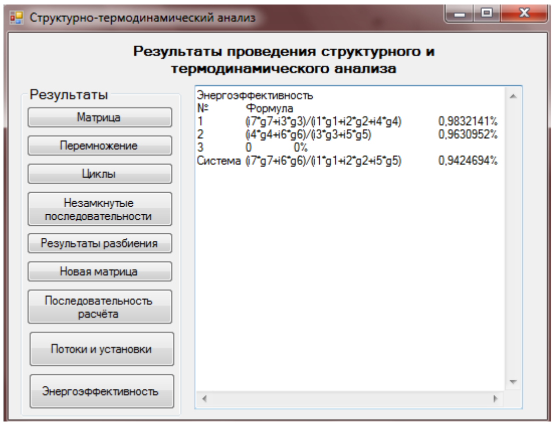
Ввод исходных данных	
Ввод матрицы	matrix input
Ввод информации о потоках	input streams information
Ввод информации об установках	input elements information
Провести структурный анализ	apply structural analysis
Сохранить введенные данные	save entered data
Потоки и установки	streams and elements
Энергоэффективность	energy efficiency
Результаты проведения структурного и термодинамического анализа	results of structural and thermodynamic analysis
Формула	formula
Номер установки	installation number
Система	system

b)

Fig. 3. Notation software: (a) - structural analysis; (b) - thermodynamic analysis.



a)



b)

Fig. 4. The work of the program during the thermodynamic analysis (a, b).

proposed return system. The circuit for returning the airflow 117 [14, 15] is shown in Figure 5.

It has been proposed to use a heat pump in the drying part of a cardboard machine for utilizing the heat flow of spent moist air 17 in order to bring the parameters of the spent moist air to the required parameters of heating dry air. Cold air enters the condenser of the heat pump 2, where it is heated to the required technology temperature of 110 °C and sent to the drying chamber 5. The air temperature in the drying chamber decreases and the

Table 1. The flow parameters of the board machine.

Stream name	№ stream	From the apparatus	Into the apparatus	Pressure P, MPa	Temperature T, °C	Outgo G, kg/s	Thermal power Q, kW	Exergy power E_T, kW
Warm air	116	-	34, 35, 36, 37	0.3	110	31.17	3440.13	987.64
Condensate	106	34	60	0.332	137.0	0.79	454.92	151.95
Condensate	107	35	60	0.332	137.0	0.79	454.92	151.95
Condensate	110	36	61	0.332	137.0	0.79	454.92	151.95
Condensate	111	37	61	0.332	137.0	0.79	454.92	151.95
Boiling pairs	109	60	36, 37	0.329	137.0	0.2	545.96	182.36
Condensate	108	60	62	0.332	137.0	1.39	795.03	265.56
Condensate	112	61	62	0.332	137.0	1.59	909.84	303.91
Condensate	113	62	63	0.332	137.0	2.97	1704.87	569.47
Steam	115	64	34, 35, 36, 37	0.345	138.4	3.17	8652.82	2909.85
Exhaust air	117	34, 35, 36, 37	-	0.3	74.0	31.17	2942.44	627.22

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Table 2. The results of exergic calculation of elements included in the block.

No. of flow at the entrance to the element - No. of flow at the exit from the unit	Exergic power flow, kW	Change of exergy power in the element, kW	Losses of exergy power in the element, kW	Exergetic efficiency, %
Headbox CMM 29				
29, 79 (input)	6132.71	149.51	149.51	97.56
30, 83 (output)	5983.20			
Pre-dehydration site 30				
30, 71 (input)	5073.28	217.96	217.95	95.70
31, 84, 87 (output)	4855.32			
Removal of water in the suction box 31				
31, 80 (input)	654.06	2.77	2.77	–
32, 88 (output)	651.28			
Water removal in gauch-shaft 32				
32, 81 (input)	438.29	54.57	54.57	87.54
33, 89, 97 (output)	383.72			
Dehydration and compaction in the press section of the CMM 33				
33, 82 (input)	556.00	229.96	229.96	58.64
34, 90, 91, 96 (output)	326.04			
Drying in the 1st cylinder group of the drying part 34				
115.1, 116.1 – 106, 117	2106.06 – 813.39	1292.67	492.53	61.89
34 – 35, 94.4	105.21 – 905.39	800.14		
Drying in the 2nd cylinder group of the drying part 35				
115.2, 116.2 – 107, 117.2	2106.06 – 813.39	1292.67	396.15	69.35
35 – 36, 94.3	216.18 – 1112.67	896.52		
Drying in the 3rd group of cylinders of the drying part 36				
115.3, 116.3, 109.1 - 110, 117.3	2282.50 – 1123.81	1158.69	469.47	59.48
36 – 37, 94.2	423.45 – 1112.67	689.21		
Drying in the 4th group of cylinders of the drying part 37				
115.4, 116.4, 109.2 – 111, 117.4	2282.5 – 1675.12	607.38	322.56	46.89
37 – 38, 94.1	423.45 – 708.27	284.81		
Surface Enhancement in Machine Calender and Peripheral Winding 38				
38 (input)	19.05	0.13	0.13	–
39, 93 (output)	18.92			
Longitudinal cutting machine 39				
39 (input)	18.66	7.06	7.06	–
40, 92 (output)	11.59			

moisture content rises due to heat and mass transfer. Moisture is removed from the product and this moisture is transferred to the air stream. Next, moist air with a temperature of 74 °C is sent to the evaporator of the heat pump 4, where it is cooled. Simultaneously with the cooling process, the precipitated moisture is removed. In the evaporator 4, the exhaust moist air acts as a source of thermal energy, the potential of which rises in the heat pump.

The results of the calculations showed that the heat of the outgoing air is sufficient to heat the air entering the drying unit.

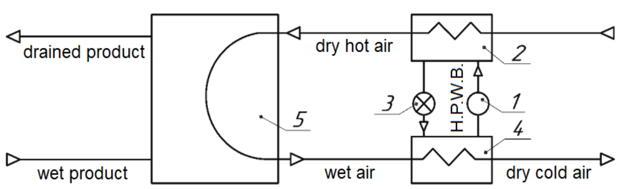

Fig. 5. Scheme of the return heat of the flow of exhaust air in the drying part of the cardboard machine: 1 – compressor; 2 – capacitor; 3 – throttle valve; 4 – evaporator; 5 – drying chamber; H.P.W.B. – heat pump working body.

Using the scheme with a heat pump, 6245.89 kW of additional thermal energy was obtained through the use of 2942.44 kW of wet flue gas energy. In the case of using a drying installation with a conventional air heater, an additional 3789.24 kW of energy would be consumed in the electric heater.

As a result of the use of the heat pump during the drying process, the exergic coefficient of system utilization [12] of the block under consideration increased from 49.5 % to 65.6 %.

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