

PAPER • OPEN ACCESS

Increasing the efficiency of energy use in the thermal scheme of a steam boiler house

To cite this article: R N Valiev *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **288** 012125

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Increasing the efficiency of energy use in the thermal scheme of a steam boiler house

R N Valiev¹, Sh G Ziganshin¹, A V Maryashev²

¹Kazan State Energy University, Kazan, Russia

²Povolzhsky State Technological University, Yoshkar-Ola, Russia
valievkgeu@yandex.ru

Annotation. This article discusses the issues of increasing the efficiency of energy use in the thermal scheme steamed boiler house. A positive effect is achieved by transforming the excess energy of water vapor into electricity and avoiding the use of steam at the stage of heating the raw water.

Description of the object and method of investigation

The thermal scheme of the steam boiler house is shown in Fig.1. The main elements of the thermal scheme are: steam boiler 1; deaerator 2; water treatment plant 12; pumps 4, 6, 7; network preheater 5; consumers of steam 13 and network water 14.

To determine the heat-and-power efficiency of the thermal scheme, a thermodynamic analysis is carried out, which consists of four parts: information part, heat part, exergic part and analytical part. In the information part, the processing of the initial information is carried out and the following data are determined: the structure of the circuit, the characteristics of the elements, and the parameters of the flows. In the heat part, the values of the heat flows at the input and output of the circuit elements are determined. In the exergic part, the values of the exergy flows at the input and output of the circuit elements are determined. In the analytical part, an analysis is carried out with an assessment of the heat and exergic efficiency of the circuit.

Balance calculations of the elements of the thermal scheme are carried out in a package of Microsoft Excel based on the principles of decomposition calculation and methods of structural analysis [1, 2]. The thermodynamic analysis is carried out according to the procedure [3, 4]. Exergy of the substance flow is determined by the formula in accordance with [5,6]:

$$E=H-H_0-T_0(S-S_0), \text{ kcal/h}$$

where H , H_0 , S , S_0 are flux enthalpies and entropies at the parameters of the substance flow and the environmental parameters, respectively (kcal/h); T_0 is the ambient temperature in the Kelvines, upon which it becomes impossible to heat exchange between the streams of matter in the circuit under consideration. The lowest temperature of the substance flow in the thermal scheme is $T_0 = 5^\circ\text{C}$. As the ambient pressure, we take the pressure $P_0 = 1$ bar.

The coefficient of heat flux is defined as the ratio E/Q [7].



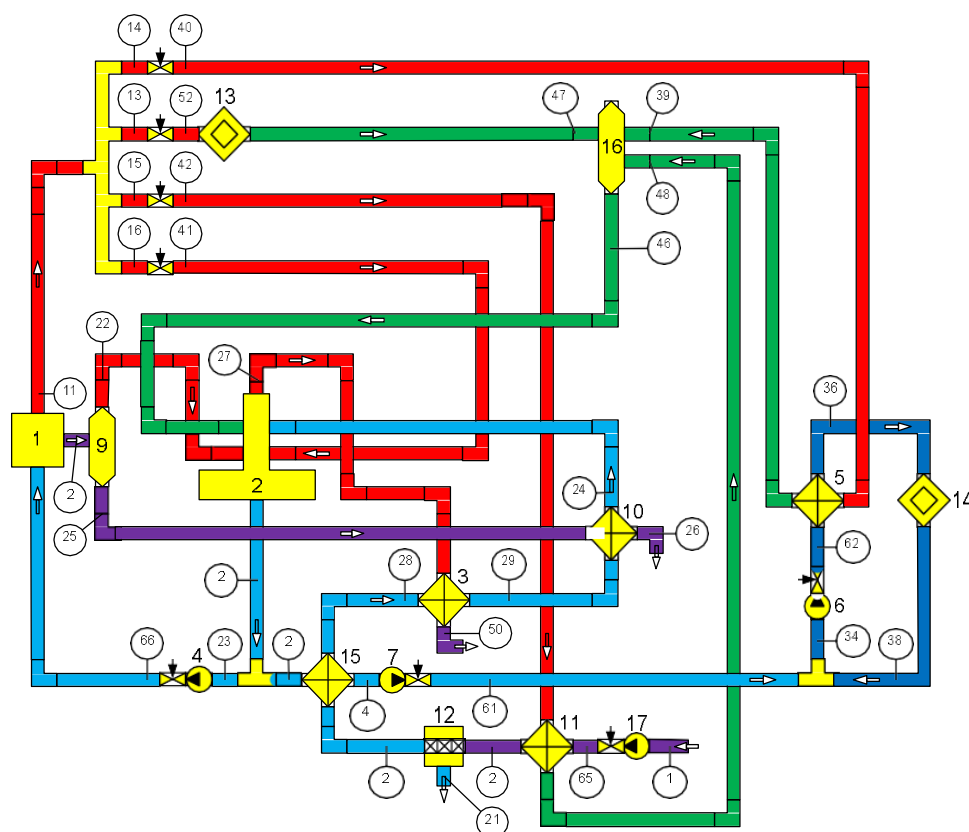


Fig.1. Thermal scheme of a steam boiler house.

Digital designations: 1 - steam boiler; 2 - atmospheric deaerator; 3 - vapor cooler; 4 – feed pump; 5 - preheater of network water; 6 - network pump; 7 - make-up pump; 8 - throttling device; 9 - continuous blowdown separator; 10 - blowdown waters cooler; 11 - preheater of raw water; 12 - water treatment plant; 13 - industrial consumers of steam; 14 - consumers of network water; 15 - deaerated water cooler; 16 - tank for collection condensate; 17 - raw water pump. The circles show the numbering of the flows (see Table 1).

Based on the results of the calculation, an information table is compiled, in which each element is represented as a node into which the flows of matter enter and exit. The results of the determination exergy of flows substances and the values of the coefficients of heat flow are given in Table 1.

Table 1. The results of the determination exergy of flows substances and the values of the coefficients of heat flow

Implemented processes	№ flow's	G , kg/h	t , °C	P , bar	H , kcal/h	S , kkal/°C/h	E , kcal/h	E/Q , % от Q
	2	3	4	5	6	7	8	9
Pressure increase in the pump 17	1	15679.8	5	5.9	78390	295.5	0.0	0.0
	65	15679.8	5.1	8	79965	301.3	0.0	0.0
Heating in the heat exchanger 11	65	15679.8	5.1	8	79965	301.3	0.0	0.0
	2	15679.8	35.1	7	550310	1896.0	26779.2	4.9
Cooling in the heat exchanger 11	42	800	175.7	7	532630	1293.0	173178.1	32.5
	48	800	77.8	6	62278	200.4	6732.7	10.8
Heating in the heat exchanger 15	3	15366.2	35.1	7	539310	1858.0	26272.1	4.9
	28	15366.2	49.7	6	763640	2567.0	53393.7	7.0
Cooling in the heat exchanger 15	7	6404.6	104.8	1.2	672840	2081.0	95579.0	14.2
	4	6404.6	70	1.2	448520	1461.0	43712.0	9.7
Heating in the heat exchanger 3	28	15366.2	49.7	6	763640	2567.0	53393.7	7.0
	29	15366.2	61.6	5	946310	3122.0	81690.5	8.6

Continuation of Table. 1

1	2	3	4	5	6	7	8	9
Cooling in the heat exchanger 3	27	311.7	104.8	1.2	199730	543.4	48659.7	24.4
	50	311.7	54.7	1.2	17052	56.9	1312.8	7.7
Heating in the heat exchanger 10	29	15366.2	61.6	5	946310	3122.0	81690.5	8.6
	24	15366.2	68.4	4	1051300	3432.0	100454.0	9.6
Cooling in the heat exchanger 10	25	2496	113.3	1.6	283760	867.2	43159.8	15.2
	26	2496	71.6	1.6	178720	580.7	71.6	10.0
	24	15366.2	68.4	4	1051300	3432.0	68.4	9.6
	22	419.9	113.3	1.6	270320	722.3	643.8	25.7
Processes in the deaerator 2	41	4686	157.9	1.6	3119900	8313.0	665.8	25.9
	46	83439.7	79.6	1.2	6650200	21340.0	79.7	11.1
	27	311.7	104.8	1.2	199730	543.4	640.8	24.4
	5	103600.1	104.8	1.2	10884000	33670.0	105.1	14.2
Pressure increase in the pump 4	23	97195.4	104.8	1.2	10211000	31590.0	105.1	14.2
	66	97195.4	105.4	17	10266000	31730.0	105.6	14.3
	66	97195.4	105.4	16	10266000	31730.0	105.6	14.3
	11	94279.6	195.2	14	62770000	145600.0	665.8	35.5
Processes in the steam boiler 1 $\eta = 92\%$	6	2915.9	195	15	579650	1590.0	198.8	23.8
	q_1				57699620			104.0
	q_2				3461977			29.3
	52	42683	175.7	7	28418000	68970.0	665.8	32.5
Condensation and cooling in the consumers of the heat 13	47	42683	80	5	3417400	10960.0	80.1	11.1
	47	38414.7	80	1.2	3075600	9866.0	80.1	11.1
	39	44225	79.4	1.2	3512300	11280.0	79.4	11.0
Processes in the tank for collection condensate 16	48	800	77.8	1.2	62278	200.4	77.8	10.8
	46	83439.7	79.6	1.2	6650200	21340.0	79.7	11.1
	62	320230	70.2	9	22494000	73230.0	70.2	9.8
Heating in the network preheater 5	36	320230	150	8	48426000	140800.0	151.2	19.3
Condensation and cooling in the network preheater 5	40	44225	175.7	7	29444000	71460.0	665.8	32.5
	39	44225	79.4	6	3512300	11280.0	79.4	11.0
Processes in the continuous blowdown expander 9	6	2915.9	195	15	579650	1590.0	198.8	23.8
	22	419.9	113.3	1.6	270320	722.3	643.8	25.7
	25	2496	113.3	1.6	283760	867.2	113.7	15.2
Pressure increase in the pump 7	4	6404.6	70	1.2	448520	1461.0	70.0	9.7
	61	6404.6	70.2	6	449590	1464.0	70.2	9.8
Pressure increase in the pump 6	34	320230	70	4	22427000	73040.0	70.0	9.8
	62	320230	70.2	10	22494000	73230.0	70.2	9.8
Cooling in the consumers of the heat 14	36	320230	150	7	48426000	140800.0	151.2	19.3
	38	320230	70	5	22426000	73040.0	70.0	9.8

Changes in the Q and E flows of matter in the elements are determined by subtracting the input stream from the output stream. For heat exchange equipment with heat transfer through the wall, the variation for each flow separately (conditional dividing into the cooled and heated streams) is taken into account. For the heat-exchange equipment of the mixing type (the deaerator, the tank for collection condensate, the continuous blowdown separator), the required operating mode is selected (isoentropic expansion, calculating the heat load by pressure and amount of evaporation, calculating the heat load and output flow parameters by input flow parameters), and changing Q and E is taken into account as the difference between the total values of all input and output streams. For pumps, the change in Q and E is determined by the difference between the values at the inlet and outlet. The electric power consumption for the pump drive (taking into account $\eta = 0.7$) is calculated separately using the standard formula for calculating the pump power [6].

Table 2 presents the results of determining the changes in Q and E of the substance flows as it passes through the main elements of the thermal circuit of the steam boiler house. The heat efficiency ($\Sigma Q_{\text{out}} / \Sigma Q_{\text{in}} \times 100$) and the exergy efficiency of the thermal scheme (see Table 2), taking into account the elements included in the review, are 79.36% and 42.81%, respectively. The total amount of electricity spent on creating pressure in pumps with $\eta = 70\%$ is 145.047 kW.

Table 2. Results of changes in Q and E of substance fluxes

Implemented processes	N ^o flow's	Q_{in} , kcal/h	Q_{out} , kcal/h	E_{in} , kcal/h	E_{out} , kcal/h	ΔQ , kcal/h	ΔE , kcal/h	N_{el} , kcal/h
1	2	3	4	5	6	7	8	9
Pressure increase in the pump 17	1	78390.0		0.0				
	65		79965.0		0.0	1575.0	0	-1575.55
Heating in the heat exchanger 11	65	79965.0		0.0				
	2		550310.0		26779.20	470345.0	26779.20	
Cooling in the heat exchanger 11	42	532630.0		173178.05				
	48		62278.0		6732.74	-470352.0	-166445.31	
Heating in the heat exchanger 15	3	539310.0		26272.06				
	28		763640.0		53393.71	224330.0	27121.65	
Cooling in the heat exchanger 15	7	672840.00		95578.99				
	4		448520.0		43711.99	-224320.0	-51867.00	
Heating in the heat exchanger 3	28	763640.00		53393.71				
	29		946310.0		81690.46	182670.0	28296.75	
Cooling in the heat exchanger 3	27	199730.00		48659.66				
	50		17052.0		1312.76	-182678.0	-47346.90	
Heating in the heat exchanger 10	29	946310.00		81690.46				
	24		1051300.0		100453.96	104990.00	18763.50	
Cooling in the heat exchanger 10	25	283760.00		43159.85				
	26		178720.0		17809.82	-105040.00	-25350.03	
	24	1051300.00		100453.96				
	22	270320.00		69515.13				
Processes in the deaerator 2	41	3119900.0		808787.13				
	46	6650200.0		734921.96		-7990.00	-120946.72	
	27		199730.0		48659.66			
	5		10884000.0		1544071.82			
Pressure increase in the pump 4	23	10211000.0		1448054.65				
	66		10266000.0		1464113.65	55000.00	16059.0	-54948.80
	66	10266000.0		1464113.65				
Processes in the steam boiler 1	11		62770000.0		22294458.8	53083650.0	20968451.0	
$\eta = 92\%$	6		579650.0		138105.90			
	q_1	57699619.6		60007604.35				
	q_2		3461977.17		1012660.24	-54237642.4	-58994944.1	
Condensation and cooling in the consumers of the heat 13	52	28418000.0		9244451.95				
	47		3417400.0		379333.45	-25000600.0	-8865118.50	
	47	3075600.0		340783.81				
Processes in the tank for collection condensate 16	39	3512300.0		385603.25				
	48	62278.0		6732.74		22.00	1802.16	
	46		6650200.0		734921.96			
Heating in the network preheater 5	62	22494000.0		2203532.75				
	36		48426000.0		9340937.25	25932000.0	7137404.50	
Condensation and cooling in the network preheater 5	40	29444000.0		9578236.25				
	39		3512300.0		385603.25	-25931700.0	-9192633.0	
	6	579650.0		138105.90				
Processes in the continuous blowdown expander 9	22		270320.0		69515.13	-25570.0	-25430.92	
	25		283760.0		43159.85			
Pressure increase in the pump 7	4	448520.0		43711.99				
	61		449590.0		43947.54	1070.0	235.55	-1073.91
Pressure increase in the pump 6	34	22427000.0		2189381.25				
	62		22494000.0		2203532.75	67000.0	14151.50	-67119.7
Cooling in the consumers of the heat 14	36	48426000.0		9340937.25				
	38		22426000.0		2188381.25	-26000000.0	-7152556.0	
Total		252252263	200189022	98626899	42223287	-52063240	-56403612	-124718
Efficiency, %		by heat: 79.36		by exergy: 42.81		by electricity: 70		

The results of the study and their discussion

To achieve the intended results, the following changes were made to the thermal scheme of the steam boiler house: a) heat exchangers in the preheating stage of raw and chemically purified water were reconnected with each other in order to make fuller use of heat; b) installed steam turbines instead of

throttling devices to use the excess steam pressure after the boilers and generate electricity. The thermal scheme of the steam boiler room after the introduction of changes is shown in Fig.2.

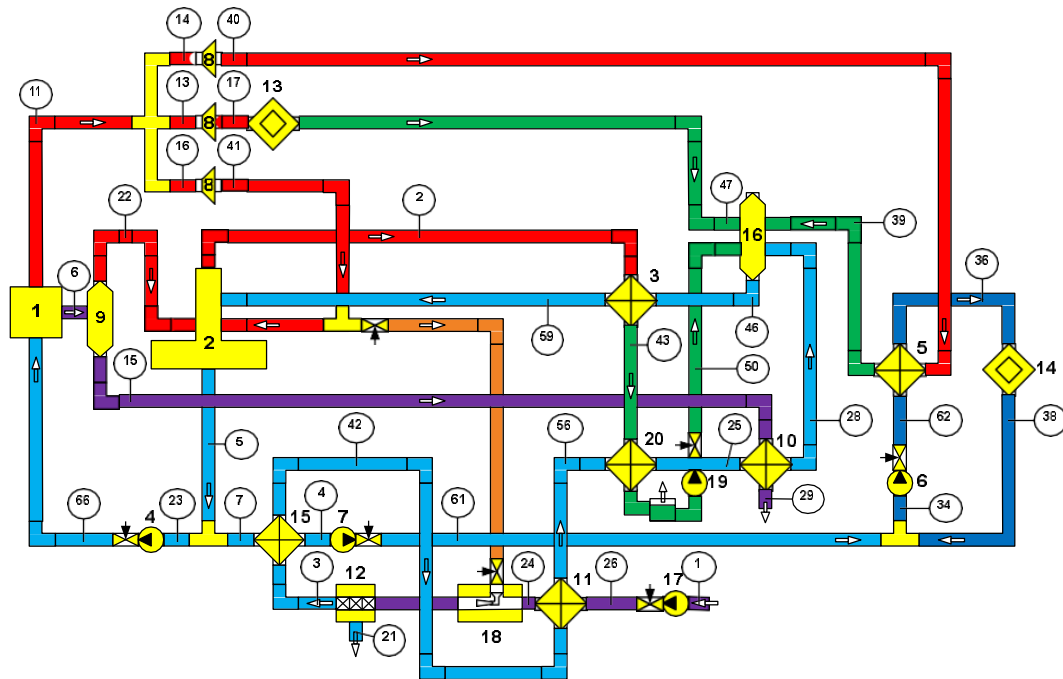


Fig.2. Thermal scheme of the steam boiler room after the changes.

Digital designations: 1÷7 - the same as in Fig.1; 8 - steam turbine; 9÷17 are the same as in Fig.1; 18 - steam utilizer; 19 - condensate pump; 20 - condensate subcooler. In the circles, the accepted numbering of the flows after the changes is given.

In connection with the organization of more complete use of low-potential heat in the boiler house scheme, the consumption of steam from boilers is reduced. The heat exchanger 11 ceases to use steam as a heat carrier and switches to the use of chemically purified water after the heat exchanger 15. A direct-acting heater 18 is used as a starting and backup device. The chemically purified water after the water purification installation 12 passes successively through the heat exchangers 15, 11, 20 and 10. All condensate streams and chemically purified water are connected in a condensate collection tank 16. Before being fed to the atmospheric deaerator 2, condensate and chemically purified water are heated in a heat exchanger 3. To generate electricity at excess steam pressure after boilers it is proposed to install steam turbines in place of the throttling devices 8. In order for steam turbines to work in the best conditions, steam should be passed through the superheater. If there is no superheater in the boiler, it is recommended to use expansion machines for working on wet steam [8].

Changes in the thermal scheme can be considered energetically effective, if as a result of their implementation, other things being equal, the consumption of fuel and energy resources will decrease or additional profit will be obtained [9]. Heat and exergic efficiency for the thermal scheme of the steam boiler house after the changes (Fig.2), were determined by the same method as for the circuit in Fig.1. Heat and exergy efficiency of the scheme after the changes: 80.72% and 50.55%, respectively. The total amount of electricity to create pressure in the pumps taking into account $\eta = 70\%$: 147.704 kW, the total amount of electricity produced in steam turbines taking into account $\eta = 75\%$: 2596.99 kW. The indicators of the heat and exergy efficiency of the thermal scheme of the steam boiler house before and after changes are summarized in Table. 3.

Table 3. Comparison of the efficiency of the thermal scheme of the boiler plant

Indicator name	Before making changes	After making changes	Increment of indicators
Heat efficiency, %	79.36	80.72	+1,36
Exergy efficiency, %	42.81	50.55	+7,74
Electric power for electric pump drive, kW	-145,047	-147,704	-2,657
Electricity produced by steam turbines, kW	0	2596,987	+2596,987

Conclusions

The analysis of the heat and exergic efficiency of the thermal scheme of the steam boiler house is carried out. Considered and proposed solutions that increase the energy efficiency of the thermal circuit. It is shown that power generation and non-use of steam at the stage of raw water heating increases the energy efficiency of the thermal scheme of the steam boiler house (see Table 3).

References

- [1] L V Plotnikova, L A Kashipova and R A Ishmuratov (2016) Modeling of Heat and Power System Optimal Structure Using Software. *Journal of Engineering and Applied Sciences*, **11** (14): 3028-34
- [2] L V Plotnikova, L A Kashipova, A A Zvegintsev, R A Ishmuratov and N K Nuriev (2015) Program implementation of the system analysis of the complex-structured chemical-technological scheme of petrochemical production. *Bulletin of the Technological University*, **8**: 198-202
- [3] R N Valiev and Yu G Nazmeev (2001) Analysis of the thermodynamic efficiency of the heat engineering scheme for the dehydrogenation of isoamylenes into isoprene in the production of synthetic isoprene rubber SKI-3. Part 1. *News of Higher Educational Establishments. Problems of energy: scientific and technical and industrial journal*, 1/2: 37-52
- [4] R N Valiev and Yu G Nazmeev (2001) Analysis of the thermodynamic efficiency of the heat engineering scheme for the dehydrogenation of isoamylenes into isoprene in the production of synthetic isoprene rubber SKI-3. Part 2. *News of Higher Educational Establishments. Problems of energy: scientific and technical and industrial journal*, 3/4: 49-57
- [5] G Wall and M Gong (2001) On exergy and sustainable development - Part 1: Conditions and concepts. *Exergy Int. J.*, **1**(3): 128-145
- [6] I Dincer and M A Rosen (2013) *Exergy: Energy, Environment and Sustainable Development* (Elsevier: Oxford, UK) p 576
- [7] B M Malakhov and V N Senich (1997) Thermal pollution of the environment by industrial enterprises: analyte. review (Novosibirsk: State Public Scientific and Technical Library of the Siberian Branch of the Russian Academy of Sciences-Tekhnenergokhimprom-Himmashheкологиya) p 68
- [8] B M Khrustalev, V N Romanyuk, V A Sednin, A A Bobich, D B Muslina and T V Bubyр (2014) To the issue of development of energy supply of industrial heat technologies and heat supply systems in Belarus. *Power engineering. Izvestiya of higher educational institutions and energy associations of the CIS*, **6**: 31-47
- [9] R N Valiev, Sh G Ziganshin, Yu V Vankov and R R Garipov (2017) Increasing efficiency the combined-cycle plant with a waste heat boiler due to inclusion in the scheme of the absorption transformer of the heat. *Proceedings of higher educational institutions. Problems of energy: scientific and technical and industrial journal*, 9/10: 40-50