Two New Alternative Options for Residues Cost Distribution Ratio

Seyyed Masoud Seyyedi[1], A.S. Dogonchi[2*]

Abstract – An energy system that produces work, heat and so forth, contains unintended remaining flows of matter or energy called residues. In the conventional thermo economic cost accounting methods, as it is already known, the problem of the residues cost has not been considered thoroughly. The residues cost allocation is a complex problem practically, because it is intertwined with the nature of such flows and the way they are formed. There are several options for the residues cost allocation among which two more important options are: (1) distribution of the residues cost proportionally to the exergy and (2) distribution of the residues cost proportionally to the entropy generation or negentropy. In this paper, for the residues cost distribution ratio, two alternative options are proposed. The proposed options are applied to a combined cycle and results are compared with two different possible options. The results suggest that the proposed options are more proper and reasonable than the alternative options.

Keywords: Combined cycle, Exergo economic, Residues, Cost allocation, Negentropy

I. Introduction

Unintended remaining flows of matter or energy, called residues, appear in any energy system that produces work, heat and so forth. Unavoidably, in any productive process, the achievement of functional products is inseparable from the generation of residues and waste disposals [1]. In conventional thermo-economic methods, such as exergetic cost theory, (ECT) [2], average cost theory (ACT) [3], the problem of the cost of residues has not been considered thoroughly. The residue cost allocation is a complex problem since it depends on the nature of such flows and the way they are formed [1]. Torres et al. [1] have presented the mathematical basis for the cost assessment and the formation process of residues. Based on their work, a residue cost distribution ratio should be defined. For more details see section 3 and Ref. [1]. This residue cost distribution ratio can be defined in several ways, depending on the type and nature of the residue, but there is not a general criterion to define the residue cost distribution ratios. Two more important options for the residues cost allocation are: first, distribution of the cost of the residues proportionally to the exergy [1] and second, distribution of the cost of the residues proportionally to the entropy generation or negentropy [4, 5]. In this paper, two new alternative options are proposed. A combined cycle, which is fully described in [6], was selected to illustrate the proposed options and the comparison of results with two another different, while important options [1, 4, 5]. Fig. 1 shows the physical model of the combined cycle and Table. 1 represents the corresponding thermodynamic properties. The results show that the proposed options are more suitable and rational than the other options.

2* **Corresponding Author** : Mechanical Engineering Department, Babol Noshirvani University of Technology, Babol, Iran. Email : sattar.dogonchi@yahoo.com

1-Department of Mechanical Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

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II. Thermo-economic Model

In order to perform a thermo-economic analysis of an energy system, thermo-economic model is used. The productive structure, which is called productive or functional diagram, is a graphical representation of the fuel and product distribution given by the thermo-economic model [7]. On the other hand, thermo-economic model represents the productive purpose of each component. In this model, for each component, fuel and product is defined in terms of exergy flows. Table. 2 represents definition of fuel and product for each component. Table. 3 represents the values of fuel (F), product (P), irreversibility (I), exergetic efficiency (ε) and specific exergy destruction (kI), for each component. In the productive or functional diagram [4, 5], the inputs of each component are the fuels and the outputs are the products. The exergy carried out by each flow is denoted as $E_{i,j}$ that represents the product of the ith component used as fuel of the jth component. Fig. 2 shows the productive diagram of the combined cycle which is shown in Fig.1. In an energy system, all components can be divided into two groups, productive components and dissipative components. The last column in Table. 2 represents the type of components.

III. The Cost Formation Process of Residues [1]

In the same way in which there is a process of cost formation of the functional products, there also exists a cost formation process of the residues. The product cost of the ith component, in a general form, is given by

$$C_{P,\,i} = C_{F,\,i} + C_{R,\,i} + Z_i \tag{1}$$

where

$$C_{R,\,i} = \sum_{r \in \mathscr{V}_D} C_{ri} \tag{2}$$

In order to determine the Cri values, a residue cost distribution ratio ψir must be defined such that,

$$C_{ri} = \psi_{ir} C_{r0} \quad \text{with} \quad \sum_i \psi_{ir} = 1 \tag{3}$$

As mentioned above, this allocation can be done in several ways, depending on the type and nature of the residue. However, there is not a general criterion to define the residue cost distribution ratios. The following system of linear equations, allows determining the production cost of each component simultaneously:

$$C_{P,i} - \sum_{j \in \mathscr{V}_P} y_{ij} C_{P,j} - \sum_{r \in \mathscr{V}_D} \psi_{ir} C_{P,r} = C_{e,i} + Z_i \qquad i = 1,\dots,n \tag{4}$$

It can also be written in matrix notation as:

$$(U_D - \langle FP \rangle - \langle RP \rangle) C_P = C_e + Z \tag{5}$$

where $\langle FP \rangle$ is a $(n \times n)$ matrix whose coefficients are the cost distribution ratios of productive unit y_{ij} ($y_{ij} = E_{j,i} / P_j$) and $\langle RP \rangle$, a $(n \times n)$ matrix whose coefficients ψ_{ij} are the cost distribution ratios of the dissipative unit. The reader can consult Ref. [1] for more information about deriving these equations.

IV. Review of the Two More Important Options for the Residues Cost Allocation

In Refs. [4, 5], the residues cost allocation has been considered proportional to the entropy generated along the process. As mentioned by Torres and et al. [1], this allocation works for closed cycle, like Rankine or refrigeration cycles, but it fails for other types of processes like gas turbines. Since in closed cycles the sum of the entropy generated in each productive process is equal to the entropy saved on the dissipative process, therefore it is logical to distribute the cost of the wastes proportionally to the entropy generation. However, this is not true in case of open cycles. For example, in the case of a simple gas turbine with a heat recovery steam generator, this process saves only a part of entropy generated in the global process.

A. Allocate the Cost of Residues Proportionally to the Entropy Generated along the Process

In order to obtain the production cost of each component from (5), the values of ψ_{ir} , i.e. coefficients in matrix $\langle RP \rangle$, must be determined first. In this section, allocation the cost of residues proportionally to the entropy generated along the process is described. To derive values of ψ_{ir} , the values of entropy in Table. 1 are used. Table. 4 shows description of this option which is denoted as option 1.

B. Allocate the Cost of Residues Proportionally to the Exergy

In Ref. [1], a simple method has been proposed to define the residue cost distribution ratios, which make them proportional to the exergy of the flows processed in the dissipative units according to the productive structure of the plant

$$\psi_{ir} = \frac{E_{i,r}}{F_r} \tag{6}$$

where $E_{i,r}$ represents the exergy of the flow that is produced in the ith component and is processed (dissipated) in the rth component. The main advantage of this criterion is that these ratios could be obtained directly from the information provided by the productive diagram. It is important to remark that this option simplifies the software implementation of the costs computation, but it is neither the only way nor the best option for any type of dissipative unit. For more details see Ref. [1].

In this section, allocation of cost of residues proportionally to the exergy is described. Toward this end, the first step is that a fuel-product (FP) table to be constructed. FP table is a mathematical representation of the thermoeconomic model. It is constructed using exergy of each flow, shown in Table 1. FP table represents distribution of fuel and product through the power plant. On the other hand, each element of FP table is $E_{i,j}$, which was defined in previous sections. Table. 5 represents FP table for the combined cycle. Using (6) and the values of $E_{i,j}$ in Table. 5, values of ψir are calculated. Table. 6 depicts description of this option which is denoted as option 2.

V. Proposal for Tow New Alternative options for the Residues Cost Distribution Ratio

The two new proposed options, are presented here. They are called alternative 1 and alternative 2, so that the reader, hopefully, would not take one for another by mistake.

A. Alternative 1:

As it is mentioned above, allocation of the cost of residues proportionally to the entropy generation along the process (option 1) works for closed cycle, like Rankine or refrigeration cycles, but it fails for other types of process like gas turbines. On the other hand, allocation of the cost of residues proportionally to the exergy (option 2) is more appropriate for other types of process like gas turbines. Therefore we propose for combined cycles that both options are applied. For example, in the combined cycle shown in fig. 1 the criterion used in option 1 is applied for the steam line (the Rankine cycle) and the criterion used in option 2 is applied for air and gases line (Brayton cycle). The following formula is proposed for alternative 1. For the purpose of readability, alternative 1 is also called as option 3.

$$\psi_{ir} = \begin{cases} \dfrac{\Delta s_{i,r}^{H}}{\Delta s_{T}^{H}} & \text{For Heat (here } r = 10) \\ \dfrac{E_{i,r}}{F_r} & \text{For Gases (here } r = 11) \end{cases} \quad (7)$$

B. Alternative 2:

In alternative 2, we suggest that options 1 and 2 are combined by a positive value between zero and one:

$$\psi_{ir} = \begin{cases} \dfrac{\alpha E_{i,r} + (1-\alpha)\Delta S_{i}^{H}}{\alpha F_r + (1-\alpha)\Delta S_{T}^{H}} & \text{For Heat (here } r = 10) \\ \dfrac{\alpha E_{i,r} + (1-\alpha)\Delta S_{i}^{G}}{\alpha F_r + (1-\alpha)\Delta S_{T}^{G}} & \text{For Gases (here } r = 11) \end{cases} \quad (8)$$

In (8), α is a positive value between zero and one ($0 \le \alpha \le 1$). Alternative 2 is also denoted as option 4. It should be mentioned that if α be equal to zero ($\alpha = 0$), option 1 is obtained and if α be equal to one ($\alpha = 1$), option 2 is obtained. Therefore when α is between zero and one, the values of option 4 are between the values of options 1 and 2.

$$\psi_{ir}^{\text{Option 1}} \le \psi_{ir}^{\text{Option 4}} \le \psi_{ir}^{\text{Option 2}} \quad \text{Or}$$

$$\psi_{ir}^{\text{Option 2}} \le \psi_{ir}^{\text{Option 4}} \le \psi_{ir}^{\text{Option 1}} \quad (9)$$

Note: in (8), in order to derive entropy in Kilowatts, we need to multiply the specific entropy by the environment temperature and the mass flow rate since the entropy term must be in kilowatts. Therefore it can be written as:

1-

$$\Delta S_{i}^{H} = T_0 \times (m_{\text{out}} \times s_{\text{out}} - m_{\text{in}} \times s_{\text{in}})_{i}^{H} \quad \text{and} \quad \Delta S_{T}^{H} = \sum_{i=1}^{n_p} \Delta S_{i}^{H} \quad (10)$$

2-

$$\Delta S_{i}^{G} = T_0 \times (m_{\text{out}} \times s_{\text{out}} - m_{\text{in}} \times s_{\text{in}})_{i}^{G} \quad \text{and} \quad \Delta S_{T}^{G} = \sum_{i=1}^{n_p} \Delta S_{i}^{G} \quad (11)$$

where the dummy indices i and np represent the ith component and the number of productive components, respectively.

C. Appropriate value for α:

As stated, α must be a positive value from the interval [0, 1]. Therefore as an appropriate value, we propose that α is settled equal to the exergetic efficiency of the cycle (εtotal), since when the total irreversibility of the cycle decreases (or, the exergetic efficiency of the cycle increases), the total entropy generation decreases, too. Therefore, in order to decrease the importance of the entropy generation term in (8), it is appropriate that α be selected equal to εtotal. On the other hand, it is appropriate that α be settled equal to εtotal in order to bring the values of ψ in (8) close to the values of ψ in option 2.

VI. Results and Discussion

Alternatives 1 and 2 are applied to the combined cycle shown in fig.1. Hereafter, alternatives 1 and 2 are denoted as options 3 and 4, respectively. In the case of alternative 2, α has been settled equal to exergetic efficiency of the cycle (εtotal). Table. 7 represents values of residues cost distribution ratios (ψ) for all options. As it is seen, all values of options 3 and 4 are between those of options 1 and 2. This shows that options 3 and 4 are more proper and suitable than the two other options. Table. 8 represents the exergoeconomic cost of product of each component for all options. The last column in this table shows the exergoeconomic costs of components that have been calculated by average cost theory (ACT) method. As shown in Table. 8, the exergoeconomic cost of generator for all options is the same as those obtained by ACT method. Exergoeconomic costs of condenser and stack are the same in option 2 and ACT method. Also in the cases of condenser and stack, the values of exergoeconomic costs corresponding to options 3 and 4 are between the values of options 1 and 2. Combustor is one of the most important components because it usually produces maximum irreversibility in a cycle. Therefore, its exergoeconomic cost is important, too. Exergoeconomic cost of the combustor in options 2 and 3 is the same and this value is near to the corresponding value to that of ACT method. This value in option 4 is 12.65 % more than the corresponding value in option 2 and 2.65% less than the corresponding value in option 1. Table. 9 represents the exergoeconomic costs of components corresponding to option 4. For other options similar values can be obtained.

VII. Conclusions

Two new alternative options has been proposed alongside the two important options of residues cost distribution ratio. In alternative 1, it has been proposed that in the combined cycles, allocation of the cost of residues be proportional to the entropy for closed cycles such as, Rankine cycle and allocation of the cost of residues be proportional to the exergy for open cycles such as, Brayton cycle are used, respectively. On the other hand, in alternative 2, a linear combination of the two already known options has been proposed I which, we assumed that the coefficients of each option must a positive value from the interval [0, 1]. Also, it was shown that an appropriate value for this coefficient can be exergetic efficiency of the cycle. For the purpose of comparison, a combined cycle was selected and all options were applied to it. Also exergoeconomic costs of components were calculated from average cost theory (ACT) method. Results show that the proposed two new alternative options are more appropriate and suitable than the two already known options.

Table 1: Thermodynamic properties of the combined cycle

No.	*Flow description*	*p (bar)*	*T (°C)*	*M (kg/s)*	*s (kJ/kg · K)*	*h (kJ/kg)*	*H (kW)*	**E (kW)**
0	Environment	1.013	20.00					
1	Air inlet compressor	1.013	25.00	309.930	0.0170	5.02	1555.85	13.12
2	Air outlet compressor	9.100	331.23	309.930	0.0963	312.47	96843.83	88091.52
3	Gas inlet turbine	9.009	870.00	314.055	0.9585	994.50	312327.70	224086.23
4	Gas inlet superheater	1.044	444.17	314.055	1.0383	496.28	155859.22	60266.99
5	Power compressor						95288.91	95288.91
6	Power gas turbine						61180.17	61180.17
7	Fuel combustor	1.013	25.00	4.125	0.0000	53306.00	219887.25	219880.32
8	Gas inlet boiler	1.033	406.09	314.055	0.9774	451.73	141868.07	51931.62
9	Gas inlet economizer	1.023	262.22	314.055	0.7018	283.39	89000.05	24425.76
10	Gas outlet economizer	1.013	184.20	314.055	0.5204	192.11	60333.11	12450.16
11	Outlet LP turbine	0.065	37.64	30.904	7.1956	2225.88	68788.59	3723.19
12	Outlet condenser	0.065	37.67	30.904	0.5408	157.64	4871.71	64.66
13	Steam inlet economizer	40.804	37.91	30.904	0.5441	162.77	5030.24	193.36
14	Steam inlet boiler	40.400	251.00	30.904	2.8007	1090.41	33698.03	8426.93
15	Steam inlet superheater	40.400	251.00	30.904	6.0681	2801.08	86564.58	31708.09
16	Steam inlet HP turbine	40.000	417.13	30.904	6.8281	3253.80	100555.44	38817.60
17	Power steam turbine						31766.76	31766.76
18	Electric power						90000.00	90000.00
19	Condense heat						63916.89a	3633.28b
20	Power extraction pump						158.53c	158.53

a $Q_{Condenser} = m_{12}(h_{11} - h_{12}) = 30.904 \times (2225.88 - 157.64) = 63916.89 \text{ kW}$

b $E^{Q}_{Condenser} = (1 - \frac{T_0}{T_{12}}) Q_{Condenser} = (1 - \frac{293.15K}{310.82K}) \times 63916.89 = 3633.28 \text{ kW}$

c $W_{Pump} = m_{12}(h_{13} - h_{12}) = 30.904 \times (162.77 - 157.64) = 158.53 \text{ kW}$

Table 2: Definition of fuel and product for each component

No.	*Device*	*Fuel*	*Product*	**Type of component**

1	Combustor	E7	E3 – E2	Productive
2	Compressor	E5	E2 – E1	Productive
3	Gas Turbine	E3 – E4	E5 + E6	Productive
4	LP Turbine	E16 – E11	E17	Productive
5	Superheater	E4 – E8	E16 – E15	Productive
6	Boiler	E8 – E9	E15 – E14	Productive
7	Economizer	E9 – E10	E14 – E13	Productive
8	Pump	E20	E13 – E12	Productive
9	Generator	E6 + E17	E18 + E20	Productive
10	Condenser	E11 – E12	E19	Dissipative
11	Stack	E10	E21	Dissipative

Table 3: The values of fuel (F), product (P), irreversibility (I), exergetic efficiency (ε) and specific exergy destruction (kI) for each component

No.	*Device*	*F (kW)*	*P (kW)*	*I (kW)a*	*εa*	**kIa**
1	Combustor	219880.32	135994.71	83885.61	0.6185	0.6168
2	Compressor	95288.91	88078.40	7210.51	0.9243	0.0819
3	Gas Turbine	163819.24	156469.08	7350.16	0.9551	0.0470
4	LP Turbine	35094.41	31766.76	3327.65	0.9052	0.1047
5	Superheater	8335.37	7109.51	1225.86	0.8529	0.1724
6	Boiler	27505.56	23281.16	4224.40	0.8464	0.1814
7	Economizer	11975.60	8233.57	3742.03	0.6875	0.4545
8	Pump	158.53	128.70	29.83	0.8118	0.2318
9	Generator	92946.93	90158.53	2788.40	0.9700	0.0309
10	Condenser	3658.53	3633.28	25.25	0.9931	0.0069
11	Stack	12450.16	12450.16	0	1.0000	0.0000
	Total	219880.32	90000	113809.7b	0.4415c	—

a $I_i = F_i - P_i$ and $\varepsilon_i = \dfrac{P_i}{F_i}$ and $\mathrm{kI}_i = \dfrac{I_i}{P_i}$

b $I_{Total} = E_1 + E_7 - (E_{18} + E_{19} + E_{21}) = \sum_{i=1}^{11} I_i = 113809.7\,\mathrm{kW}$

c $\varepsilon_{Total} = 1 - \dfrac{I_{Total}}{(E_1 + E_7 - E_{19} - E_{21})} = 0.4415$

Table 4: Allocation the cost of residues proportional to the entropy generated along the process (Option 1)

No.	Device	Δs^G	Δs^H	$\psi_i^G = \dfrac{\Delta s_i^G}{\Delta s_T^G}$	$\psi_i^H = \dfrac{\Delta s_i^H}{\Delta s_T^H}$
1	Combustor	$s_3 - s_2 = 0.8622$	—	1.7127	0.0000
2	Compressor	$s_2 - s_1 = 0.0793$	—	0.1576	0.0000
3	Gas Turbine	$s_4 - s_3 = 0.0798$	—	0.1585	0.0000
4	LP Turbine	—	$s_{11} - s_{16} = 0.3675$	0.0000	0.0552
5	Superheater	$s_8 - s_4 = -0.0609$	$s_{16} - s_{15} = 0.7600$	-0. 1210	0.1142
6	Boiler	$s_9 - s_8 = -0.2756$	$s_{15} - s_{14} = 3.2674$	-0.5475	0.4909
7	Economizer	$s_{10} - s_9 = -0.1814$	$s_{14} - s_{13} = 2.2566$	-0.3603	0.3391
8	Pump	—	$s_{13} - s_{12} = 0.0033$	0.0000	0.0005
9	Generator	—	—	0.0000	0.0000

$$\Delta s_T^G = \sum_{i=1}^{9} \Delta s_i^G = 0.5034 \qquad \Delta s_T^H = \sum_{i=1}^{9} \Delta s_i^H = 6.6548$$

Table 5: FP table for the combined cycle

	F0	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*	*F11*	**Total**
P0		219880	13										219893
P1				99420		5059	16693	7268				7556	135996
P2				64390		3276	10811	4707				4894	88078
P3			95288							61180			156468
P4										31767			31767
P5					6438						671		7109
P6					21083						2198		23281
P7					7456						777		8233
P8					117						12		129
P9	90000								158				90158
R10	3633												3633
R11	12450												12450
		219880	95301	163810	35094	8335	27504	11975	158	92947	3658	12450	

Table 6: Allocation the cost of residues proportional to the exergy (Option 2)

No.	Device	$\psi_i^G = \frac{E_{i,10}}{F_{10}}$	$\psi_i^H = \frac{E_{i,11}}{F_{11}}$
1	Combustor	0.6069	0.0000
2	Compressor	0.3931	0.0000
3	Gas Turbine	0.0000	0.0000
4	LP Turbine	0.0000	0.0000
5	Superheater	0.0000	0.1835
6	Boiler	0.0000	0.6008
7	Economizer	0.0000	0.2125
8	Pump	0.0000	0.0033
9	Generator	0.0000	0.0000

Table 7: Residues cost distribution ratios

No.	Device	Option 1		Option 2		Option 3		Option 4	
		Heat	Gases	Heat	Gases	Heat	Gases	Heat	Gases
1	Combustor	0.0000	1.7127	0.0000	0.6069	0.0000	0.6069	0.0000	1.5206
2	Compressor	0.0000	0.1576	0.0000	0.3931	0.0000	0.3931	0.0000	0.1970
3	Gas Turbine	0.0000	0.1585	0.0000	0.0000	0.0000	0.0000	0.0000	0.1307
4	LP Turbine	0.0552	0.0000	0.0000	0.0000	0.0552	0.0000	0.0527	0.0000
5	Superheater	0.1142	–0. 1210	0.1835	0.0000	0.1142	0.0000	0.1174	–0.0998
6	Boiler	0.4909	–0.5475	0.6008	0.0000	0.4909	0.0000	0.4960	–0.4514
7	Economizer	0.3391	–0.3603	0.2125	0.0000	0.3391	0.0000	0.3333	–0.2971
8	Pump	0.0005	0.0000	0.0033	0.0000	0.0005	0.0000	0.0006	0.0000
9	Generator	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 8: The exergoeconomic cost of product of each component for all options

No.	Device	CP (€/h)

		option 1	option 2	option 3	option 4	ACT
1	Combustor	4321.1	3737.0	3737.0	4209.6	3466.5
2	Compressor	4656.0	4274.2	4274.2	4581.6	3741.7
3	Gas Turbine	6931.5	6146.3	6146.3	6780.3	5559.2
4	LP Turbine	1654.6	1961.7	1961.6	1713.8	1627.0
5	Superheater	305.9	347.8	334.0	311.9	340.0
6	Boiler	978.7	1171.0	1148.8	1012.3	1160.9
7	Economizer	391.2	505.5	530.0	416.9	523.7
8	Pump	7.9	8.5	7.9	7.9	8.2
9	Generator	4374.8	4374.8	4374.8	4374.8	4374.8
10	Condenser	164.2	197.1	196.0	170.4	197.1
11	Stack	498.8	445.1	445.1	488.4	445.1

Table 9: Exergoeconomic costs of components corresponding to option 4

No.	Device	cp (¢/kWh)	CF (€/h)	CR (€/h)	Z (€/h)	CP (€/h)
1	Combustor	3.0954	3465.9	742.7	0.98	4209.6
2	Compressor	5.2017	4129.2	96.2	356.19	4581.6
3	Gas Turbine	4.3333	6426.9	63.9	289.63	6780.3
4	LP Turbine	5.3948	1583.9	9.0	120.83	1713.8
5	Superheater	4.3867	327.0	–28.7	13.61	311.9
6	Boiler	4.3483	1079.1	–136.0	69.23	1012.3
7	Economizer	5.0637	469.8	–88.3	35.44	416.9
8	Pump	6.1574	7.7	0.1	0.13	7.9
9	Generator	4.8523	4364.9	0.0	9.88	4374.8
10	Condenser	4.6890	165.1	0.0	5.24	170.4
11	Stack	3.9231	488.4	0.0	0.00	488.4

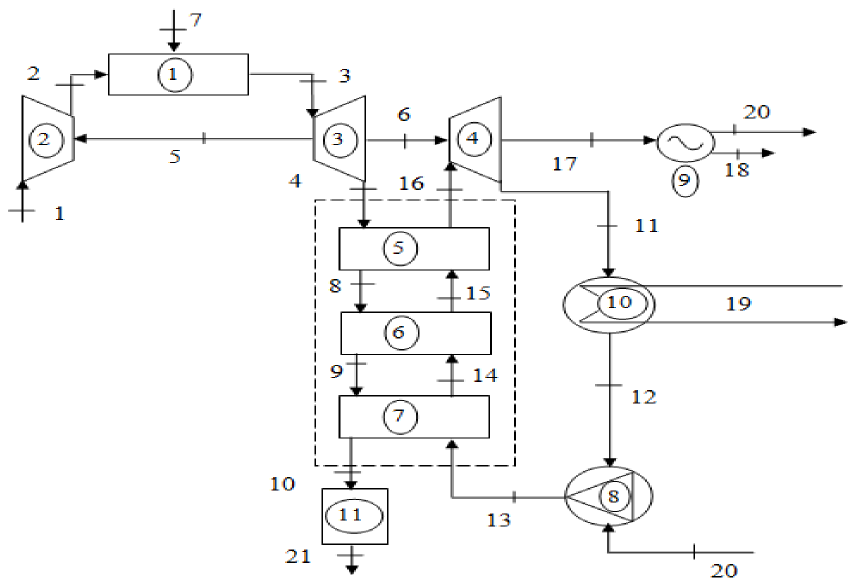

Fig.1: Physical structure of simple combined cycle.

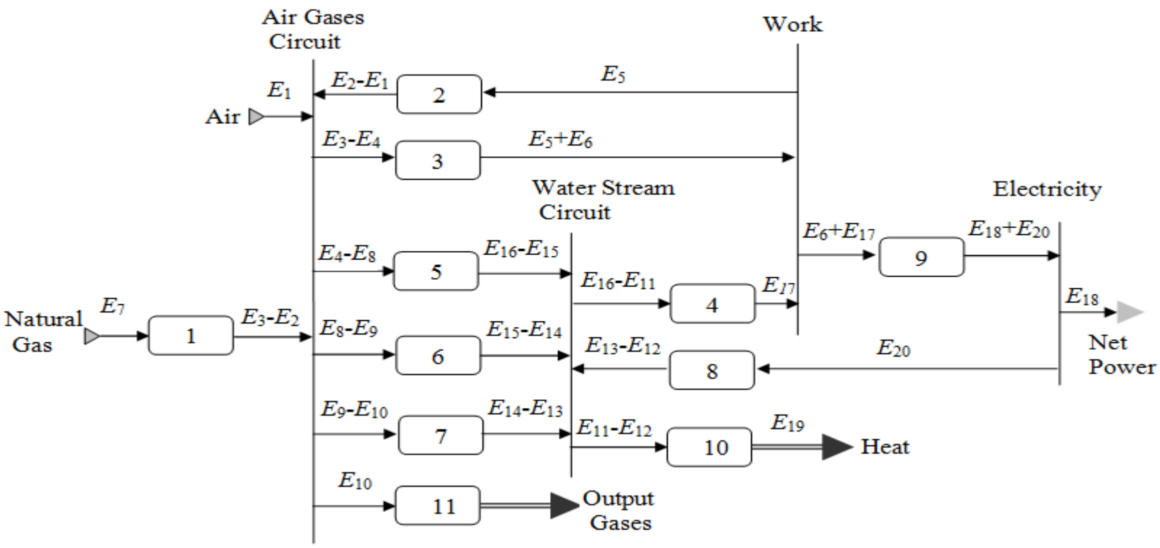

Fig.2: Fuel product diagram of a simple combined cycle.

Nomenclature			
c	unit exergoeconomic cost (¢/kWh)	ψ	residue cost distribution ratio
C	exergoeconomic cost (€/h)	Matrices and vectors	
E	exergy of a flow (kW)	Z	capital cost vector $(n \times 1)$
F	fuel exergy of a component (kW)	CF	fuel cost vector $(n \times 1)$
h	specific enthalpy (kJ/kg)	CP	product cost vector $(n \times 1)$
H	enthalpy of a flow (kW)	CR	residue cost vector $(n \times 1)$
I	irreversibility of a component (kW)	UD	identity matrix $(n \times n)$
kI	specific exergy destruction	⟨FP⟩	matrix $(n \times n)$ which contains the distribution ratios
m	mass flow rate (kg/s)	⟨RP⟩	matrix $(n \times n)$ which contains the residue ratios
n	number of components	Subscripts	
p	pressure (bar)	0	index for environment (reference state)
P	product exergy of a component (kW)	e	system inlet
Q	heat flow rate (kW)	F	fuel, related to fuel
s	specific entropy (kJ/kg .k)	in	inlet
T	temperature (K)	i, j	indexes for productive components
W	work flow rate (kW)	out	outlet
y	distribution exergy ratios	P	related to product
Z	Capital cost rate of a component (€/h)	r	index for dissipative components
VP	set of productive components	R	related to residue
VD	set of dissipative components	total	total
Greek letters		Superscripts	
α	a positive value used in Eq. (8)	G	related to gas
Δ	absolute change in a variable	H	related to heat
ε	exergetic efficiency		

References

[1] C. Torres, A. Valero, V. Rangel, A. Zaleta, "On the cost formation process of the residues", Energy, 33 (2008): 144–152.

[2] MA. Lozano, A. Valero, "Theory of the exergetic cost", Energy, 18(9) (1993): 939–960.

[3] A. Bejan, G. Tsatsaronis, M. Moran,"Thermal & design optimization", New York: John Wiley and Sons, 1996.

[4] M. A. Lozano, A. Valero, "Thermoeconomic analysis of a gas turbine cogeneration system", ASME Book no. H00874, WAM 1993, AES, Vol. 30, pp. 312–320.

[5] CA. Frangopoulos, "Thermoeconomic functional analysis. In: CA. Frangopoulos, editor. exergy, energy system analysis and optimization, from encyclopedia of life support system (EOLSS)", Developed under the Auspices of the UNESCO. Oxford: EOLSS Publishers; 2004. Available at: ⟨http://www.eolss.net⟩.

[6] Y. El-Sayed, "The thermoeconomics of energy conversions", Oxford: Elsevier; 2003.

[7] B. Erlach, L. Serra, A. Valero, "Structural theory as standard for thermoeconomics", Energy Conversion and Management , 40 (1999): 1627–1649.