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Complex exergy analysis of an integrated oxy-fuel combustion power plant with CO_2 transport and storage

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Abstract

The paper presents a method of the complex system exergy analysis, as well as an example of application in the case of an integrated oxy-fuel combustion (OFC) power plant with CO_2 transport and storage. Complex exergy analysis consist of (a) local exergy losses, (b) cumulative exergy consumption, (c) cumulative exergy losses and (d) cumulative degree of thermodynamic perfection. The algorithms of the complex system exergy analysis are based on "input-output method" of the direct energy and material consumption. In the structure of the balance we distinguished main products (e.g. electricity), by-products (e.g. nitrogen) and external supplies (e.g. hard coal). The considered system (OFC power plant with CO_2 transport and storage infrastructure) consists of seven interconnected modules, viz. boiler island, steam cycle, air separation unit, cooling water and water treatment module, flue gas quality control module, CO_2 processing unit and CO_2 transport and storage module, among which there also exist feedback relations.

Keywords: exergy analysis, oxy-fuel combustion, cumulative exergy consumption, cumulative exergy losses, cumulative degree of thermodynamic perfection

1. Introduction

The oxy-fuel combustion (OFC) technology is one of three CO_2 capture technologies which might be used to drastically cut the CO_2 emissions from power sector, but also that could be used in other industry sectors like steel or cement production. The OFC capture technology is based on using high-purity oxygen (≈95% purity) in the combustion process instead of atmospheric air. Therefore flue gases have a high concentration of CO_2 (which results from no nitrogen dilution), allowing to evade chemical based post-combustion processes. Due to the limited adiabatic temperature of combustion some part of CO_2 must be recycled (65...70%) to the boiler in order to maintain a proper flame temperature. The considered OFC power plant consists of technological modules, viz. boiler island, steam cycle, air separation unit (ASU), cooling wa-

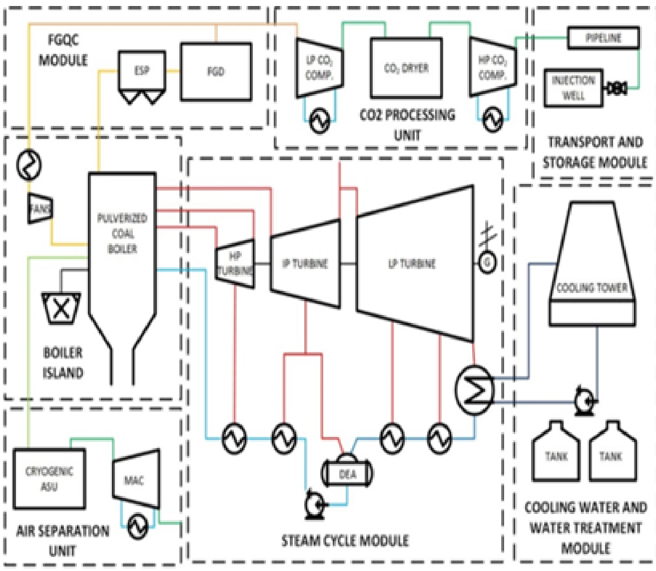

Figure 1: Block-diagram of an integrated OFC power plant with T&S module

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ter and water treatment module, flue gas quality control (FGQC) module and CO_2 processing unit (CPU). Additional, whole CCS chain is taken into account, thus CO_2 transport and storage (T&S) module is also considered. Fig. 1 presents the scheme of an integrated oxy-fuel combustion power plant with CO_2 T&S module.

Several exergy analysis of an OFC power plants can be found in the literature, where exergy is used to evaluate the thermodynamical performance of the cycle and its potential improvements [1–5]. In [5] the 600 MW_{el} oxy-combustion pulverized-coal-fired power plant was analyzed, where the exergy cost was introduced and the results where compared with the conventional coal-fired power plant. The obtained results showed that the exergy cost in OFC power plant for each component are about 10% higher than in the conventional power unit, resulting mostly from additional power consumption. In the paper [5], also the exergy cost decomposition was introduced (decomposed into three parts: fuel, exergy destruction and negentropy), where results suggest that the fuel part have the biggest share in unit exergy costs for most of the components. In [3] the global exergy losses were analyzed in order to improve the architecture of oxy-pulverized coal power plants. The main exergy losses occur in the boiler and steam generation. Several improvements for an OFC power plant where proposed (e.g. compression heat integration), which resulted in improving the exergy efficiency (CO_2 also a product) from 36.4% to 39.6% and overall exergy destruction diminution of 16% [3]. In [1] the exergy analysis was also used to evaluate the potential of heat integration in an coal-based oxy-combustion power plant. The presented results shows that only 6.6% of exergy losses are connected with ASU, and 2.1% with CPU. The theoretical benefits of heat integration are presented, which result in an increase of thermal efficiency by up to 0.72 percentage point [1]. The exergy analysis in [2] was also used to assess the energy penalty improvement potential of a first generation oxy-fired power plants. As stressed by the Authors [2] the exergy analysis provides a useful information about the location and the magnitudes of the irreversibilities occurring in the system, which allows the more precise identification of potential process improvements. The heat integration (ASU and CPU interstage compressor waste heat utilization in the steam cycle) leads to the 1.7% improvement of net plant efficiency. Alternative flue gas recirculation, as well as ASU and CPU novel architecture lead to the higher net efficiency of the analyzed OFC power plant [2]. In [4] the exergy analysis was used to assess the oxy-steam combustion as an alternative for the next generation OFC technology. The results indicates that the novel oxy-steam cycle net exergy analysis is 0.153% lower than the conventional OFC power plant, resulting from the increase of the exergy destruction associated with the oxy-steam furnace [4].

An integrated OFC power plant with CO_2 transport and storage is a large energy system, the design of which and further also its exploitation ought to be optimized by means of system methods. Also the analysis of local and cumulative exergy losses, as well as cumulative exergy consumption requires a system approach. As stressed by Szargut and Sama “consider the influence of the proposed changes in energy management on the exergy losses in other links of the system” [6]. This means that in a system consisting of many elements, the improvement of not only one of them should be considered, because the decrease of exergy losses in one element may involve in the system both positive and negative effects. This requirement can be satisfied if the complex exergy analysis is assessed by means of system analysis. System approach requires that all the balance equations resulting both from the I and II Law of Thermodynamics are considered jointly. In the analysis of large energy systems commonly Leontief’s “input-output analysis” is applied [7–9].

2. System approach to the complex exergy analysis

In this paper the system approach (“input-output” analysis [10–12]) is proposed to evaluate:

1. direct energy and materials consumption,
2. local (internal) exergy losses (LExL),
3. cumulative exergy consumption (CExC),
4. cumulative exergy losses (CExL),
5. cumulative exergy efficiency (CExE) also known as cumulative degree of thermodynamic perfection (CDP),

of main products and net electricity production of the analysed OFC power plant with CO_2 transport and storage module.

2.1. “Input-output” model of direct energy and materials consumption

The core of system analysis is the “input-output” model of direct energy and material consumption, which was in details described by the Authors in their previous publications [10, 12]. The integrated OFC power plant with CO_2 T&S module is a system consisting of energy branches (technological modules) connected with each other by interbranch relations. The “input-output” table [10] presents the system of interbranch connections concerning analyzed system.

The mathematical model of the balance of direct energy and material consumption, based on the presented "input-output" Table [10] takes the following form:

$$\Lambda_{i-1}^{n} : G_i + \sum_{j-1}^{k} f_{ij}^{FG} G_j + D_{Gi} = \sum_{j-1}^{k} a_{ij}^{G} G_j + K_{Gi} \quad (1)$$

$$\Delta_{l-n+1}^{m} : \sum_{j-1}^{k} f_{ij}^{F} G_j = \sum_{j-1}^{k} a_{ij}^{F} G_j + K_{Fl} \quad (2)$$

$$\Delta_{p=m+1}^{S} : D_p = \sum_{j=1}^{k} a_{pj}^{D} G_j \quad (3)$$

where: G_i, $K_{G\,i}$ and $D_{G\,i}$—main production, final production and external supply of i-th main product;$f_{i\,j}^{FG} G_j$and $f_{l\,j}^{F} G_j$—by-production supplementing i-th main product and by-production of l-th by-product not supplementing the main production in j-th technological module; $a_{i\,j}^{G} G_j$, $a_{l\,j}^{F} G_j$ and $a_{p\,j}^{D} G_j$—consumption of i-th main product, l-th by-product or p-th external supply in j-th technological module;$K_{F\,l}$—final production of l-th by-product not supplementing the main production;D_p—supply from outside of p-th external supply. Eq. 1, Eq 2 and Eq 3 corresponds to the balance of main products including by-production and external supplies supplementing the main production, the balance of by-products not supplementing the main production and the balance of external supplies not supplementing the main production, respectively [10, 12].

The universal structure of the "input-output" mathematical model of direct energy and material consumption (Eq 1, Eq 2 and Eq 3) together with the distinguished main products, by-products and external supplies (Table 1) of an integrated OFC power plant with CO_2 transport and storage allows to build a mathematical model of different technological configurations of power cycles both working with OFC technology or not (without CO_2 capture).

2.2. *"Input-output" model of local exergy losses*

The calculation algorithms of local system exergy losses are based on "input-output analysis". Fig. 2 illustrates the diagram of exergy balance concerning the j-th module (energy branch) formulated in compliance with the "input-output" tables [10].

Based on the diagram of exergy balance concerning the j-th module, the set of exergy balances concerning all the modules takes the following form:

Table 1: List of energy carriers and materials of an OFC power plant with CO_2 T&S module

No.	Energy carrier or material
Main products	i = 1 ... n
1	HP & IP process steam, MJ
2	Electricity, MJ
3	Cooling duty, MJ
4	CO_2-rich stream, Mg
5	Gaseous oxygen (GOX), Mg
6	CO_2 product, Mg
7	CO_2 stored, Mg
By-products	l = n+1 ... m
8	LP process steam, MJ
9	LT process heat, MJ
10	MT process heat, MJ
11	HT process heat, MJ
12	Preheated air process heat, MJ
13	Flue gases, Mg
14	Primary recycle stream, Mg
15	Secondary recycle stream, Mg
16	Bottom ash, Mg
17	Fly ash, Mg
18	Gypsum, Mg
19	Liquid oxygen (LOX), Mg
20	Gaseous nitrogen (GAN), Mg
21	Liquid nitrogen (LIN), Mg
22	Liquid argon (LAR), Mg
23	Vent, Mg
24	CO_2 utilized, Mg
25	Make-up water, Mg
26	Wastewater, Mg
External supplies	p = m+1 ... s
27	Coal, MJ
28	Biomass, MJ
29	Natural gas, MJ
30	Ammonia, MJ
31	Activated carbon, MJ
32	Raw water, MJ
33	Limestone, MJ

$$\Lambda_{j=1}^{k} \vdots \sum_{i=1}^{n} (a_{ij}^{G} G_j) \cdot b_{Gi} + \sum_{l=n+1}^{m} (a_{lj}^{f} G_j) \cdot b_{Fl} + \sum_{p=m+1}^{S} (a_{pj}^{D} G_j) \cdot b_{Dp} = G_j b_{Gj} + \sum_{i=1}^{n} (f_{ij}^{FG} G_j) \cdot b_{Gi} + \sum_{l=n+1}^{m} (f_{lj}^{F} G_j) \cdot b_{Fl} + \delta B_j \quad (4)$$

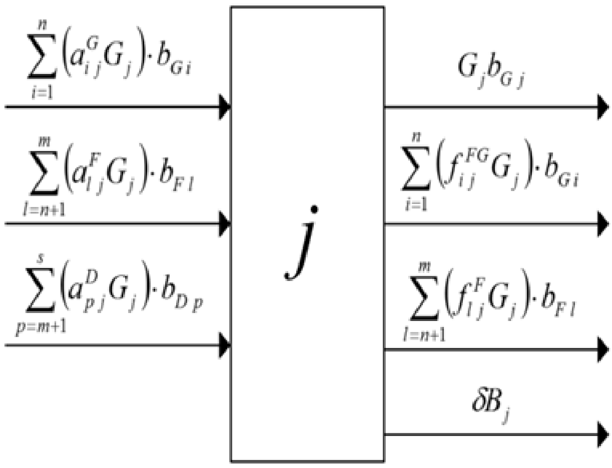

Figure 2: Calculating diagram of local exergy losses

where: $b_{G.i}$ and $b_{G.j}$ are the specific exergy of the i-th or j-th main product and $b_{F.l}$ and $b_{D.p}$ are the specific exergy of l-th by-product and p-th external supply, respectively. From Eq. 4 the local (internal) exergy losses δB_j can be calculated for each of the modules.

All the specific exergies of each energy carrier or material have been calculated based on the general rules introduced by Szargut [13**?** , 14]. The reference environment model and standard chemical exergy of pure substances has also been taken after Szargut [13**?** , 14]. The detailed approach for calculation of each specific exergy have been presented in [15].

2.3. *"Input-output" model of cumulative exergy consumption*

The mathematical model of the system approach to the cumulative exergy consumption is based on the principle of the mathematical "input-output" model of direct energy and materials consumption, similarly as the methodology of calculating the cumulative energy consumption [16, 17]. Cumulative exergy consumption charging the products of the process equals the sum of the cumulative exergy consumption of substrates of the process [18]. In the case of an integrated OFC power plant the "input-output method" was applied assuming that the interconnections between the analyzed power plant and domestic economy (e.g. energy, industry) system are rather weak. Such an assumption allows to apply in the calculations indices of the CExC of external supplies ($b^*_{D.p}$) as quantities known a'priori [17, 18]. The suggested model assumes that supplies from outside are charged by cumulative exergy consumption determined as an averaged value of the country and in this paper they are taken over from the Ecoinvent database, where the Cumulative Exergy Consumption method is introduced [19]. By-products are charged by the cumulative exergy consumption ($b^*_{F.l}$) resulting from the principle of replacing (the avoided cumulative exergy consumption in a single-aimed process) [17]. The input data are also taken over from the Ecoinvent database [19]. Fig. 3 illustrates the diagram of cumulative exergy consumption balance concerning the j-th module (energy branch) formulated in compliance with the "input-output" tables [10].

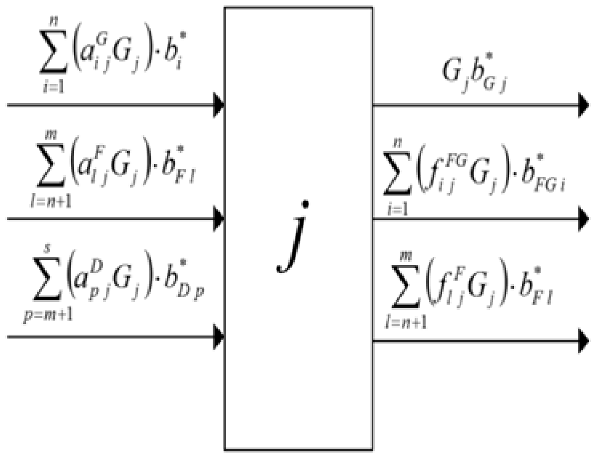

Figure 3: Calculating diagram of cumulative exergy consumption

The set of balance equations of cumulative exergy consumption take the following form:

$$\begin{gathered}\Delta_{j=1}^{n} \vdots \sum_{i=1}^{n}(a_{ij}^{G}G_j) * b_i^* + \sum_{l=n+1}^{m}(a_{ij}^{F}G_j)\cdot b_{Fl}^* + \\ \sum_{p=m+1}^{S}(a_{pj}^{D}G_j)\cdot b_{Dp}^* \\ = G_j b_{Gj}^* + \sum_{i=1}^{n}(f_{ij}^{FG}G_j)\cdot b_{FGi}^* + \sum_{l=n+1}^{m}(f_{lj}^{F}G_j)\cdot b_{Fl}^*\end{gathered} \tag{5}$$

where the average-weighted index of cumulative exergy consumption is defined as follows:

$$b_i^* = r_{Gi}b_{Gi}^* + r_{FGi}b_{FGi}^* + r_{DGi}b_{DGi}^* \tag{6}$$

where $r_{G.i}$, $r_{FG.i}$,$r_{DG.i}$ denote the share of main production, by-production supplementing the main production and external supplies supplementing the main production in the input of the i-th energy carrier and $b^*_{FG.i}$, $b^*_{DG.i}$ denote indices of cumulative exergy consumption concerning the i-th by-production supplementing the main production and external supply supplementing the main production. Base on the Eq. 5 and Eq. 6 the indices cumulative exergy consumption of the j-th main product ($b^*_{G.j}$) can be calculated.

When we apply the idea of the cumulative exergy consumption to the "input-output" analysis, from the algorithm presented above (Eq. 5 and Eq. 6), we get the cumulative exergy consumption of each to the main products (gross). When the whole integrated OFC power plant with CO_2 T&S is considered, we have to take into account the energy carriers or materials intersecting the cover balance sheet. This can be calculated based on the general balance equation of the cumulative exergy consumption [18, 20] or based on the obtained results concerning the CExC of main products. For a more clear interpretation of the results, the unit CExC of net electricity production (b*) can be introduced, which is defined as:

$$b^* = \frac{\sum_{i=1}^{n} K_{Gi} * b^*_{Gi}}{K_{G_2}} \tag{7}$$

where $K_{G.2}$ denotes the net electricity production of the whole system (CCS chain).

2.4. Cumulative exergy losses and cumulative exergy efficiency

The difference between the cumulative exergy consumption and the specific exergy of the given product represent the cumulative exergy losses (CExL) and may be calculated by means of the equation [21–24]:

$$\delta b^*_{Gi} = b^*_{Gi} - b_{Gi} \tag{8}$$

where δb^*_{Gi} denotes the index of cumulative exergy loss associated with the production of the i-th main product.

The cumulative exergy efficiency (CExE), also called cumulative degree of thermodynamic perfection (CDP), can be calculated from the equations [17, 21]:

$$\eta^*_{Bi} = \frac{b_{Gi}}{b^*_{Gi}} = 1 - \frac{\delta b^*_{Gi}}{b^*_{Gi}} \tag{9}$$

where $\eta^*_{B.i}$ (CExE or CDP) is always smaller then 1, because of exergy losses resulting from the irreversibility of the links of the analyzed system.

3. Example

The example presented in this paper is based on [25], where several advanced OFC technologies for bituminous coal power plants are analyzed. The current oxycombustion case have been chosen and, as the whole CCS chain in this paper is analyzed, the CO_2 transport and storage has been chosen base on [26] and databases for different CO_2 T&S options [27]. The characteristic parameters for the analyzed OFC power plant with CO_2 transport and storage are listed in Table 2.

The presented OFC power plant has been equipped with a conventional cryogenic distillation air separation unit in order to generate the oxygen at 95% purity. The flue gas quality control module consist of baghouse unit for particles separation and a wet desulfurization unit for SO_2 control. After the FGD, part of the flue gases (about 70%) are recycled to the boiler in order to reduce the inlet oxygen concentration and maintain the theoretical adiabatic flame temperature in the boiler (2031°C). The recycled part of the flue gases are heated up (by 9K) to prevent the introduction of liquid water into the primary and secondary fans as wet recycle is realized. The remaining flue gases are dehydrated in the CPU and compressed to 15.3 MPa. Detailed information concerning the configuration and applied technologies for each module can be found in [25]. Then the CO_2 is transported 100 km to a geologic sequestration filed for injection into a saline formation. Due to the assumption made along the way (concerning the pressure drop in the pipeline), there is no need for recompression of the stream of CO_2 in the pipeline. Additionally, the injection of the CO_2 into the saline aquifer cause brine water production which reinjection without treatment is assumed. Both storing of CO_2 and brine water management cause additional electricity consumption in the CO_2 T&S module. The CO_2 is stored in saline formation at the pressure of 8.4 MPa [25]. No CO_2 leakage is assumed during the CO_2 transport and storage.

First, in order to perform a complex exergy analysis based on "input-output" approach the mathematical model of direct energy and materials consumption have been elaborated based on the presented process model [25]. Also the additional data have been collected (e.g. flue gas composition, temperature level of process heat) in order to calculate the specific exergy of each main product, by-product and external supply occurring in the analyzed case. In order to calculate the indices of cumulative exergy consumption of main production, the values of CExE for external supplies and by-production have been gathered and introduced into the mathematical model of cumulative exergy consumption. The values of calculated specific exergies, as well as assumed and calculated (Table 3) values of CExC have been presented in Table 3. Some of the by-products and external supplies do not occur in the analyzed case (e.g. high-temperature process heat or natural gas).

The CExC of external supplies have been taken over from the EcoInvent database [19], as well as the data for the by-products (based on assumed replaced processes). The CExC of low-pressure steam, as well as, low-temperature process heat have been calculated with the

Table 3: Specific exergy and cumulative exergy consumption of energy carriers and materials (referred to Table 1)

No.	Specific exergy		Cumulative exergy consumption	
1	0.5781	MJ_{ex}/MJ	1.528	MJ_{ex}/MJ
2	1	MJ_{ex}/MJ	3.315	MJ_{ex}/MJ
3	0.02195	MJ_{ex}/MJ	0.0789	MJ_{ex}/MJ
4	363.6	MJ_{ex}/Mg	1345	MJ_{ex}/Mg
5	146.6	MJ_{ex}/Mg	2977	MJ_{ex}/Mg
6	605.3	MJ_{ex}/Mg	2810	MJ_{ex}/Mg
7	593.0	MJ_{ex}/Mg	3021	MJ_{ex}/Mg
8	0.38	MJ_{ex}/MJ	3.01	MJ_{ex}/MJ
9	0.175	MJ_{ex}/MJ	2.685	MJ_{ex}/MJ
13	478.9	MJ_{ex}/Mg	1266	MJ_{ex}/Mg
14	363.6	MJ_{ex}/Mg	1345	MJ_{ex}/Mg
16	672.4	MJ_{ex}/Mg	5250	MJ_{ex}/Mg
17	1380	MJ_{ex}/Mg	5250	MJ_{ex}/Mg
18	149.3	MJ_{ex}/Mg	2330	MJ_{ex}/Mg
20	19.77	MJ_{ex}/Mg	0	MJ_{ex}/Mg
25	67.94	MJ_{ex}/Mg	340	MJ_{ex}/Mg
26	68.48	MJ_{ex}/Mg	0	MJ_{ex}/Mg
27	1.086	MJ_{ex}/MJ	1.295	MJ_{ex}/MJ
32	67.94	MJ_{ex}/Mg	101	MJ_{ex}/Mg
33	162.9	MJ_{ex}/Mg	1030	MJ_{ex}/Mg

use of so called exergy key [13, 14], where the reference values of CExC and the corresponding temperature and pressure values gathered from EcoInvent database [19]. The CExC of fly ash and bottom ash results from the assumption that 50% of them is usefully utilized in cement industry and the value results from the difference of CExC of cement production with and without the use of ash [19]. The CExC of flue gases was calculated with the use of exergy key, where the reference state was main product of boiler island (HP & IP process steam), as the data for the replaced process concerning flue gases with high CO_2 concentration are not available. In the mathematical model of CExC we assumed that certain by-products (gaseous nitrogen and wastewater) have the value of CExC equal to 0. This means that they are not useful by-products, which can replace other materials in the analyzed case.

Based on the Eq. (6) the unit CExC of net electricity production was calculated. The obtained value (4.368 MJex/MJ) is similar to those quoted in the literature [18, 19] and express the cumulative exergy consumption associated with the net electricity production when the whole CCS chain (including CO_2 transport and storage) is taken into account. Also the cumulative exergy efficiency was calculated including the whole CCS chain and taking into account net electricity production. The obtained value is 22.89% and its lower from the net energy efficiency (29.69%) of the whole CCS chain.

From the mathematical model of local exergy losses (Eq. 4) the LExL associated with each given technological module have been calculated. The cumulative exergy losses (CExL) and cumulative exergy efficiency (CExE) have been calculated by means of the Eq. 7 and Eq. 8, respectively. The results have been presented in Table 4.

Table 4: Specific local (LExL) and cumulative (CExL) exergy losses and cumulative exergy efficiency (CExE)

Module	LExL, MJ_{ex}/MJ	CExL, MJ_{ex}/MJ	CExE, %
Boiler island	0.5187	0.9502	37.83
Steam cycle	0.252	2.315	30.16
Cooling water module	0.012	0.057	27.81
Flue gas quality control	476.3	981	27.04
Air separation unit	666.9	2830	4.925
CO_2 processing unit	190.2	2205	21.54
CO_2 transport & storage	75.72	2428	19.63

Results concerning local exergy losses and cumulative exergy efficiency have been also presented in Fig. 4. The highest local exergy losses are associated with primary and secondary steam production in boiler island, although this module have the relatively higher cumulative exergy efficiency. The lowest value of CExE is associated with oxygen production, where the value is below 5%. This point out that further studies should focus on more efficient paths for oxygen generation (e.g. based on membrane separation process [25]).

Fig. 5 presents the shares of each components local exergy losses in total exergy losses of the whole analyzed system. The CCS related modules (ASU, CPU and CO_2 T&S) are responsible for only 11.3% of total local exergy losses, where the CO_2 transport and storage is only slightly above 1%. The CExE of CPU and CO_2 T&S module are around 20%, which could also indicate that further studies in this field may be necessary (e.g. advance CO_2 compression thru shock wave technology [25]).

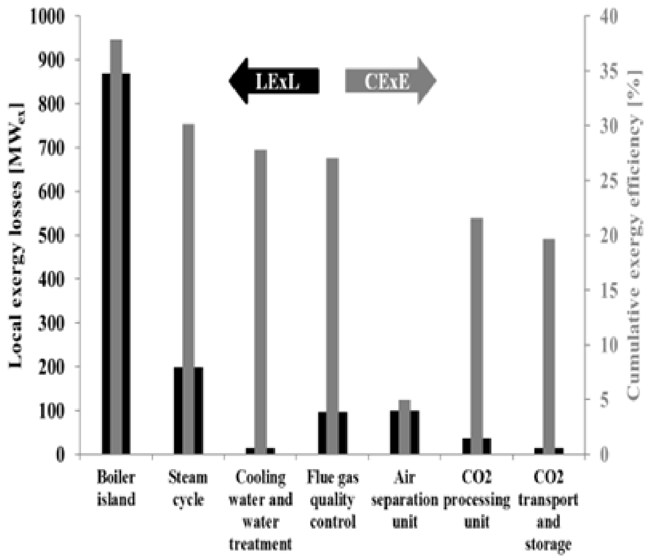

Figure 4: Local exergy losses (LExL) and cumulative exergy efficiency (CExE)

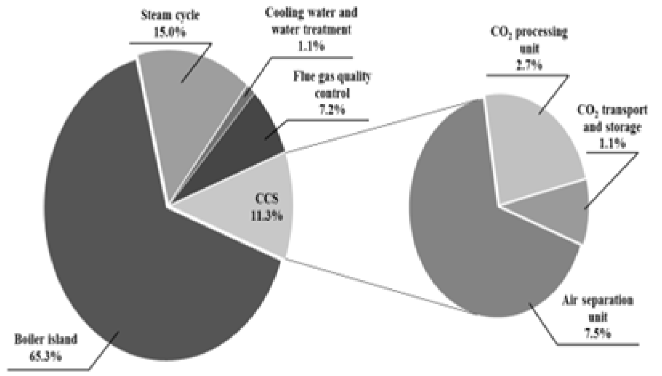

Figure 5: Share of total local exergy losses associated with each technological module of an integrated OFC power plant with CO_2 transport and storage

4. Conclusions

The obtained index of cumulative exergy consumption of net electricity production is higher than those quoted in the literature (e.g. 3.91 MJex/MJ for Polish coal fired power plants [19]). This results, first of all, from the fact that the CCS technology was applied taking into account also the CO_2 transport and storage. Then only OFC power plant is concern the CExC of net electricity production is 4.2 MJex/MJ (lower about 4%). If the solid waste products (fly ash and bottom ash) are not utilized, the index of CExC of net electricity production grows slightly to 4.434 MJex/MJ, which proves that the influence is rather small but still positive.

The results of the cumulative exergy efficiency analysis points to the necessity of further improvements of the modules related to the CO_2 capture, transport and storage. It is especially evident when the air separation unit is concern, where the CExE is below 5%. The share of local exergy losses of the CCS related modules is around 11%, which compared to the boiler island (65.3%) is not that high.

The obtained results concerning CExC, CExE and LExL are similar to those quoted in the literature, which proves the correctness of the proposed models. The "input-output" method of complex exergy analysis can be a useful for assessment of direct process changes, i.e. the oxygen production technology, including all the changes due to both direct and indirect interconnections existing in the analyzed system.

The presented algorithm are parts of the authors programme concerning system analysis of an integrated oxy-fuel power plants "OSA" (Oxy System Analysis). The programme comprise system analysis of direct and cumulative energy and exergy consumption, as well as, ecological analysis applying life cycle thermoecological cost and cumulative CO_2 emissions [20].

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Table 2: Case description—characteristic parameters

	Integrated OFC power plant [25]
Gross power, MW_{el}	790.80
Net power, MW_{el}	550.02
Live steam , MPa/°C/°C	24.1/600/620
Fuel, LHV, MJ/Mg	26,171, hard coal (Illinois No. 6)
ASU, oxygen purity, mol%	95, conventional cryogenic technology
FGQC	wet FGD/ESP
CPU technology	without purification (only CO_2 dryer)
CO_2 purity/pressure	raw product produced using oxygen from ASU, further dehydrated to 0.015% (by volume) H_2O; 83.5% CO_2 purity / 15.3 MPa
	CO_2 transport [26]
Transport option	onshore pipeline
Pipeline length, km	100
Electricity consumption, MWh/MgCO_2	0, (no recompression along the way)
	CO_2 storage [27]
Storage option	saline aquifer
Electricity consumption, MWh/Mg CO_2	0.013 (for CO_2 storage)
Brine water management	reinjection without treatment
Brine water production, Mg/Mg CO_2	1.4
Electricity consumption, MWh/Mg	0.0033 (additional for brine water management)