

EXERGETIC MODELING OF OIL SHALE-FIRED CIRCULATING FLUIDIZED BED SYSTEMS

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ABSTRACT

Oil Shale (OS) has been successfully burnt in many circulating fluidized beds due to their values for the satisfactory desulphurization and combustion efficiency, low NO_x emission as well as the adaptability to low-grade coal, appropriate capital and operation costs.

In this study, the relations related to the exergetic evaluation of the Oil Shale Fluidized Bed Systems (OSFBSs) are given for modeling purposes first. Next, this model is applied to a highly efficient OSCFBS having a boiler with a steam mass flow rate of 65 t/h designed for Huadian thermal power plant in China using the actual operational data given in the literature. The exergy efficiencies of the system are then determined to assess its performance and to elucidate potentials for improvement. Finally, the results obtained are discussed, while some recommendations are made.

INTRODUCTION

Fluidized beds can be widely used as reactors, heat exchangers, granulators and a host of other processing devices in physical and chemical processes where the need for solids mobility, temperature uniformity, or rapid heat transfer makes fluidization an attractive unit operation. Furthermore, fluidized-bed combustion is a convenient way of burning fuels of different ranks, ranging from wood to anthracite and a relatively new option that reduces both SO₂ and NO_x emissions (Hepbasli, 1998).

OS, a sapropelic deposited rock containing organic combustible materials, is rich and widespread in the earth. At present, reserves of proven OS are estimated to be about 475 Gt if converted into shale oil. OS is mainly used for burning and oil refining purposes. For improving the availability of OS, many specialists brought forward burning OS in circulating fluidized bed systems (CFBSs). By now, many OSCFBSs have been successfully put into commercial operation (Han et al., 2006).

Exergy analysis is a very useful tool, which has been successfully used by many investigators in the design, simulation and performance assessment of thermal systems. It is also important for energy resource utilization, because exergy is a part of the energy analysis; the theory behind it is essentially that of available

energy analysis. The concepts of exergy, available energy and availability are essentially similar. The concepts of exergy destruction and consumption, irreversibility, and lost work are also essentially similar. However, the terminology does not appear to have been standardized. Exergy is also a measure of the maximum useful work that can be done by a system interacting with an environment that is at a constant pressure P_0 and at a temperature T_0 . (Rosen and Dincer, 2001).

Dincer (2002) reported the linkages between energy and exergy, exergy and the environment, energy and sustainable development, and energy policy making and exergy in detail. He provided the following key points to highlight the importance of the exergy and its essential utilization in numerous ways: (a) it is a primary tool in best addressing the impact of energy resource utilization on the environment. (b) It is an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems. (c) It is a suitable technique for furthering the goal of more efficient energy-resource use, for it enables the locations, types, and true magnitudes of wastes and losses to be determined. (d) It is an efficient technique revealing whether or not and by how much it is possible to design more efficient

energy systems by reducing the inefficiencies in existing systems. (e) It is a key component in obtaining a sustainable development.

It should be noticed that exergy is always evaluated with respect to a reference environment (i.e. dead state). When a system is in equilibrium with the environment, the state of the system is called the dead state due to the fact that the exergy is zero. At the dead state, the conditions of mechanical, thermal, and chemical equilibrium between the system and the environment are satisfied: the pressure, temperature, and chemical potentials of the system equal those of the environment, respectively. In addition, the system has no motion or elevation relative to coordinates in the environment. Under these conditions, there is neither possibility of a spontaneous change within the system or the environment nor an interaction between them. The value of exergy is zero. Another type of equilibrium between the system and environment can be identified. This is a restricted form of equilibrium, where only the conditions of mechanical and thermal equilibrium (thermo-mechanical equilibrium) must be satisfied. Such state is called the restricted dead state. At the restricted dead state, the fixed quantity of matter under consideration is imagined to be sealed in an envelope impervious to mass flow, at zero velocity and elevation relative to coordinates in the environment, and at the temperature T_0 and pressure P_0 taken often as 25°C and 1 atm (Moran, 1982).

Studies conducted on exergetic performance evaluation of OSCFBSs based on the actual operational data have not appeared in the open literature to the best of the author's knowledge, although those on the design, operation and energetic evaluation of these systems are much in numbers. In this regard, there have been some studies on exergetic evaluation of fluidized bed systems, which have been investigated as part of a whole system and have also been simulated (i.e., Eskin and Kilic, 1996; Zhang et al., 2002; Martin et al., 2006; Panopoulos et al., 2006; Ozdemir, 2006).

The main objective of the contribution is to evaluate exergetically the performance of a OSCFBS, which was designed for Huadian thermal power plant in China. The performance of this system has been energetically analyzed and assessed by Han et al. (2006), whose some data and results have been used in this study.

GENERAL RELATIONS

For a general steady state, steady-flow process, the four balance equations (mass, energy, entropy and exergy) are applied to find the work and heat interactions, the rate of exergy decrease, the rate of irreversibility, the energy and exergy efficiencies (Dincer et al., 2004; Balkan et al., 2005).

Mass, Energy and Exergy Balances

The mass balance equation can be expressed in the rate form as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

where \dot{m} is the mass flow rate, and the subscript *in* stands for inlet and *out* for outlet.

The general energy balance can be expressed below as the total energy inputs equal to total energy outputs.

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \quad (2)$$

In the absence of electricity, magnetism, surface tension and nuclear reaction, the total exergy of a system \dot{E}_x can be divided into four components, namely (i) physical exergy \dot{E}_x^{PH} , (ii) kinetic exergy \dot{E}_x^{KN} , (iii) potential exergy \dot{E}_x^{PT} , and (iv) chemical exergy \dot{E}_x^{CH} [16].

$$E\dot{x} = E\dot{x}^{PH} + E\dot{x}^{KN} + E\dot{x}^{PT} + E\dot{x}^{CH} \quad (3)$$

Although exergy is extensive property, it is often convenient to work with it on a unit of mass or molar basis. The total specific exergy on a mass basis may be written as follows:

$$ex = ex^{PH} + ex^{KN} + ex^{PT} + ex^{CH} \quad (4)$$

The general exergy balance can be written as follows:

$$\Sigma \dot{E}x_{in} - \Sigma \dot{E}x_{out} = \Sigma \dot{E}x_{dest} \quad (5a)$$

or

$$E\dot{x}_{heat} - E\dot{x}_{work} + E\dot{x}_{mass,in} - E\dot{x}_{mass,out} = E\dot{x}_{dest} \quad (5b)$$

with

$$E\dot{x}_{heat} = \Sigma \left(1 - \frac{T_0}{T_k}\right) \dot{Q}_k \quad (6a)$$

$$E\dot{x}_{work} = \dot{W} \quad (6b)$$

$$E\dot{x}_{mass,in} = \Sigma \dot{m}_{out} \psi_{out} \quad (6c)$$

$$E\dot{x}_{mass,out} = \Sigma \dot{m}_{out} \psi_{out} \quad (6d)$$

where \dot{Q}_k is the heat transfer rate through the boundary at temperature T_k at location k and \dot{W} is the work rate.

The flow (specific) exergy is calculated as follows:

$$\psi = (h - h_0) - T_0 (s - s_0) \quad (7)$$

where h is enthalpy, s is entropy, and the subscript zero indicates properties at the restricted dead state of P_0 and T_0 .

The specific exergy (flow exergy) of an incompressible substance (i.e., water) is given by (Szargut, 2005).

$$\psi_w = C(T - T_0 - T_0 \ln \frac{T}{T_0}) \quad (8)$$

Assuming air to be a perfect gas, the specific physical exergy of air is calculated by the following relation (Kotas, 1995).

$$\psi_{a,per} = C_{p,a} \left(T - T_0 - T_0 \ln \frac{T}{T_0} \right) + R_a T_0 \ln \frac{P}{P_0} \quad (9)$$

For calculating the chemical exergy of fuels, there are various approaches in the literature. Based approximation method for fuel chemical exergy, the following relations are widely used.

$$\beta_{LHV} = \frac{\dot{E}x_{CH}}{LHV} \quad (10)$$

$$\beta_{HHV} = \frac{\dot{E}x_{CH}}{HHV} \quad (11)$$

where β is the proportionality constant (or quality factor or exergy coefficient), while LHV and HHV denote the lower heating (net caloric) and higher heating (gross caloric) values, respectively (Hepbasli et al., 2006).

The specific chemical exergy of flue gases on the molar basis are calculated as follows:

$$\bar{e}^{CH} = \sum x_k \bar{e}_k^{CH} + \bar{R}T_0 \sum x_k \ln x_k \quad (12)$$

where x_k is the mole fraction of the k-th component in the mixture.

Energy and Exergy Efficiencies

Numerous ways of formulating exergetic (or exergy or second-law) efficiency (effectiveness, or rational efficiency) for various energy systems are given in detail elsewhere (Cornelissen, 1997). It is very useful to define efficiencies based on exergy (sometimes called *Second Law efficiencies*). There is no standard set of definitions in the literature.

Here, in a similar way, exergy efficiency is defined as the ratio of total exergy output to total exergy input, i.e.

$$\varepsilon = \frac{\dot{E}x_{output}}{\dot{E}x_{input}} = 1 - \frac{\dot{E}x_{dest}}{\dot{E}x_{input}} \quad (13)$$

where "output or out" stands for "net output" or "product" or "desired value" or "benefit", and "input or in" stands for "given" or "used" or "fuel".

The exergy efficiency of a heat exchanger (i.e., air preheater) is determined as the increase in the exergy of the cold stream divided by the decrease in the exergy of the hot stream, on a rate basis, as follows:

$$\varepsilon_{HE,1} = \frac{E\dot{x}_{cold,out} - E\dot{x}_{cold,in}}{E\dot{x}_{hot,in} - E\dot{x}_{hot,out}} \quad (14a)$$

$$\varepsilon_{HE,1} = \frac{\dot{m}_{cold}(\psi_{cold,out} - \psi_{cold,in})}{\dot{m}_{hot}(\psi_{hot,in} - \psi_{hot,out})} \quad (14b)$$

Assuming that exergy destructions due to heat transfer over a finite temperature difference and pressure losses in the two streams have equal shares in the total exergy destruction (irreversibility), the following relation for calculating the exergy (rational) efficiency of a heat exchanger may be used (Kotas, 1995).

$$\varepsilon_{HE,2} = 1 - \frac{2T_0 \frac{\Delta T}{T_{1,m}^2}}{\frac{T_{1,m} - T_0}{T_{1,m}} + T_0 \frac{\Delta T}{T_{1,m}^2}} \quad (15a)$$

with

$$\Delta T = T_{1,m} - T_{2,m} \quad (15b)$$

where $T_{1,m}$ and $T_{2,m}$ may be taken as the mean temperatures of the streams.

Exergetic Improvement Potential

Van Gool (1997) has proposed that maximum improvement in the exergy efficiency for a process or system is obviously achieved when the exergy loss or irreversibility ($E\dot{x}_{in} - E\dot{x}_{out}$) is minimized. Consequently, he suggested that it is useful to employ the concept of an exergetic "improvement potential" when analyzing different processes or sectors of the economy. This improvement potential in the rate form, denoted $I\dot{P}$, is given by

$$I\dot{P} = (1 - \varepsilon)(E\dot{x}_{in} - E\dot{x}_{out}) \quad (16)$$

SYSTEM DESCRIPTION

Fig. 1 illustrates a schematic of the OSCFBS investigated, which was put into commercial operation in 1996 (Zhang et al., 2006), while detailed information about its design and operation experience may be found in Ref. (Jiang et al., 2001).

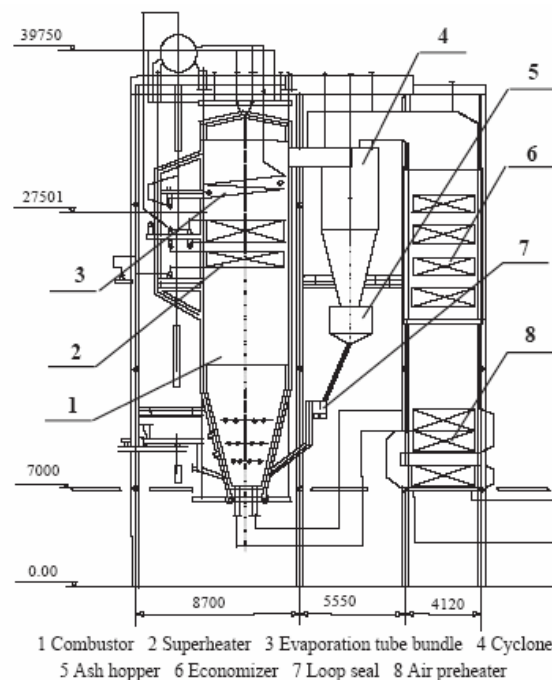


Fig. 1. Schematic diagram of the OSCFBS investigated (Zhang et al., 2006).

As can be seen in Fig. 1, this system consists of mainly four components, which are evaluated using exergy analysis method. These include a combustor, a superheater, an evaporator (or evaporation tube bundle), an economizer and an air preheater. Other energy consuming components, such as pumps,

fans, are not considered in the analysis. For the accurate exergetic analysis, the exergy destructions in all parts of the system (i.e., losses due to pipe lines, valves, etc.) should also be taken into consideration.

The energetic performance of the OSCFBS

is assessed at various steam capacities, namely at steam capacities of 71.4, 48.06 and 64.74 t/h. In this study, the last steam capacity of 64.74 t/h is taken into account, while the values used in the analysis are presented in Tables 1 and 2, where some energetic data of the boiler and the ultimate and proximate analysis of Huadian oil shale are included, respectively (Han et al., 2006).

Table 1. Some energetic data of the boiler (Han et al., 2006).

Items	Unit	Value
Steam capacity	t/h	64.74
Steam pressure	MPa	5.2
Steam temperature	°C	449
Lower heating value	kJ/kg	7087
Feed water temperature	°C	161
Air temperature	°C	26.37
Stack gas temperature	°C	151
Fly ash carbon	%	0.41
Bottom ash carbon	%	0.74
Bottom ash temperature	°C	848
Fly ash fraction (bottom ash %)	%	52.6
Bottom ash fraction	%	47.4
Waste heat loss	%	7.20
Unburned gas loss	%	0
Unburned carbon loss	%	1.53
Heat leakage	%	0.80
Thermal loss of bottom ash	%	3.53
Combustion efficiency	%	98.47
Thermal efficiency	%	87.83

Table 2. Ultimate and proximate analysis of Huadian oil shale (Han et al., 2006)

Ultimate analysis (% by weight)				
Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
31.63	4.370	7.764	0.726	1.000
Proximate analysis (% by weight)				Lower heating (net calorific) value (kJ/kg)
Moisture	Volatile matter	Ash	Fixed carbon	
2.90	41.89	51.61	3.60	8374

APPLICATION OF EXERGY ANALYSIS TO SYSTEM

The following assumptions are used during the exergy analysis of the OSCFBS.

- All processes are steady-state and steady-flow with negligible potential and kinetic energy effects and no nuclear reactions.
- Heat transfer to the system and work transfer from the system are positive.

- c) Heat transfer and pressure drops in pipe lines and ducts are neglected.
- d) Heat losses from the system components are not considered.
- e) Air is an ideal gas with a constant specific heat.
- f) The composition of the flue gases on the molar basis are as follows: $x_{CO_2} = 0.1668$, $x_{SO_2} = 0.0052$, $x_{N_2} = 0.7759$, $x_{O_2} = 0.0305$ and $x_{H_2O} = 0.0216$. These values were calculated using the relations given in FDBR-Handbook (1980) and the elemental analysis data of the fuel presented in Table 2 at an excess air coefficient of 1.3.
- g) The exergetic evaluation of fans and pumps is not performed, since power inputs to these devices have not been given by Zhang et al. (2006). These power inputs to the system components are also not included in the calculations.
- h) The values for the reference state temperature and pressure are 298.15 K and 1.013 bar (about 1 atm).

Exergy destructions obtained from exergy balances for some of the OSCFBS components illustrated in Figure 1 as well as exergy efficiencies are derived as follows:

For furnace (combustor):

The furnace consists of mainly two parts, namely active and free beds. The exergy balance relations should be derived for each of these beds. In the present study, this was not realized since the data in the relevant reference (Zhang et al., 2006) were insufficient. For example, active bed contains horizontal (or immersed tubes) and vertical tubes consisting of the furnace wall, but their heating surfaces and temperatures were not available. Therefore, the exergy efficiency of the furnace on the benefit/fuel basis was calculated as follows, while the exergies of the fly and bottom ashes were neglected.

$$\varepsilon_{\text{furnace}} = \frac{\dot{E}x_{\text{absorbed}}}{\dot{E}x_{\text{CH,os}} + \dot{E}x_{\text{hot air}}} \quad (17a)$$

where $\dot{E}x_{\text{CH,os}}$ is the chemical exergy of the oil shale, while it is calculated using the following relation proposed by Kotas (1995) for solid fuels at a limit of $(Z_{O_2} / Z_C) \leq 0.667$

$$E\dot{x}_{\text{CH,os}} [\text{kJ/kg}] = [\text{LHV}[\text{kJ/kg}] + 2442w]\beta_{\text{LHV,dry}} + 9417Z_s \quad (17b)$$

with

$$\beta_{\text{LHV,dry}} = 1.0437 + 0.1882(Z_{H_2} / Z_C) + 0.0610(Z_{O_2} / Z_C) + 0.0404(Z_{N_2} / Z_C) \quad (17c)$$

where Z_i is mass fraction of element i .

The exergy of the absorbed heat ($\dot{E}x_{\text{absorbed}}$) is calculated in a similar way as given by Eq. (6a).

$$E\dot{x}_{\text{absorbed}} = \left(1 - \frac{T_0}{T_{\text{combustion}}}\right) \dot{Q}_{\text{absorbed}} \quad (17d)$$

The exergy of the hot air ($\dot{E}x_{\text{hot air}}$) is calculated using Eq. (9) as follows:

$$\dot{E}x_{hot\ air} = \dot{m}_{hot\ air} \psi_{hot\ air} \quad (17e)$$

For heat exchangers, such as superheater, economizer and air heater, the exergy efficiency is calculated using Eqs.(14) and (15).

For the convection bank and divert room, the exergy efficiency is found as follows:

$$\epsilon_{conv\ bank,\ diroom} = \frac{\dot{E}x_{flue\ gas}}{\dot{E}x_{absorbed}} \quad (18)$$

where $\dot{E}x_{flue\ gas}$ is the exergy of the flue gases.

The exergy efficiency (or the rational efficiency) of the whole system is calculated as follows.

$$\epsilon_{rat} = \frac{\dot{E}x_{steam} - \dot{E}x_{water}}{\dot{E}x_{CH,os}} \quad (19)$$

RESULTS AND DISCUSSION

Using Eqs. (16b) and (16c) along with the values given in Table 2, the chemical exergy of the oil shale was calculated to be about 9265 kJ/kg with $\beta_{LHV} = 1.106$ given in Eq. (10). Taking $\beta_{LHV} = 1.106$ and LHV= 7087 kJ/kg given in Table 1, the chemical exergy of the oil shale was found to be about 7838 kJ/kg, which was used in the analysis.

Some thermodynamic data of the system components are listed in Tables 3a and 3b where the state numbers considered are shown in the parentheses. The values given in this table were taken from Ref. (Han et al., 2006), while some of them were calculated using the data given in the reference. In fact, all necessary data to be used in the analysis have not been found in this reference. Therefore, the analysis included seven system components, excepting for the cyclone and the stack, as shown in Table 3.

Table 3a. Some thermodynamic data of the system components I and II

Mass flow rate of steam: 17.98 k/s	
Steam pressure: 52 bar	
Steam temperature: 449°C	
Feed water temperature: 161 °C	
<i>Furnace (I)</i>	
Outlet temperature of flue gas (1)	850°C
Hot air temperature (2)	240 °C
Mass flow rate of hot air	19.64 kg/s
Mass flow rate of flue gas	66.93 kg/s
Absorbed heat	14662 kW
Mass flow rate of oil shale	6.54 kg/s
<i>High temperature superheater (II)</i>	
Inlet temperature of flue gas	850 °C
Outlet temperature of flue gas	775.5 °C
Inlet temperature of working fluid	340 °C
Outlet temperature of working fluid	450 °C

Table 3b. Some thermodynamic data of the system components III-VII

<i>Low temperature superheater (III)</i>	
Inlet temperature of flue gas	775.5 °C
Outlet temperature of flue gas	669.9 °C
Inlet temperature of working fluid	272.9 °C
Outlet temp. of working fluid	393 °C
<i>Convection bank (IV)</i>	
Inlet temperature of flue gas (3)	669.9 °C
Outlet temperature of flue gas (4)	537 °C
Absorbed heat	10521.8 kW
<i>Divert room (V)</i>	
Inlet temperature of flue gas (5)	537 °C
Outlet temperature of flue gas (6)	525 °C
Absorbed heat	770.7 kW
<i>Economizer (VI)</i>	
Inlet temperature of flue gas	525 °C
Outlet temperature of flue gas	287.8 °C
Inlet temperature of working fluid	150 °C
Outlet temp. of working fluid	254 °C
<i>Air heater (VII)</i>	
Inlet temperature of flue gas (7)	287.8 °C
Outlet temperature of flue gas (8)	153.4 °C
Mass flow rate of flue gas	31.06 kg/s
Inlet temperature of working fluid (9)	20 °C
Outlet temp. of working fluid (10)	240 °C
Mass flow rate of working fluid	19.64 kg/s

Exergy values obtained using the data given in Table 3a and 3b as well as the above relations are also illustrated in Table 4.

Table 4. Exergy values of the system components

Stream no	Specific exergy (kJ/kg)	Exergy rate (kW)
1	451.40	30212.2
2	54.75	1075.3
3	451.40	30212.2
4	420.72	28158.8
5	342.21	22904.1
6	319.41	21378.1
7	227.84	6122.1
8	178.34	4791.9
9	0.04	0.79
10	54.75	1075.3
Exergy of oil shale = 51260.5 kW		
Specific exergy of superheated steam: 1416.59 kJ/kg		
Specific exergy of feed water : 151.74 kJ/kg		

Using the values given in Table 4 and exergy efficiency relations, the exergy efficiency values for each of the system components were calculated, as illustrated in Table 5. Note that the exergy efficiency values for the low and high temperature superheaters as well as economizer were obtained using Eq. (15) due to the insufficient data for calculating using Eq. (14).

Table 5. Exergy efficiency values of the system components

Component no.	Component name	Exergy efficiency (%)
I	Furnace	20.57
II	High temperature Superheater	74.59
III	Low temperature Superheater	56.93
IV	Convection bank	29.57
V	Divert room	31.77
VI	Economizer	61.92
VII	Air heater	80.77

As can be seen in Table 5, the exergy efficiency values ranged from 20.57 to 80.77%, while the furnace had the lowest one.

Using Eq. (19), the exergy efficiency (or the rational efficiency) of the whole system was calculated to be 44.36%. By comparison, the first law (thermal) efficiency of the boiler has been reported to be 87.83% by Han et al. (2006). The reason for the big difference between two efficiency values are due to fact that the exergy efficiency takes into account three types of losses: (i) Intrinsic irreversibility of the adiabatic combustion process, (ii) Irreversibility due to heat transfer over a finite temperature difference, and (iii) Irreversibility due to dissipation of exergy of the products of combustion, as also denoted by Kotas (1995).

Using Eq. (16), the improvement potential rate of the air heater was calculated to be 49.17 kW.

CONCLUSIONS

In the recent years, exergy analysis has been widely used by many investigators in the design, simulation and performance evaluation of thermal systems. However, studies conducted on exergetic assessment of OSFBSs based on actual operational data have not appeared in the open literature to the best of the authors' knowledge, although those on the design, operation and energetic evaluation of these systems are much in numbers. In this regard, this study presented exergetic relations to model OSFBSs and to evaluate their performances.

The following main conclusions may be drawn from the results of this study:

- Exergy efficiency values of the furnace, high and low temperature superheaters are found to be 20.57, 74.59 and 56.93%, while those for convection bank, divert room, economizer and air heater are obtained to be 29.57, 31.77, 61.92 and 80.77%, respectively.
- The exergy (rational) efficiency of the whole system is calculated to be 44.36%.
- The system studied would be evaluated in a more accurate way if the sufficient data could be available. Therefore, this could be realized by the collaboration of the author with Han et al. (2006).
- For a further work, an exergoeconomic analysis should be performed for providing useful insights into the relations between thermodynamics and economics.

NOMENCLATURE

C	specific heat, kJ/kgK
\dot{E}	energy rate, kW
ex	specific exergy, kJ/kg
\dot{E}_x	exergy rate, kW
h	specific enthalpy, kJ/kg
HHV	higher heating (gross calorific) value, kJ/kg
$\dot{I}P$	improvement potential rate, kW
LHV	lower heating (net calorific) value, kJ/kg
\dot{m}	mass flow rate, kg/s
P	pressure, kPa
\dot{Q}	heat transfer rate, kW
R	ideal gas constant, kJ/kgK
s	specific entropy, kJ/kgK
T	temperature, °C or K
w	water content, dimensionless
\dot{W}	rate of work (or power), kW
x	mol fraction, dimensionless
Z	mass fraction, dimensionless

Greek Letters

ψ	flow (specific) exergy, kJ/kg
Δ	interval
β	proportionality constant (or quality factor or exergy coefficient)
ε	exergy (second law) efficiency, dimensionless

Subscripts

in	inlet
out	outlet
dest	destroyed, destruction
w	water
a	air
p	constant pressure
CH	chemical
HE	heat exchanger
m	mean, average
os	oil shale
rat	rational
0	dead (reference) state

Superscripts

KN	kinetic
PH	physical
PT	potential

CH chemical
- on the molar basis

Abbreviations

OSFBS oil shale fluidized bed system

OSCFBS oil shale circulating fluidized bed
 system

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