An Analysis of Energy and Exergy Utilization in the Industrial Sector of India

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Received: May 10, 2018 Accepted: June 22, 2018

ABSTRACT *A detailed analysis based on utilization aspects of energy and exergy for Indian industrial sector is presented in this paper. According to the Energy Statistics of India issued in 2017, the annual consumption of petroleum fuels in India's industrial sector in the year 2015 was 3.294×10⁶ tonnes whereas the consumption of raw coal and lignite was 874.6×10⁶ tonnes for the same year. Statistics of energy consumption in Indian industrial sector, as available, is presented for a period of 11 years from 2005 to 2015 in this paper. The overall mean energy as well as exergy efficiency values for the complete sector are 67.34% and 62.60% respectively. When compared with other countries such as Turkey and Denmark, the Indian industrial sector is found to be more efficient in terms of energetic and exergetic aspects.*

Keywords: *Energy, Exergy, Efficiency, Industrial sector of India.*

I. INTRODUCTION

The industrial sector of the country is one that produces completed finished products which can then be used in the construction as well as manufacturing industry. Industrial sector can also be called manufacturing or secondary sector. It is considered among the three sectors which builds a country's economy. The industrial sector can be grouped in two types, namely, heavy industry and light industry. Many of the industries consume major quantities of energy for the purpose to run their manufacturing processes. The industrial sector of India uses about 50% of the total available commercial energy in the country. Of the commercial sources of energy, i.e. coal, lignite, and oil and natural gas are mainly used [1].

The motive of this study is to represent a careful analysis of the development and growth of the idea of exergy along with its related applications in the society. This report is based on a careful consultation of a number of journal articles, published books, research papers, etc. This paper deals with the study the utilization of energy as well as exergy in Indian industrial sector. The results obtained in this report have direct consequences on application decisions as well as on the research and development directions targeting towards energy security as the country's goal.

II. EXERGY: A THEORETICAL CONCEPT

The concept of exergy

Exergy is the energy that is obtained to be used, i.e., it can measure the maximum capability of an energy system for performing some useful work. In simple words, exergy can be defined as the capacity to generate work. The extraction of the available work from a source of energy depends on the corresponding condition of its surroundings. The more there is a difference in temperature between the surroundings and energy source, the capability for extraction of work from the system will also be greater [2].

In thermodynamics, the definition of exergy or available work of a system is based on the maximum useful work that can be obtained during a process which helps to bring equilibrium between the system and the heat reservoir or surrounding [3]. Exergy analysis is hence a way to prevail over the deficiencies of energy analysis. Exergy analysis is conceptually based on the second law of thermodynamics. It is a very useful tool for identifying the locations, causes and also the magnitudes of various process inefficiencies which energy analysis cannot reveal alone. The exergy is a quantitative estimation of its usefulness or quality. The exergy analysis takes into account that its quality can be degraded.

Values of energy and exergy for commodities in macrosystems

Energy resources are usually measured in energy units similarly as exergy resources. The exergy value of an energy resource can be simply expressed as a product of the energy content and its quality factor. A material can be quantified in terms of exergy units by multiplying its quantity by an exergy based unit factor for the respective material. The quality factor is nothing but the ratio of exergy to energy. In regional and national assessments, hydrocarbon fuels are encountered as the most common material flows at near ambient conditions. In this type of material flow, the physical exergy approximately turns to be zero. As a result, the specific exergy of that material converts into fuel-specific chemical exergy (ex_f), which is expressed as:

$$ex_f = \gamma \times LHV \quad (1)$$

where, γ represents the exergy grade function of the fuel and LHV represents the lower heating value of the fuel.

Table-1 lists some of the typical fuels encountered in various regional and national assessments along with their LHV and γ values.

Table-1
Properties (LHV) of selected fuels [4], [5], [6]

Fuel	LHV (kJ/kg)	Exergy Factor (γ)
Gasoline	43,070	1.07
Diesel	42,652	1.06
Natural Gas	36,220	1.06
Fuel Oil	41,816	1.06
Raw Coal	24,230	1.076
Lignite	16,077	1.07

III. REFERENCE ENVIRONMENT

Evaluation of exergy is always made with respect to a reference environment. For the various macrosystems, the reference environment has been used in many different evaluation processes. It is based basically on the model prepared by Gaggioli and Petit in 1977 [7]. The reference model is having a temperature T_0 of 25°C, pressure P_0 of 1atm and also chemical composition consisting of air that is saturated completely with water vapor, along with the following materials at condensed phases: water (H_2O), gypsum ($CaSO_4 \cdot 2H_2O$) and limestone ($CaCO_3$). In this study, this reference environment model has been used, but by considering a temperature of 10°C [2].

IV. METHODOLOGY AND DATA SOURCES

Analysis of the industrial sector

The industrial sector's energy consumption amounts to petroleum products such as gasoline, high speed diesel oil and fuel oil and also fossil fuels such as raw coal and lignite. Energy and exergy utilization in the industrial sector is evaluated and analyzed. The industrial sector of India is composed of many industries and predominantly the manufacturing industries which mainly uses petroleum based fuels (viz. high speed diesel oil (HSDO), light diesel oil (LDO) and furnace oil (FO)) as well as coal based fuels (viz. raw coal and lignite). Other types of fuels that are used for industrial purposes are low sulphur heavy stock oil and kerosene. However, these fuels have not been considered as they have no/low contribution in the industrial sector.

Mean energy and exergy efficiencies are calculated by multiplying the energy used (percentage consumption) in each mode by the corresponding operating efficiency. Then, all the yearly energy and exergy values are added in order to obtain the overall efficiency of the whole sector.

Data sources

Amount of fuel consumption by different manufacturing processes carried out in the industrial sector are collected from Energy Statistics of India 2017 [8], 2014 [9] and 2012 [10]. The energy consumption data is thus presented in Table-2. The table shows fuel consumption in '000 tonnes and the corresponding energy consumption in Peta Joule (PJ).

Steps and procedures for energy and exergy analysis

Energy and exergy efficiencies were determined using the given equations considering grade function as unity. The sectoral overall energy efficiency can be found easily by dividing the total energy produced/output by the total input energy. Then, the overall weighted mean was obtained for the energy and exergy efficiencies for the fossil fuel processes. Weighing factors are the ratio of energy input of each fuel to the total input energy of the sector. The exergy efficiencies are evaluated using data for the years 2005-2015. Energy and exergy efficiency values for each mode were then calculated to determine the overall energy and exergy efficiency of the Indian industrial sector.

Table-2
Energy consumption data for the Industrial Sector of India for 11 years (2005-2015) [8], [9], [10], [11]

Year	Fuel	Consumption ('000 tonnes)	Energy Consumption		Energy Efficiency (%)	
			PJ	%	Rated Load	Estimated Operating Load
2005-06	HSDO	964	40.35	0.58	28	22
	LDO	325	13.60	0.19	28	22
	FO	1,828	76.52	1.10	-	15
	Raw Coal	395590	6341.31	91.13	80	70
	Lignite	30340	486.35	7.00	46	40
2006-07	HSDO	1,234	51.65	0.7	28	22
	LDO	244	10.21	0.14	28	22
	FO	1,830	76.60	1.04	-	15
	Raw Coal	419800	6729.39	91.41	80	70
	Lignite	30800	493.72	6.71	46	40
2007-08	HSDO	1,241	51.95	0.65	28	22
	LDO	200	8.37	0.11	28	22
	FO	1,634	68.40	0.86	-	15
	Raw Coal	453570	7270.72	91.40	80	70
	Lignite	34660	555.60	6.98	46	40
2008-09	HSDO	1,310	54.83	0.64	28	22
	LDO	171	7.16	0.08	28	22
	FO	2,843	119.00	1.40	-	15
	Raw Coal	489170	7841.40	91.80	80	70
	Lignite	32420	519.70	6.08	46	40
2009-10	HSDO	1,502	62.87	0.70	28	22
	LDO	143	5.98	0.07	28	22
	FO	3,135	131.23	1.46	-	15
	Raw Coal	513790	8236.05	91.80	80	70
	Lignite	33430	535.88	5.97	46	40
2010-11	HSDO	1,440	60.28	0.66	28	22
	LDO	127	5.31	0.06	28	22
	FO	2,774	116.12	1.26	-	15
	Raw Coal	523470	8391.22	91.30	80	70
	Lignite	38530	617.63	6.72	46	40
2011-12	HSDO	1,649	69.02	0.65	28	22
	LDO	102	4.27	0.04	28	22
	FO	2,408	100.80	0.95	-	15
	Raw Coal	608170	9748.96	92.02	80	70
	Lignite	41880	671.33	6.34	46	40
2012-13	HSDO	1,628	68.15	0.55	28	22
	LDO	74	3.09	0.030	28	22
	FO	2,019	84.51	0.69	-	15
	Raw Coal	713390	11435.64	93.10	80	70
	Lignite	43150	691.69	5.63	46	40
2013-14	HSDO	687	28.75	0.23	28	22
	LDO	64	2.68	0.02	28	22
	FO	1,833	76.73	0.60	-	15
	Raw Coal	739340	11851.62	93.59	80	70
	Lignite	43900	703.71	5.56	46	40
2014-15	HSDO	794	33.23	0.24	28	22
	LDO	55	2.30	0.02	28	22
	FO	1,748	73.17	0.53	-	15
	Raw Coal	804450	12895.33	93.74	80	70
	Lignite	46950	752.61	5.47	46	40
2015-16	HSDO	1,096	45.88	0.32	28	22
	LDO	61	2.55	0.02	28	22
	FO	2,137	89.45	0.63	-	15
	Raw Coal	832390	13343.21	94.25	80	70

	Lignite	42210	676.62	4.78	46	40

V. DATA ANALYSIS

Using Table-1, Table-2 along with the following equations under this section (for energy and exergy) and considering part load efficiencies as mentioned in the previous section, the weighted mean overall energy and exergy efficiency values are calculated from 2005 to 2015.

Mean and overall energy efficiency analysis

The expressions for energy (η) and exergy (ψ) efficiencies for the principal types of processes in macrosystems are commonly based on standard definitions as shown [11]:

η = (Energy in products output) / (Total energy input) (2)

ψ = (Exergy in products output) / (Total exergy input) (3)

At first, the weighted mean energy efficiencies can be found for each type of fuel by multiplying a weighing factor (f) with the operating energy efficiency (η) for that fuel. Weighing factor is the ratio of energy input of each fuel to the total sectoral input energy. This can be expressed by,

f = (Energy input of a fuel) / (Total energy input) (4)

Weighted energy efficiency for a fuel is given by,

$\eta_{fuel} = \eta \times f_{fuel}$ (5)

Finally, the overall mean or weighted mean energy efficiency (η_o) can be expressed by,

$\eta_o = \Sigma\, \eta_{fuel}$ (6)

Mean and overall exergy efficiency analysis

Exergy efficiencies can often be written as a function of the corresponding energy efficiencies by assuming the exergy grade function (exergy factor, γ) to be unity (or equal to 1), which is valid mainly for those fuels such as, gasoline, diesel oil, natural gas and fuel oil.

Obviously, $\psi = \eta / \gamma$ (7)

When exergy factor (γ) equals 1, exergy efficiency simply equals the conventional energy efficiency, i.e.,

$\psi = \eta$ (8)

With the exergy consumption fraction of each form of fuel as the weighting factor, the weighted exergy efficiency for a fuel is given by,

$\psi_{fuel} = (\eta / \gamma_{fuel}) \times f_{fuel} = \eta_{fuel} / \gamma_{fuel}$ (9)

Therefore, the overall mean or weighted mean exergy efficiency (ψ_o) can be expressed by,

$\psi_o = \Sigma\, \psi_{fuel}$ (10)

VI. RESULTS AND DISCUSSION

Based on the data listed in Tabl-1 and Table-2 and using equations (6) and (10), the energy and exergy efficiencies are evaluated. Mean and overall energy and exergy efficiency calculations are done in the following steps:

The weighted mean energy efficiency for the industrial sector in the year 2005 is calculated as,

$\eta_o = (22\%)\times0.0058 + (22\%)\times0.0019 + (15\%)\times0.011 + (70\%)\times0.9113$
$+ (40\%)\times0.07$
$= 66.91\%$

The weighted mean exergy efficiency for the industrial sector in the year 2005 is calculated as,

$\psi_o = (22\% / 1.07)\times0.0058 + (22\% / 1.06)\times0.0019 + (15\% / 1.06)\times0.011$
$+ (70\% / 1.076)\times0.9113 + (40\% / 1.07)\times0.07$
$= 62.21\%$

The weighted mean energy and exergy efficiencies for all the remaining years of the sector are evaluated in similar way.

The results obtained are depicted in a tabular form which shows the efficiency values for a 11 year period. The results are also represented using suitable graph which shows variation of efficiency values over the years. The following Table-3 shows the yearly data analysis of the sector.

Table-3

Yearly data analysis of Indian Industrial Sector for 11 year period (2005-2015)

Year	Energy (η_o)	Exergy (ψ_o)
2005	66.91	62.21
2006	67.01	62.29
2007	67.07	62.35

2008	67.06	62.34
2009	67.03	62.32
2010	66.94	62.24
2011	67.24	62.51
2012	67.65	62.89
2013	67.88	63.10
2014	67.94	63.16
2015	68.05	63.26

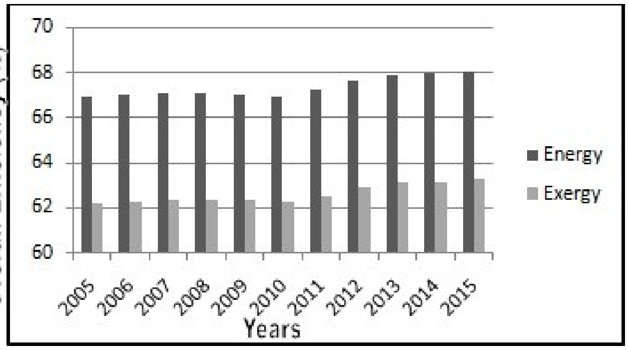

Figure-1
Overall energy and exergy efficiencies of Indian Industrial Sector from 2005-2015

From the above data analysis and corresponding yearly graph we can see that the total energy consumed in 2015 was 2.03 times of the energy consumption of industrial sector in 2005, representing that growth of energy consumption in industrial sector was not proportional to the development of economy in India.

Decreasing trend could be observed in some of the years at both energy and exergy efficiencies, which was not desirable. Energy efficiency ranged from 66.91% in 2005 to 68.05% in 2015 with the mean of 67.34%. Exergy efficiency ranged from 62.21% in 2005 to 63.26% in 2015 with the mean of 62.60%.

VII. COMPARISON WITH OTHER COUNTRIES

Sectoral and overall energy and exergy efficiencies for India, Turkey [12] and Denmark [5] are compared. The comparison is based on previous studies, and the data considered is for the year 2015 for India, 2006 for Turkey and 2012 for Denmark. Figure-2 shows a comparison of Indian industrial sector with that of other countries. It is seen that the efficiencies are slightly different from each other.

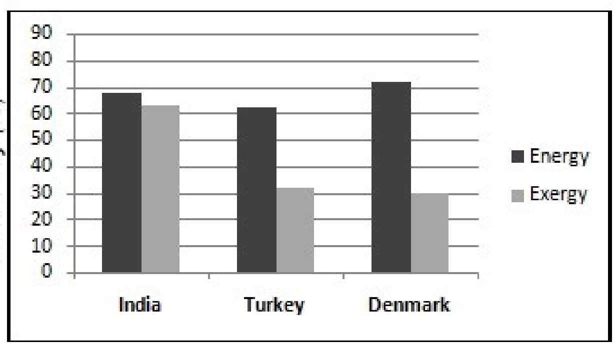

Figure-2
Comparison of overall energy and exergy efficiencies of the Industrial Sector between India, Turkey and Denmark

From the above results it can be said that when compared to some other countries like Turkey and Denmark, the way energy is used in Indian industrial sector is better. Still there is a lot of scope for improvement and thereby reduction in the quantity of energy usage. The Indian industrial sector (including power sector) is more efficient and such difference is inevitable due to dissimilar structure of the industries in these countries.

It can be expected that the results of this study will really be very helpful in developing highly productive planning for the future energy policies, especially for further investigation in the other sectors of the country as well.

VIII. CONCLUSION

In summary, it can be concluded that the exergy analysis has a much more ability and potential in its usefulness in sectoral energy utilization. This study provided a general overview of India's industrial sector and its related energy consumption. Here, we investigated the energy and exergy utilization in the industrial sector of India and conducted the analysis which was based on the actual data by considering energy and exergy use in the sector for the years 2005 to 2015.

Detailed energy statistics for the 11 year period (from 2005 to 2015) has been presented in this paper. By using these statistical data values, energy and exergy efficiencies of this sector were accurately determined and calculated annually. The overall exergy efficiencies in the industrial sector resulted in slightly less values than the corresponding energy efficiencies. The average overall energy and exergy efficiencies for the sector are found to be 67.34% and 62.60% respectively. Fuels such as lignite and raw coal are used only in the industrial sector. According to the calculations, values of energy and exergy efficiencies did not significantly change in the 11 year period, which revealed the lack of a well defined industrial policy in India. Hence, suitable government policies should be actively undertaken.

The results yielding through exergy analysis are very crucial and helpful not only in the sectoral level but also in the national level. Furthermore, the results could provide important guidelines and deep insights for future research and development allocations and projects.

ACKNOWLEDGMENT

The authors wish to acknowledge the support provided by Jalpaiguri Government Engineering College, Jalpaiguri, West Bengal-735101 (India) and Maulana Abul Kalam Azad University of Technology (formerly known as WBUT).

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