"EXERGY ANALYSIS OF DIESEL ENGINE"

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ABSTRACT

Exergy of a system is maximum useful work possible during that brings the system into equilibrium with heat reservoir energy accounts for the irreversibility of due to increase in entropy. Effective energy utilization and its management for the minimizing irreversibility has made human to look for efficient energy consumption and conservation. Exergy analysis is a method that uses the conservation of the mass and conservation of energy principle together with the second law of thermodynamics for the analysis, design and improvement of the energy system and also to measure the system performance. Following system are taken as case study for carrying out exergy analysis as diesel engine.

Performance of some key observation has made and each presented in this project. Exergy could be use as the measure of the systems sustainability level, it shows quality of heat transfer process and energy is more complex measure for assessment cases than energy. The aim of this project is to analyze the exergy of some thermal system so that any process in the system which handle that having the largest exergy destruction can be identify that help thermal engineer to improve the performance of the components present in that system.

Keywords: Energy, exergy, second law of thermodynamics, exergy analysis, energy destruction

INTRODUCTION

Exergy is generally not conserved as energy but destroyed in the system. It is an extensive property of the system and depends on both the state of the system and on the properties of the environment. The state of the environment is referred to as the dead state, defined by the environmental temperature, pressure and composition.[5]

The first law of thermodynamics deals with the amounts of energy of various forms transferred between the system and its surrounding and with the changes in the energy stored in the system. It treats work and heat interaction as equivalent forms of energy in transient and offers no indication about possibility of spontaneous process proceeding in a certain direction. The first law places no restriction on the direction of process, but satisfying the first law does not ensure that the process can actually occur. This inadequacy of the first law to identify whether a process can takes place is remedied by introducing another general principle of second law of thermodynamics.

The method of exergy analysis is based on second law of thermodynamic and the concept of irreversible production of entropy. The fundamentals of the exergy method were laid down by Carnot in 1824 and clausius in 1865. The energy related engineering systems are designed and their performance is evaluated primarily by using the energy balance deduced from the first law of thermodynamics. Engineers and scientist have been traditionally applying the first law of thermodynamics to calculate the enthalpy balances for more than a century to quantify the loss of efficiency in a process due to the loss of energy.

The exergy has gained considerable interest in the thermodynamics analysis of thermal process and plant system, since it has been seen that, first law analysis has been insufficient froman energy performance stand point.

1.1 Exergy

"The maximum useful work that can be obtained from system at a given state in a given environment. In other words, the most work you can get out of a system." In the last decades, exergy analysis has begin to be used for system optimization.[4]

1.2 Exergy Analysis

Exergy analysis involves the application of exergy concepts, balances, and efficiencies to evaluate and improve energy and exergy of other systems. Many engineers and scientist suggested that devices are best evaluated and improved using exergy analysis in addition to or in place of energy analysis.

1.3 Characteristics of Exergy

Some important characteristics of exergy are described and illustrated as follows:

1) A system in complete equilibrium with its surrounding does not have any exergy. No difference appears in temperature, pressure.
2) The exergy of a system increases the more it deviates from the environment. A block of ice carries a little exergy in winter while it can have significant exergy in summer.
3) Exergy is the part of the energy that is useful.
4) Exergy by definition depends not just on the state of a system, but also of the environment.

1.4 Exergy Efficiency

Exergy efficiency (Ψ) is defined as the ratio of the exergy output and exergyinput of the system. Exergy efficiency is an efficiency based on the second law of thermodynamics. [4]

Exergy in = exergy output in product + exergy emitted with waste+ exergy destruction.

$$\Psi = \frac{\text{Exergy output in product}}{\text{Exergy input}} = \frac{e_{out}}{e_{in}} = \frac{e_{out}}{e_{out}+\sum \Delta e} = \frac{e_{in}-\sum \Delta e}{e_{in}}$$

$$= 1 - \frac{\text{Exergy losses}}{\text{Exergy input}} = 1 - \frac{\sum \nabla e}{e_{in}} = 1 - \sum \in \; = \Delta e + \sum \in = 1$$

Where $\in$ = relative energy loss in the component.

$$\in = \frac{\nabla e}{e_{in}}$$

Percentage loss in component can be expressed as:

$$\%\ \text{loss} = \frac{\nabla e}{e_{in}} \times 100$$

LITERATURE SURVEY

This chapter includes brief information about research papers referred during exergy analysis of the systems mention below. A lot of work is done in past and still going on Exergy analysis of thermal systems particularly on Air conditioning system. Useful information and formulae required to carry out analysis is taken from research papers and thus, these research papers stands as a backbone to carry out analysis.

"A.Vamshikrishna Reddy and T.Sharath kumar et al." [6] Energy is a fundamental concept of thermodynamics and one of the most significant aspects of engineering analysis. It is crucial to know the maximum possible performance of the dual fuel modes which can provide a vital comparison parameter with base engine. In addition, impact of process changes such as, load and pilot fuel quality etc. in the system in terms of system losses is also to be assessed. These findings will help in reducing the available energy loss to improve the overall engine performance. . The study of this analysis is done by coupling 1st law and 2nd law of thermodynamics. This gives a clear picture on fuel consumption, brake thermal efficiency, Exergy efficiency and different availabilities with the varying load and compared to the corresponding diesel values.

"Yunus A. Cengel, Michael A. Boles" [2] This book gives introduction about exergy, definition of second law of efficiency, exergy concepts, formulations, applications of exergy based system. Moreover, example of exergy concepts are illustrated with simple concepts. It includes exergy analysis of vapor compression refrigeration system.

"Prateek D. Malwe, Bajirao S. Gawali et. Al" [3] Energy consists of two parts, one is available energy and other is unavailable energy. The available energy is useful part of energy from which maximum useful work is obtained which is known as Exergy. Unavailable energy accounts for the losses and irreversibility's occurring in the system. Exergy analysis is an assessment technique for systems and processes that is based on the second law of thermodynamics. It has been increasingly applied over the last several decades largely because of its advantages over energy analysis.

"Mehmet Kopac and Lutfi Kokturk" [8] In this study, energy and Exergy analysis are applied to the experimental data of an internal combustion engine operating on the conventional Otto cycle. The data are collected using an engine test unit which enables accurate measurements of fuel flow rate, combustion air flow rate, engine load, engine speed and all the relevant temperatures. Energy and Exergy efficiencies are calculated for different engine speeds and compared.

"Ibrahim Dincer and Marc A. Rosen" [5] This book is a research oriented textbook and therefore includes practical features in a usable format. Theory and analysis are emphasized through in this book, reflecting new technique used in regards of Exergy analysis, models and applications, together with complementary materials and recants information. It includes basic information like concepts in thermodynamics, entropy generation, Exergy analysis of various practical case studies.

1.5 EXERGY ANALYSIS METHODOLOGY

Procedure for Exergy Analysis

1) Subdivide the process under consideration.

2) Perform conventional mass and energy balances.

3) Select a reference – environment model.

4) Calculate energy and exergy values at each point of system components.

5) Evaluate energy and exergy efficiency.

6) Interpret the results and draw appropriate conclusions, suggesting theoretical remedies.

General Assumptions

1) Kinetic exergy, potential exergy and chemical exergy were neglected.
2) Specific assumptions were made in the analysis of each subsystem.
3) Ambient conditions: P0=1 bar , T0=300 K.

1.6 Exergy Balance

We have seen how to calculate exergy of heat, e_q, exergy in flow process, e and exergy of closed system (e_c).We are in a position to find out the exergy values at the beginning and end of process has to satisfy the following principle:

1) Principle of conservation of mass
2) Principle of conservation of energy
3) Principle of increase of entropy
4) Principle of decrease of exergy

Exergy input is nothing but the exergy output and losses.

Exergy input = Exergy output + losses = $E_{in} = E_o + \sum \nabla E$

Or, for unit mass, $e_{in} = e_o + \sum \nabla E$

One of the main uses of concert of exergy is an exergy balance in the analysis of thermal system. An exergy analysis is a mathematical tool for evaluation of exergy flows through a system and has been cited as powerful tool for optimization studied and as a primary tool in addressing the impact of energy resources utilization on environment. A careful evaluation of processes using exergy analysis enables the identification of the sources of inefficiencies and waste which leads to improved design of some thermal systems and resultant saving of energy and thus consequently exergy[5].

1.6 Management of Exergy Efficiency

Figure shows that whenever we supply energy to any system or its component, complete conversion of it into useful work output is not possible due to losses and irreversibility associated with it. Similar principle applies to exergy also. Losses include loss due to friction, leakages, etc. while irreversibility include exergy destruction because of internal and external irreversibility such as heat transfer due to finite temperature difference etc. Thus whatever energy supplied to system, some part of it is lost and some is associated with system known as exergy of a system. Remaining is the exergy available to used .However, it is important to note that, there is no such any concept like law of conservation of exergy as it is for energy.

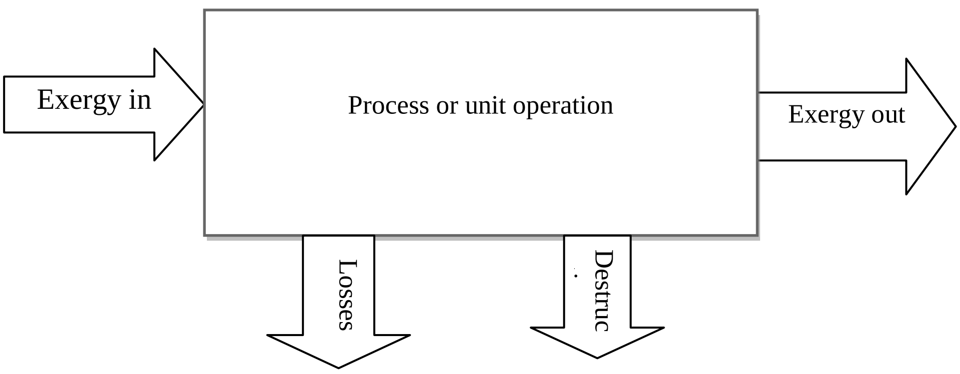


Fig. 1.6.1: Exergy flow diagram for system

1.7 Case Study 2: Single Cylinder Four Stroke Diesel Engine

In this case study, experimental readings are taken on single cylinder four stroke diesel engine. It consists of cooling system, lubrication system, control system, flywheel, starter system, exhaust system. Exergy analysis of single cylinder four stroke diesel engine with the help of cooling water temperature, speed, exhaust gas temperature etc is done and results are shown in tabular form.

Fig1.7.1: Single cylinder four stroke diesel engine set up

1.7.1 Specifications of the Engine:

Table 1.7.1: Specifications of diesel engine

Sr. no.	Parameters	Specification
1	Engine type	Diesel engine
2	General details	Single cylinder Water cooled
3	Stroke	4 stroke
4	Connecting rod length	95 mm
5	Cylinder dia.	80 mm
6	Orifice dia.	24 mm
7	Rated output	5 kW at 1520 rpm
8	Density of fuel	850 kg/m^3

1.7.2 Formulae:

A. Energy Analysis

In an engine, the input chemical energy of fuel is usually converted to the following forms:

1) The energy input (Q_{in}) in any IC engine is contained in its fuel.

2) Useful work output or shaft energy (P_{shaft})

3) Energy transferred to cooling water (Q_{cw})

4) Energy transferred to the exhaust gases (Q_{eg})

5) Uncounted losses ($Q_{uncounted}$) due to friction, radiation, heat transfer to surroundings, operating auxiliary equipment, etc. The amount of each of these energies stated above evaluated on the basis of the first law of thermodynamics is now described.

1) The input energy (Q_{in}) to the diesel engine is the amount of fuel energy content in the supplied fuel and it is given by,
For a diesel mode,

$$Q_{in} = [\ (M'_d / 3600) \times LHV_d\ ]\ (kW)$$

2) P_{shaft} = The energy converted to shaft output,

$$P_{shaft} = 2 \times \Pi \times N \times W \times r\ (kW)$$

3) The heat loss from the engine block to the cooling water is given by,

$$Q_{cw} = [M'_{we} \times C_{P_w} \times (T_2 - T_1)]\ (kW)$$

4) The energy wasted in form of exhaust gas losses is evaluated by

$$Q_{eg} = [M'_{eg} \times C_{P_{eg}} \times (T_5 - T_0)]\ (kW)$$

Where,

the physical property of the exhaust gas (the value of $C_{P_{eg}}$)

$$C_{P_{eg}} = 1.147 \text{ kJ/Kg K}$$

$$M'_{eg} = M'_a + M'_d$$

5) The amount of the uncounted losses is determined by performing an energy balance and is given by,

$$Q_{uncounted} = [Q_{in} - (P_{shaft} + Q_{cw} + Q_{eg})]\ (kW)$$

B. Exergy Analysis:

In an engine, the input fuel availability is converted into the following forms:

1) Availability input (A_{in})

2) Useful work output or shaft availability (A_{shaft})

3) Availability transferred to cooling water (A_{cw})

4) Availability transferred to the exhaust gases (A_{eg})

5) Uncounted availability destructions ($A_{destroyed}$) due to friction, radiation, heat transfer to surroundings etc.

From the second law of analysis, now we calculate all the availabilities transferred.

1) Chemical availability of fuel or input availability,

For diesel mode

$$A_{in} = [1.0338 \times M'_d \times LHV_d] \text{ (kW)}$$

2) Shaft availability

$$A_{shaft} = \text{Brake power output (kW)}$$

3) Availability transferred to cooling water (A_{cw}):

$$A_{cw} = \{ Q_{cw} - [(M'_{we} / 3600) \times Cp_w \times T_o \times \ln (T_2 / T_1)]\} \text{ (kW)}$$

4) Availability transferred to the exhaust gases:

$$A_{eg} = \{ Q_{eg} + [M'_{eg}/3600 \times To \times (Cp_{eg} \times \ln (T_0/T_5)$$

$$- R_{eg} \ln (P_o/P_{ego}))]\} \text{ (kW)}$$

5) Destroyed availability:

$$A_{destroyed} = [A_{in} - (A_{shaft} + A_{cw} + A_{eg})] \text{ (kW)}$$

The exergy efficiency (η_{II}) is the ratio of total availability recovered from the system to the total availability input into the system. The recovered availability includes A_{shaft}, A_{eg} and A_{cw}.

Therefore,

$$\eta_{II} = (\text{Availability recovered / Availability input})$$

$$\eta_{II} = 1 - (A_{destroyed} / A_{in}$$

1.7.3 Experimental Results:

Table 1.7.2 : Energy analysis of diesel engine operations at various loads.

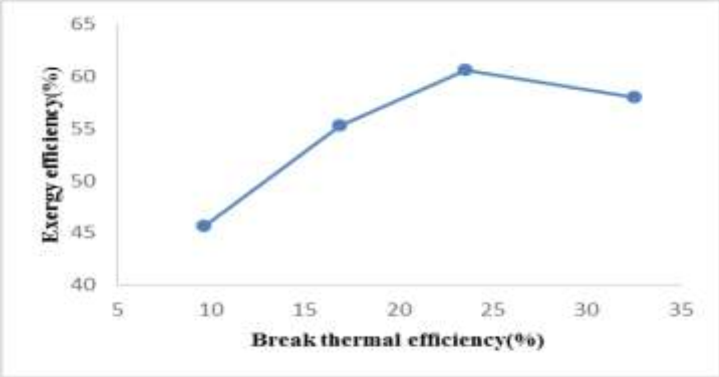
Load (kg)		Q_{in} (kW)	P_{shaft} (kW)	Q_{cw} (kW)	Q_{eg} (kW)	$Q_{uncounted}$ (kW)
w_1	w_2					
No load	No load	4.49	0	0.54	0.83	3.10

3	1.2	4.58	0.43	0.75	0.96	2.41
6	2.8	4.64	0.77	0.87	0.99	1.98
9	4.2	4.98	1.16	0.91	1.04	1.86
12	6.8	3.90	1.25	1.05	1.12	0.47
14	7	5.78	1.69	1.28	1.33	1.47

Table 1.7.3 : Exergy analysis of diesel engine operations at various loads

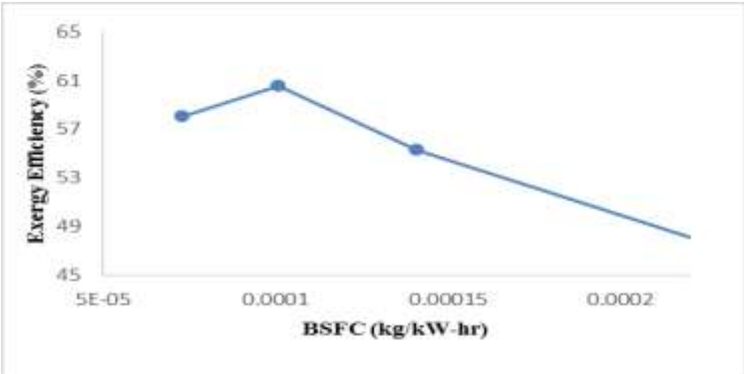
Load (kg)		A_{in} **(kW)**	A_{shaft} **(kW)**	A_{cw} **(kW)**	A_{eg} **(kW)**	$A_{destroyed}$ **(kW)**	**Exergy Efficiency (%)**
W_1	W_2						
No load	No load	4.63	0.00	0.54	0.83	3.80	18.00
3	1.2	4.72	0.43	0.75	0.96	3.32	45.43
6	2.8	4.78	0.77	0.87	0.99	3.01	37.03
9	4.2	5.15	1.16	0.91	1.04	2.94	42.85
12	6.8	4.03	1.25	1.04	1.12	1.65	59.05
14	7	5.97	1.69	1.28	1.33	2.95	50.62

1.7.4 Graphical Representation:



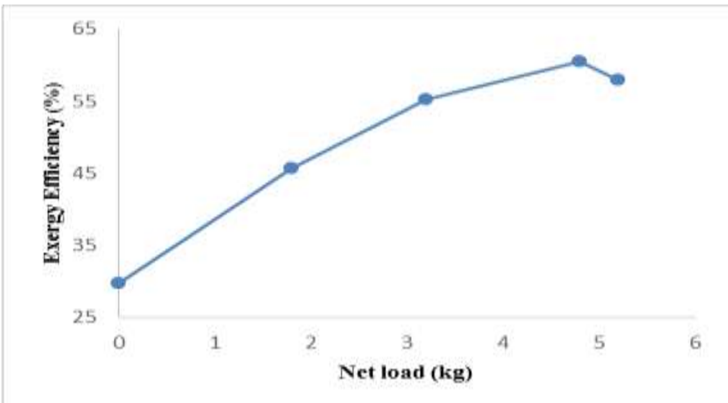
Graph 1.7.1 : variation of exergy efficiency with break thermal efficiency.

From the graph 1.7.1 it seems exergy efficiency increases with increase in break thermal efficiency and at specific point it is maximum and again goes on decreasing it means it better to operate the system at that maximum point.



Graph 1.7.2 : variation of exergy efficiency with break specific fuel consumption.

The Break specific fuel consumption of engine is higher at exergy efficiency (up to 60%) used as shown in graph 1.7.2 this is due to poor combustion efficiency of diesel. The presence of carbon dioxide in the exhaust gas cut down the burning velocity and thereby resulted in incomplete combustion that increases the BSFC of diesel.



Graph 1.7.3: variation of exergy efficiency with net load.

Graph 1.7.3 shows exergy efficiency versus net load of the diesel operation at lower loads, the lean air mixture decreases the fuel availability. When load was increased, to produce higher shaft output at respective loads, the enhanced rate of fuel energy increased the amount of kW available fuel input. I the process, a higher kW shaft availability was resulted at higher engine loads.

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