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EFFECT OF COMPRESSION RATIO AND INJECTION PRESSURE ON EXERGY ANALYSIS OF CI ENGINE FUELED WITH WCSFO BIODIESEL BLEND

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Abstract:- *Exergy analysis method has been widely used in the design, simulation and performance assessment of various types of engine for identifying losses and efficiencies. In this study, the second law of thermodynamics is employed to analyze the quality of energy in a single cylinder, 4-stroke, water cooled, and variable compression ratio (VCR) engine running with WCSFO biodiesel blend (B20). Exergy analysis includes finding of various availability such as input availability, brake power availability, cooling water availability and exhaust gas availability. From exergy analysis components of major exergy destruction can be found out. In this research energy analysis was carried out for B10 to B50 WCSFO biodiesel blends.B20 biodiesel blend gave better performance among all blend hence exergy analysis is carried out for this blend to check the effect of compression ratio (CR) and injection pressure (IP) on the exergy efficiency. All possible combination of compression ratio (16,17,18) and injection pressure (180 and 200 bar) were set on the engine. It was found that engine gives higher exergy efficiency at combination CR 16 and IP 180 bar at low and medium load and highest value was found at CR 17 and IP 180 bar at higher load condition. Also it was noticed that exhaust gas contains higher availability than cooling water.*

Keywords: *Biodiesel (WCSFO), Diesel Fuel, Blended Fuel, Exergy Analysis, Compression Ratio, Injection Pressure*

Nomentures:

WCSFO	:	*Waste Cooking Sunflower Oil*
VCR	:	*Variable Compression Ratio*
CR	:	*Compression Ratio*
IP	:	*Injection Pressure*
LCV	:	*Low Calorific Value*
B20	:	*80% Diesel, 20% Biodiesel*

I. INTRODUCTION

In recent years, increased environmental concerns, depletion of petroleum resources, and several other socio economic aspects have driven research to develop alternative fuels from renewable resources that are cheaper and environmentally acceptable. The use of biodiesel has being promoted by EU countries to partly replace petroleum diesel fuel consumption in order to reduce greenhouse effect dependency on foreign oil. Meeting has been established by the European Parliament for 2010 and 2020 would lead to a biodiesel market share of 5.75% and 10%, respectively [1]. However, many voices have claimed that the associated agricultural development would bring considerable rise of food and water prices, unless biodiesel has made from waste materials or second generation biodiesels are developed. Waste cooking oil is one of the most promising feedstock in the Mediterranean countries, and in fact, many of the biodiesel production plants are currently using it. In a wide majority of cases these plants use methanol for their transesterification processes. Which makes biodiesel (mainly composed by methyl esters) only 90% renewable. By the country, the use of Bioethanol in the production process would provide a fully renewable fuel (ethyl ester), which would further contribute to reduce life cycle greenhouse emissions from vehicles [2].

Generally engine is analysed with the energy analysis which is based on the first law of thermodynamics. It is known that first law of thermodynamics is inadequate for evaluating some features of energy utilization [3]. Hence energy analysis is enriched with the use of exergy analysis to reveal various unknown facts [3]. Concept of exergy analysis is extremely useful in this regard as main advantage of exergy analysis is possibility of finding irreversibility and from that one can identify component of major destruction of exergy in the system [5]. Irreversibility associated in the engine due to processes like combustion, mixing, heat transfer, friction etc which cause destruction or loss of exergy [6]. Hence we can say that exergy analysis has its own important and it should be also used for internal combustion engine analysis along with the energy analysis.

II. LITERATURE SURVEY

Bwonsi et al. (2017) carried out the energy and exergy analysis on 4-stroke, single cylinder, air cooled, diesel engine fuelled with palm kernel oil. It was conducted by adjusting the engine speed 3200 rpm. The engine at the set speed was run with four variable load condition 25%, 50%, 75% and 100%. It was concluded that the thermal and exergy efficiencies decrease with increasing load [7].

Mustafa Tat et al. (2015) carried out research on the effect of cetane number on the performance of 4-stroke 4-cylinder diesel engine running with yellow grease methyl ester and soybean methyl ester having different percentage of cetane improver additive. It was concluded that lower cetane number, longer ignition delay period and higher level of premixed combustion may increases the exergy efficiency of the diesel engine [8].

A Ghareghani et al. (2016) have conducted research work on 4-cylinder gasoline engine in which they checked the effect of gasoline and natural gas on the energetic and exergetic performance of the engine. It was found that energetic and exergetic efficiency of engine running with CNG was 5.4% and 3.14% higher than gasoline respectively and exergy destruction was found 5.8% higher in gasoline than CNG [9].

Sekmen et al. (2011) has investigation on 4-cylinder, direct injection diesel engine using neat soya bean methyl ester biodiesel and neat diesel. It was concluded that BTHE is higher than diesel fuel and exergetic performance was similar to the pure diesel and biodiesel fuel [3].

There is a lack of research on the exergy analysis of compression ignition engine using biodiesel and hence this research includes performance of engine with biodiesel blends and the effect of CR and IP on the exergy efficiency of the engine for best suitable blend. WCSFO biodiesel was chosen for the experiment.

III. EXPERIMENTAL SETUP AND METHODOLOGY

Experiment Setup
The Test engine set up is shown in the Fig 1. It is single cylinder, 4-stroke, and water cooled variable compression ratio (VCR) engine. Full specification of the engine is shown in table 1.

This engine set up consists of many sensors like temperature sensor, load sensor, speed sensor etc. Fuel is supplied from the fuel tank and there is glass burette attached with fuel tank for measurement of fuel consumption. Air is supplied through air box setup having manometer. This setup is required to measure mass of air consumed. Engine output shaft is connected with the eddy current dynamometer. Speed sensor and load sensor is attached with dynamometer. Engine is cooled by water and flow rate of water is controlled by valve. Flow rate value can be measured from rota meter/flow meter.

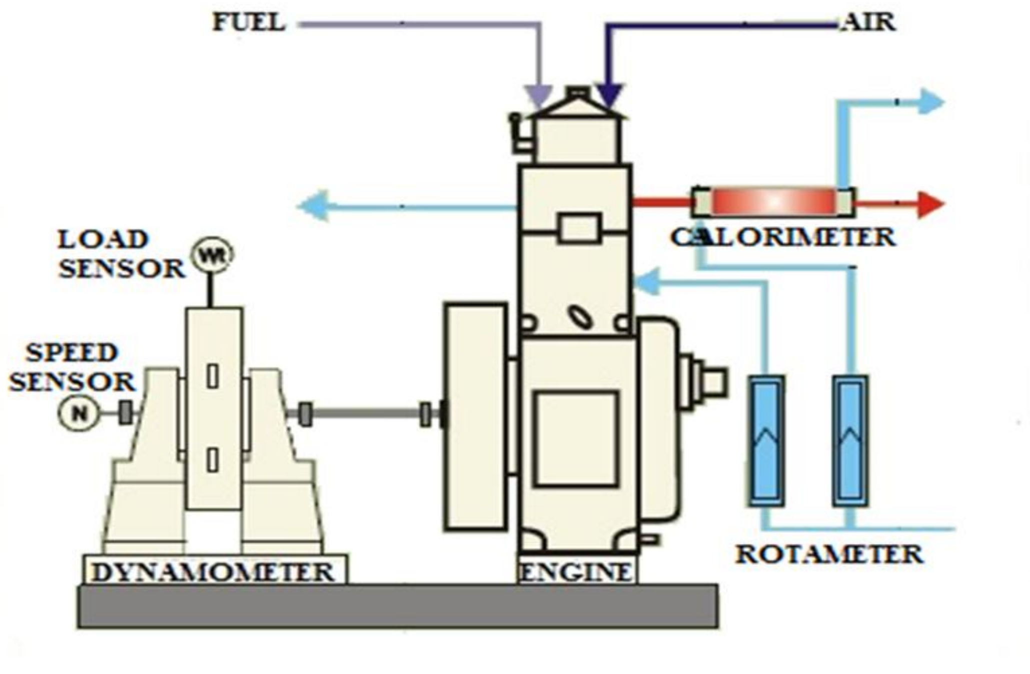

Figure 1. Schematic diagram of test engine [10]

Table 1. Test engine specification [10]

Particular	Specification
Engine type	Single Cylinder, 4-stroke, Water cooled Engine
Bore and Stoke	87.5 mm by 110 mm
Rated Power	3.5 kW at 1500 rpm
CR Range	12:1 to 18:1
Injection Variation	0-25 degree BTDC
Dynamometer	Eddy Current Type, Water Cooled With Unit Load
Calorimeter	Pipe In Pipe Type
Temperature Sensor	RTD Type PT100 And Thermocouple
Load sensor	Load Cell, Type Strain Gauge, Range 0-50 kg
Rotameter	Engine Cooling 40-400 LPH, Calorimeter 25-250 LPH

Calorimeter is attached with the exhaust line for some required measurement. For the analysis of exhaust gases separate gas analyzer is also used during experiment. This engine has arrangements to change compression ratio, injection timing, spark timing (in case of petrol engine head is attached), and injection pressure.

Experimental Method

Firstly engine was made to run at manufacturers set value of compression ratio 17.5 and readings for energy analysis were taken for different blends (B10 to B50). Engine was made to run on three different loading conditions as low, medium and high for same blends. The measurements were taken after the steady state condition was reached. Though this engine setup has facility to automatic reading measurements at some fixed interval of time with data acquisition system, due to some technical problems readings were measured and noted manually. Load was varied with the help of voltage knob and reading directly indicates values in terms of load in kilogram. Fuel consumption was measured manually by measuring time for fixed amount of fuel consumption (10cc in this case) for all fuels at different loading conditions. From the air box manometer difference was noted every time which is used to calculate mass of air consumption. Mass flow rate of water for engine cooling and for calorimeter was set by valves and values of flow rates were indicated by rota meter. Temperature readings were taken from the digital indicator connected with sensor which shows various temperature readings such as engine cooling water inlet and outlet, calorimeter water inlet and outlet and exhaust gas inlet and outlet. During this initial experiment all readings were taken at compression ratio of 17.5 and injection pressure of 180 bar. Best suitable blend was chosen whose performance was found similar to diesel fuel from initial analysis. Then after experiment was done at various combination of different compression ratio 16, 17 and 18 and injection pressure of 180 and 200 bar for that suitable blend. This second experiment was done to check the effect of change in engine parameter (CR and IP) on exergy efficiency of the engine. Readings for this second experiment were taken similar way as taken during first experiment, only difference is that operating parameters were changed and fuel blend remains same throughout this second experiment.Fuel used during experiments was purchased from the biodiesel manufacture in Ahmadabad, India. Required fuel properties were tested in chemical laboratory. Properties for pure WCSFO biodiesel (B100) are listed in Table 2. Further element analysis report for B20 blend is also shown in Table 3 which is useful in exergy analysis.

Table 2. Properties of WCSFO biodiesel [12]

Properties	WCSFO Biodiesel
Calorific Value (KJ/kg)	42650
Density (kg/m^3)	894
Flash point (°c)	138
Kinematic viscosity (N/ms)	15.11 (at 40 ^{0}c)

Table 3. Element test report for B20 blend [12]

Element	% by weight
Carbon (C)	85.02
Hydrogen (H)	11.08
Oxygen (O)	1.82
Sulphur (S)	0.025
Nitrogen (N)	0.04

IV. EXERGY ANALYSIS

The Exergy is defined as maximum theoretical work that can be obtained from a system as it comes to equilibrium with reference environment.

Step involve in the exergy analysis are as shown below [3,7]:

1) Input availability
Input availability contains two parts and it is given as below:

$$A_{in} = A^{th} + A^{ch}$$

$A^{th} = (\bar{h} - \bar{h}_0) - T_0(\bar{s} - \bar{s}_0)$
Where $\bar{h}$ and $\bar{s}$ are specific enthalpy and entropy of the fuel mixture at particular temperature and $\bar{h}_0$ and $\bar{s}_0$ are corresponding values for reference environment condition.

$$A^{ch} = \dot{m}_f \times \left[1.0401 + 0.1728\frac{h}{c} + 0.0432\frac{o}{c} + 0.2169\frac{s}{c}\left(1 - 2.0628\frac{h}{c}\right)\right] \times LCV$$

Where h , c , o , s are mass fractions of hydrogen, carbon, oxygen and sulphur respectively in the fuel. LCV indicates calorific value of fuel in KJ/kg. Thermo chemical exergy is considered as zero because fuel mixture is assuming initially at dead state condition. Dead state condition means environmental condition.

Table 4. Observation table

Sr No.	CR	IP	Load (kg)	t_2 (°c)	t_5 (°c)	t_6 (°c)	O_2 %vol	CO_2 %vol	CO %vol	NO_X ppm	HC ppm
1	16	180	1	34	204	166	18.87	1.0	0.230	3	51
2	16	180	5	35	269	227	18.12	1.5	0.10	122	38
3	16	180	9	38	343	283	17.22	2.1	0.05	557	58
4	16	200	1	34	198	160	18.97	1.0	0.23	2	47
5	16	200	5	35	260	218	18.11	1.6	0.12	97	39
6	16	200	9	38	334	271	17.14	2.2	0.05	527	38
7	17	180	1	34	189	151	18.87	1.1	0.15	25	22
8	17	180	5	35	257	215	17.96	1.7	0.06	246	31
9	17	180	9	38	331	268	17.10	2.2	0.04	720	39
10	17	200	1	34	180	142	19.00	1.1	0.13	45	27
11	17	200	5	35	248	239	18.11	1.6	0.05	296	29
12	17	200	9	38	319	256	17.06	2.3	0.04	777	37
13	18	180	1	34	186	142	18.66	1.3	0.06	216	20
14	18	180	5	35	254	200	17.96	1.7	0.03	544	25
15	18	180	9	38	337	262	17.14	2.2	0.02	1026	32
16	18	200	1	34	171	151	18.77	1.2	0.07	153	15
17	18	200	5	35	219	215	18.03	1.6	0.03	462	24
18	18	200	9	38	294	277	17.14	2.2	0.03	997	39

Where t_2 = Cooling water outlet temperature
t_5 = Exhaust gas inlet temperature
t_6 = Exhaust gas outlet temperature

2) Exhaust gas availability
Exhaust gas also contain two parts of availability thermo-mechanical and thermo-chemical. They can be found out as follows.

Thermo mechanical exergy is given as:
$$A_{ex}^{th} = \left[\sum_{i=1}^{n} a_i \left\{\bar{h}_i(T) - \bar{h}_i(T_0) - T_0\left(\bar{s}^0(T) - \bar{s}^0(T_0) - \bar{R}\ln\frac{p}{p_0}\right)\right\}\right]$$

Where h and s values represent enthalpy and entropy of i^{th} component in exhaust gas at particular temperature and a_i represent moles of i^{th} component in the exhaust gases.

Thermo chemical exergy is given as:

$$A_{ex}^{ch} = \bar{R}T_0 \sum_{i=1}^{n} a_i \ \ln \frac{y_i}{y_i^e}$$

Where $\bar{R}$ is universal gas constant, yi and ye are molar ratio of i^{th} component in exhaust gas and environment respectively. Reference environment condition is taken as N_2(75.67%) , O_2(20.35%), CO_2(0.0345%), CO(0.0007%). All value represent mole fraction of each component in atmosphere. Now, after finding thermo mechanical and thermo chemical exergy total availability of exhaust gases is given as sum of both of these.

$$A_{ex} = A_{ex}^{th} + A_{ex}^{ch}$$

3) Cooling water availability

It is assumed as heat loss availability into the environment from system boundary at constant temperature and it is given as follow:

$$A_{cw} = Q_{cw}\left(1 - \frac{T_0}{T_{cw}}\right)$$

4) Shaft power availability

It is same as that of mechanical brake power of engine as it is high grade energy and completely available

$$A_{BP=} 2\pi NT/60{,}000$$

Where N is revolution per minute (rpm) and T is torque in Nm.

5) Exergy destroyed

It is loss of availability or destruction of exergy due to process irreversibility. It include some unaccounted availabilities such as radiation heat transfer from surface of the system, lost work due to friction and other unaccounted exergy lost. It also includes loss of availability with exhaust gas and cooling water. This is given as shown below:

$$A_d = A_{in} - (A_{ex} + A_{cw} + A_{bp} + A_{un})$$

6) Second law efficiency

Second law efficiency or exergy efficiency of the system can be calculated as follow:

$$\eta_{II} = 1 - \frac{A_d}{A_{in}} \times 100\%$$

V. RESULTS AND DISCUSSION

Exergy analysis of B20 blend was carried out by changing compression ratio (16, 17 and18) and injection pressure (180 and 200 bar). Results obtained from the exergy analysis are discussed below.

Table 5. Result table

Sr No.	CR	IP	Load (kg)	A_{in} (kW)	A_{bp} (kW)	A_{cw} (kW)	A_{ex} (kW)	A_d (kW)	η_{II} (%)
1	16	180	1	7.59	0.31	0.05	1.52	5.69	25.00
2	16	180	5	9.48	1.42	0.06	2.10	5.89	37.85
3	16	180	9	12.65	2.49	0.07	2.78	7.30	42.27
4	16	200	1	8.22	0.31	0.05	1.48	6.37	22.49
5	16	200	5	10.12	1.42	0.06	2.02	6.60	34.73
6	16	200	9	12.65	2.49	0.07	2.70	7.38	41.64
7	17	180	1	7.59	0.31	0.05	1.40	5.81	23.32
8	17	180	5	9.48	1.42	0.06	2.00	6.00	36.73
9	17	180	9	12.01	2.49	0.07	2.67	6.78	43.56
10	17	200	1	8.22	0.31	0.05	1.32	6.52	20.62
11	17	200	5	10.12	1.42	0.06	1.92	6.71	33.68
12	17	200	9	12.65	2.49	0.07	2.57	7.51	40.59
13	18	180	1	7.59	0.31	0.05	1.30	5.92	21.99
14	18	180	5	10.12	1.42	0.06	1.89	6.73	33.44
15	18	180	9	12.65	2.49	0.07	2.56	7.51	40.58
16	18	200	1	8.85	0.31	0.05	1.38	7.10	19.76
17	18	200	5	10.75	1.42	0.06	1.97	7.28	32.22
18	18	200	9	13.28	2.49	0.07	2.73	7.98	39.89

From the Figure 2 it can be say that while operating at 180 bar injection pressure and if change compression ratio it can be observed from figure that at low and medium loading condition compression ratio 16 gives highest second law efficiency while at high load compression ratio 17 gives highest second law efficiency. Higher first law efficiency is direct result of higher second law efficiency because higher second law efficiency results into less destruction of energy or less irreversibility and hence results into higher first law efficiency or energy efficiency. Similarly if compare results at injection pressure of 200 bar from Figure 3 at all loading condition compression ratio of 16 has highest performance at all loading condition.

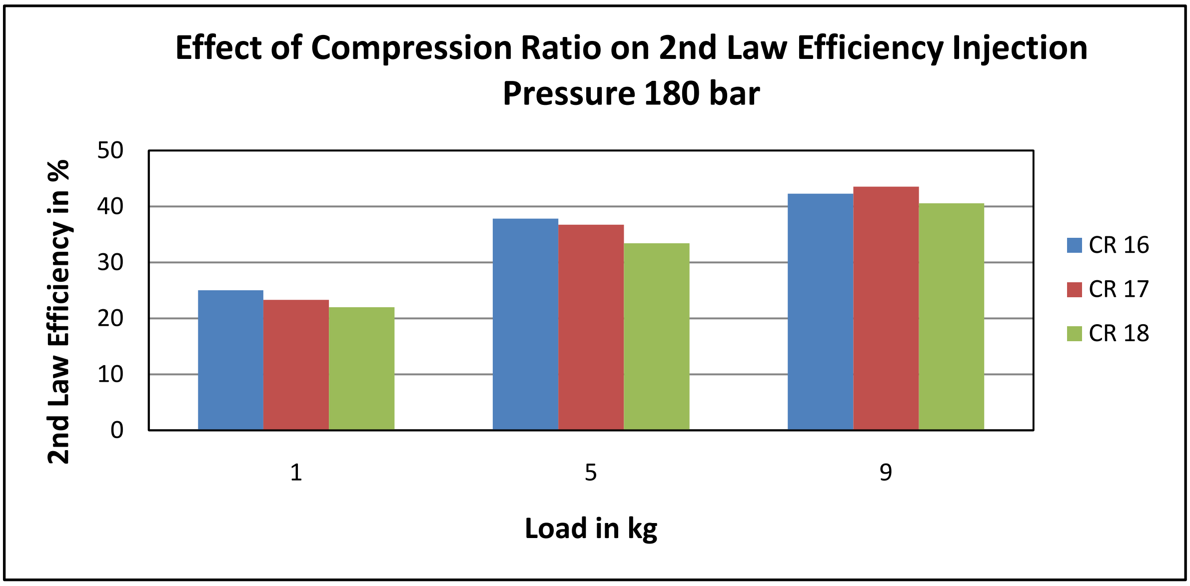

Figure 2. Comparison of brake specific fuel consumption of various blends

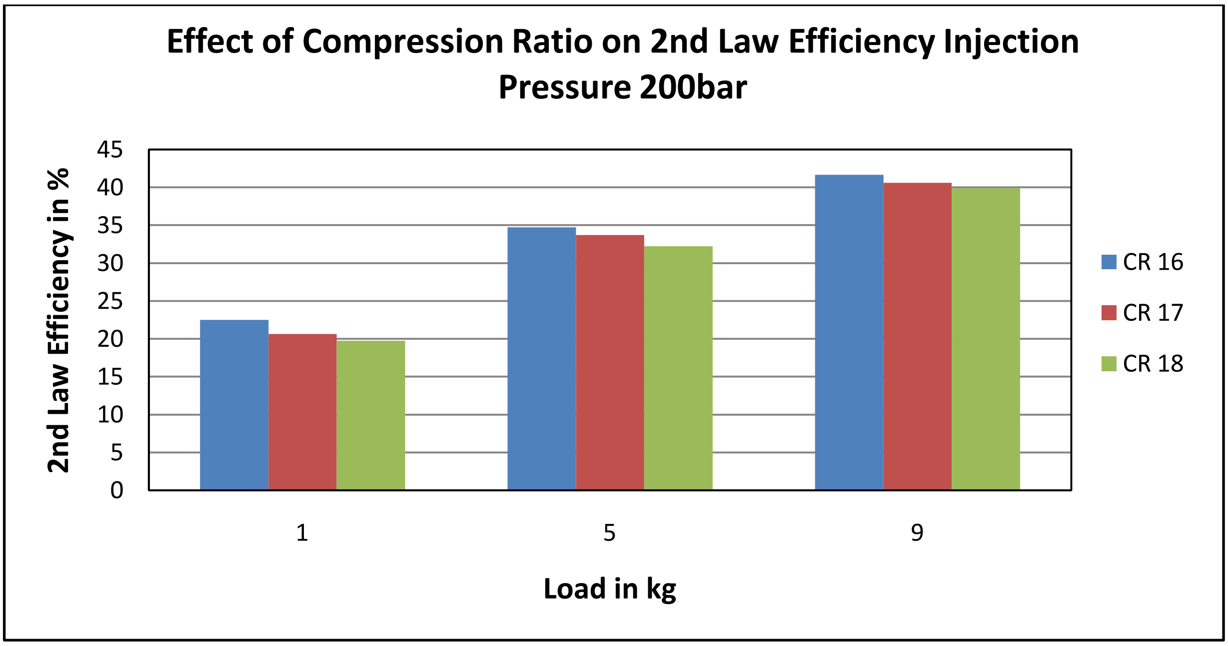

Figure 3. Comparison of brake thermal efficiency of various blends

Also if compare Figure 2 and Figure 3 it come to know the effect of injection pressure on the performance of the engine. From figures it can be see that at two injection pressures 180 and 200 bar and same compression ratio performance is different and engine has higher performance at injection pressure of 180 bar for particular compression ratio. So from this observation from the results it can be found that highest performance of the engine is at compression ratio 16 during low and medium loading and at 17 during high loading condition. Exergy efficiencies were 25.00%, 37.82% and 43.56% during above stated setting of parameter and obviously energy efficiency will be higher at this setting of parameter.
From the above exergy analysis it can be conclude that compression ratio 16 has higher performance at both set value of injection pressure 180 and 200 bar. But injection pressure 180 bar has comparatively higher performance than 200 bar.

From the Figure 4 it can be conclude that exhaust gas contains highest availability which can be recovered. It contains 22.00% of the input availability. Engine cooling water has not much availability with it; it accounts only 1.00% of input availability. Shaft power availability is 22.00% which is fully available. Exergy destruction of the energy is more than 50% due to various irreversibilities. These irreversibilities include combustion process, friction and heat loss due to finite temperature gradients. There is scope of recover the exhaust gas availability by using suitable heat recovery method. Combustion process is affected by operating parameters and hence for higher exergy efficiency operating parameters must be optimized.

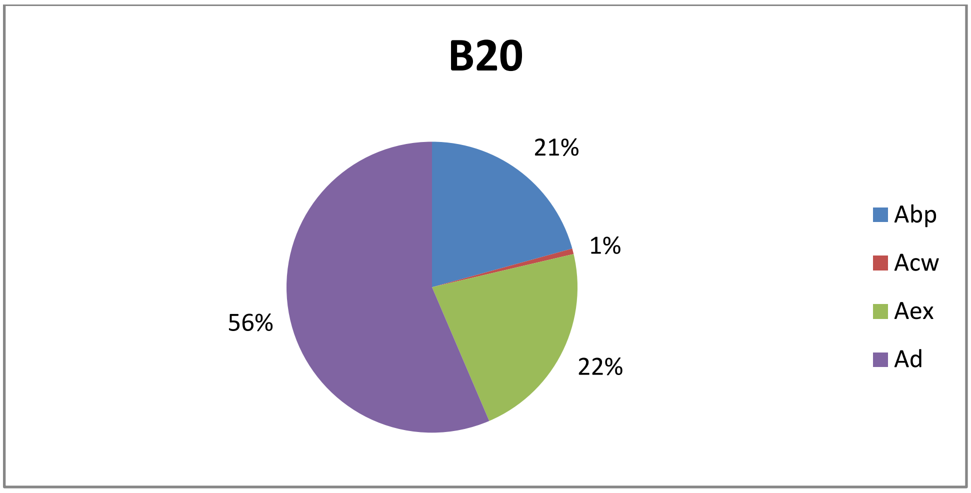

Figure 4. B20 blend exergy analysis

VI. CONCLUSION

From energy analysis it can be conclude that biodiesel gives similar performance compare to diesel. Lower blend ratio gives higher performance among all blends. Lower blend ratio is preferable because it has less fuel consumption than higher blend ratio. Though biodiesel has less calorific value than the diesel due to oxygen content in it, it promotes better combustion and hence it has similar kind of performance compare to diesel.

From the exergy analysis of the B20 blend at different compression ratio and injection pressure we can conclude that at one particular combination there will be a maximum performance. In this case at low and medium loading compression ratio 16 and injection pressure 180 bar gives maximum performance having exergy efficiency values 25.00% and 37.82% respectively and during high loading condition compression ratio 17 and injection pressure 180 gives maximum exergy efficiency(43.56%). For injection pressure 200 bar efficiency was found lower than the 180 bar injection pressure at all compression ratio and at all loading condition. Also from exergy analysis we are able to calculate the various availabilities. More than 50% of the exergy is destroyed due to irreversible process such as combustion, friction and exergy loss due to finite temperature gradient. Exhaust gases have higher value of availability than engine cooling water availability. Hence by knowing availability we can make decision about amount of energy that can be recovered.

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