Experimental Study on Utilization of Exhaust Gas of an I.C Engine

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ABSTRACT

With the increasing cost of energy of and the need to conserve the same, it has become absolute essential to save energy irrespective of its quantum in every field. In particular refrigeration and air conditioning systems consume a substantial amount of energy. In transportation of frozen foods the energy required by the refrigeration system can be supplied by the vehicle engine exhaust heat otherwise it goes as a waste heat to atmosphere. A refrigeration system which makes use engine exhaust heat without affecting the performance of the engine will be more useful in saving the energy.

Our country is gaining foreign currency by exporting especially sea foods to countries like Japan etc,. These products are to be preserved at low temperatures. The transportation up to the cold storage in ships is to be done by refrigerated trucks. So the saving of energy in these refrigeration systems will be very much justified.

In this present study an attempt is made to run a refrigerator which works on domestic Electrolux refrigeration system with the engine exhaust. An engine of 10.5 H.P is selected and the fridge available in the laboratory i.e Himalux 100 liters capacity is made use for this purpose. The electrical heating unit in the generating portion is removed and heat is supplied through the engine exhaust gases. The test results are very much satisfactory .we could run the refrigerator effectively without much fall in the engine efficiency. These test results give a hope that similar systems can be adopted on a refrigerated truck, which will be very much justified.

Keywords: Exhaust gas, Generator, Heat balance sheet, COP

1. INTRODUCTION

Due to the combustion of fuel inside the engine cylinder of I.C Engines, intense heat is generated. It has been experimentally found that about 20% of heat generated is converted into useful work at the crank shaft, 10% generated heat loss in friction, 35% exhaust heat loss to the cylinder walls and 35% heat is carried away by the exhaust gas in to atmosphere. so it may utilized for refrigeration system without affecting the performance of the engine for preserving the perishable goods like fishes, meat at low temperature while transporting from place to place.

The test is carried on a four stroke, water cooled compression ignition engine is coupled to a D.C machine (Dynamometer). The machine can run as motor from D.C supply for cold starting as well as for motoring purpose. D.C machine runs as generator.

2. EXPERIMENTAL SET UP

The set up for conducting the experiment is shown in the figure below. The equipment selected is as joined to the Engine as follow s.

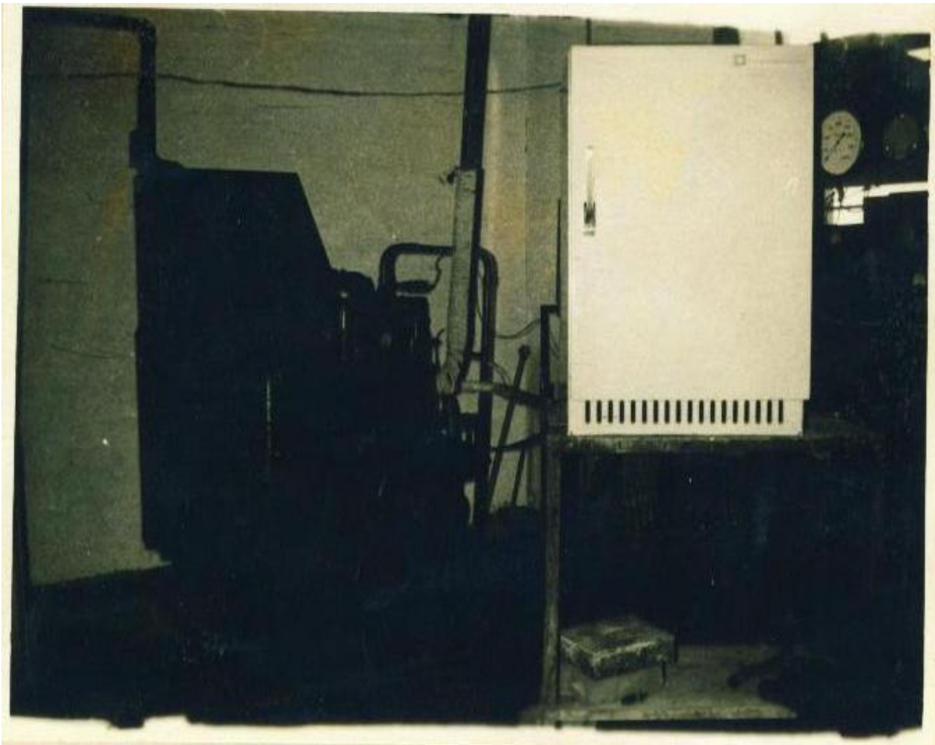


Fig1: Engine coupled with Refrigerator

Details of R.N test plant:

A. Engine

H.P = 10.5 hp

R.P.M = 1200

Bore= 4½″inch

Stroke = 6 inches

B. Dynamometer

Motor		Generator	
Voltage	220 V	Voltage	220 V
Amps	42.5	Amps	80
Rev	400/1000	Rev	1000/1200
H.P	4.6	K.W	11
Rating	continuous	rating	continuous

C. Details of Refrigerator:

Type : vapor absorption system-Domestic Electrolux type

Capacity: 100 liters

Heat input: 250 W heat coil

Make : Himalux

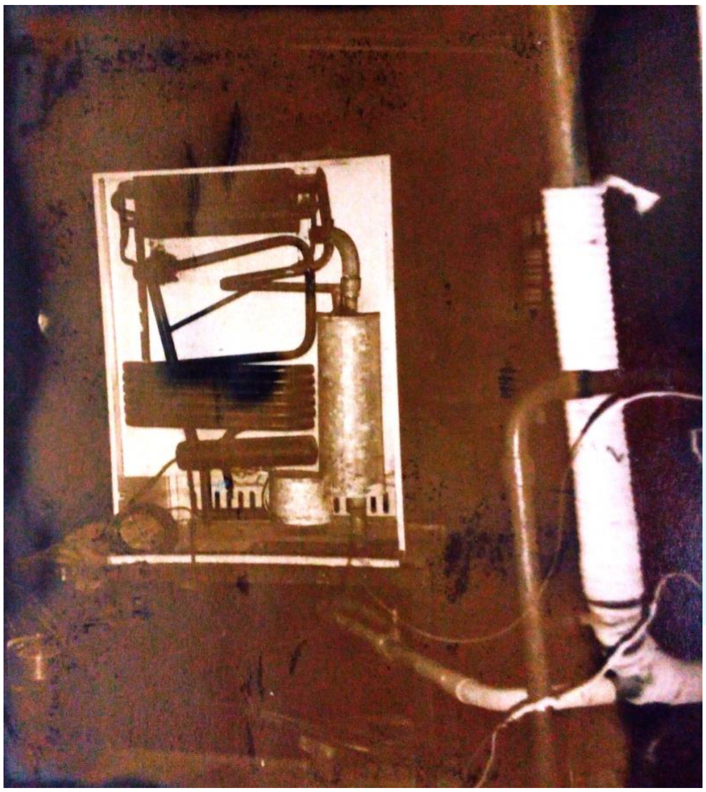


Figure2: Refrigerator connected to the Engine Exhaust gas

The R.N Test plant is connected to the generator portion of the himalux vapou r absorption type refrigerator through a pipe line. From the generator a pipe line is taken to dispose of the used exhaust gas. The length of the pipe line connecting the exhaust of the I.C Engine and generator should be as small as possible. It is seen that the length of pipe is minimized to 180 cm length. Also the number of bends used should be less. Here the number of bends is limited to two. By keeping the refrigerator on a suitable height of the table. So the height of the generator is just above the exhaust pipe line. This pipe line is to be well insulated by means of suitable insulator as it is readily available in the laboratory to reduce heat losses. Tapings are provided at the inlet and outlet of the generator portion to note the temperatures before and after the generator.

3. TEST PROCEDURE:

After starting the engine adjust the speed to 1200 rpm and voltage to 220 volts. Apply a required load on the generator by operating the switches on the panel board either independently or in combination of the resistance box, which in turns loads the engine. If any fluctuations' in voltage and speed then adjust once again the voltage to 220 V and speed to 1200 rpm constant.

Now clean the refrigerator cabin by opening the door of refrigerator and kept 4 liters of measured quantity of fresh water in a vessel. A dial thermometer is arranged outside of the refrigerator and bulb of the meter is kept in water bath inside the refrigerator to know the temperature of water. Then the door of refrigerator is closed and allows the engine to run continuously at that load.

Now take the following readings for every Half-hour -duration.

1. Time taken for 10 c.c of fuel consumption in seconds for finding total fuel consumption in kg/hr

2.Time taken for 2 liters of water collection in seconds and temperature of inlet and outlet of cooling water in degree centigrade for finding heat to cooling water in Kcal / min or KJ/min

3. Manometer reading in centimeters for finding air consumption is kg/hr

4. Temperature of exhaust gas at beginning of the exhaust manifold in ^{0}C for finding heat to exhaust gases in Kcal /min or KJ/min

5. Temperature of exhaust gas before and after the generator in ^{0}C for finding the coefficient of performance.

6. Temperature of water inside the refrigerator in ^{0}C for finding the net heat removed

Similarly experiment conducted for different loads and readings are noted down for every half an hour

4.0 FORMULA'S USED FOR CALCULATIONS

4.1. Total fuel consumption (TFCor FC)

$$TFC = \frac{\text{sp.gravity} \times V \times 3600}{t \times 1000} \quad \text{kg/hr}$$

Where V=volume of fuel in C.C

t=time taken for 10 C.C of fuel consumption in seconds

4.2. Heat to cooling water Q_C or Q_W

$$Q_W = \frac{M_w \, C_{pw}}{60} \times [t_{w2} - t_{w1}] \quad \text{Kcal /min}$$

Where M_w =collection of cooling water in liters

CP_w =specific heat of water [=1]

t_{w1} =in let temperature of cooling water in ^oC

t_{w2} = out let temperature of cooling water in ^oC

% of heat to cooling = $\frac{Qw}{Qs}$ X 100

Where Qs =heat input or supplied by fuel [kcl/min]

$Q_s = \frac{\text{cv in} \frac{kcal}{kg} \text{ X fuel consumption in kg/hr}}{60}$ [CV=10800 kcal/kg]

4.3. Air consumption [A.C]

Density (ρ) = $\frac{m}{v}$ = $\frac{p}{RT}$

Density of air = $\frac{1.033 \, x 10000}{29.2 \, x \, 273}$=1.293 kg/m^3

Conversion factor (K_o0=(12 x 2.54/100)^3 =0.0283 m^3/cft

Therefore A.C =(manometer constant x temperature correction xmeter reading) cft/min

A.C =0.8556x0.956xmanometer reading x 60 x K_o x ρ kg/hr where ρ = 1.293

4.4. Heat to exhaust gas (Q_g)

$Q_g = \frac{Mg}{60}$ x Cp ($t_e - t_r$) Kcal/min

Where M_g= mass flow rate of exhaust gas

M_g=(A.C + F.C) Kg/hr

Cp= specific heat of exhaust gas (0.27)

t_e =temperature of exhaust gas in ^0C

t_r = room temperature in ^0C

% of heat to exhaust gas = $\frac{Qg}{Qs}$ X 100

4.5. Net heat removed inside the refrigerator

= $\frac{\text{mw td cpw+ma cpa ta}}{\text{time in hours}}$

M_w =mass of water inside the refrigerator in liters

CPw= specific heat of water [=1]

t_d =difference of water temperature inside and outside the refrigerator

m_a, Cpa, t_a = corresponding value of air

m_a = mass of air = volume X density

volume = 55.5 x 44.5 x 26.1 cm^3 = 0.06446 m^3

density of air = 1.412

mass of air Ma =0.06446 x 1.412 = 0.091018 kg

Specific heat of air Cpa = 0.2403

And $t_a = t_d$

4.6. Heat absorbed in the generator

Net heat absorbed in the generator = $\frac{\text{Mg Cp}(t1-t2)}{3}$ x η

η=0.7 efficiency of generator

m_g=mass flow rate of exhaust gas kg/hr

C_p=specific heat of exhaust gas =0.27

t_1 =average temperature before generator^{0}C

t_2 = average temperature after generator^{0}C

1/3 =correction factor due to incorrect tapings

4.7. Heat to B.H.P (Q_B)

$Q_B = \frac{\text{BHP x 4500}}{427}$ kcal/min

% of heat to B.H.P = $\frac{QB}{Qs}$ X 100 (break thermal efficiency)

4.8. Unaccounted Heat (Q_{unacc})

$Q_{unacc} = Q_s - (Q_B + Q_c + Q_g)$

% of heat unaccounted= $\frac{Qunacc}{Qs}$ X 100

4.9. Coefficient of performance (COP)

c.o.p = $\frac{\text{Net Heat removed}}{\text{Net Heat absorbed}}$

5.0 TEST READINGS AND CALCUATIONS

Table-1: Heat balance sheet -without Refrigerator

1	Balance reading	8	10.5	14.5	19	21
2	Speed RPM	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	28.2	24.9	20.4	15.8	14.2
4	Manometer reading(cm)	25.6	25.1	25.2	24.6	24.1
5	Time taken for collection of 2 lit of water in sec	5.4	5.5	5.5	5.4	5.3
6	Temperature of inlet water ^{0}C	31.6	31.6	31.6	32.2	32.7
7	Temperature of outlet water ^{0}C	36	36	36	37	38
8	Temperature of exhaust gas ^{0}C	293.3	326.6	293.3	504.4	554.4
9	Room temperature ^{0}C	31	31	31	31	31

Table-2: Heat balance calculated Results -without Refrigerator-

1	BHP (kcal/min)	3.2	4.2	5.8	7.6	8.4
2	TFC (kg/hr)	1.065	1.207	1.473	1.902	2.116
3	SFC (kg/bhp-hr)	0.333	0.287	0.254	0.250	0.252
4	Air consumption(kg/hr)	45.97	45.07	45.26	44.18	43.28
5	Air fuel ratio	43:1	37:1	30:1	23:1	20:1
6	Mass flow rate of exhaust gas (AC+FC) kg/hr	47.03	46.27	46.73	46.08	45.39
7	Heat input (kcal/min)-Q_s	191.7	217.26	265.14	342.3	380.88
8	Heat equivalent to BHP(kcal/min)	33.72	44.26	61.12	80.09	88.52
	%Heat to BHP(br.thr.eff)	17.59	20.37	23.05	23.39	23.24
9	Heat to cooling water(kcal/min)-Q_c	89.62	87.99	87.99	106.22	118.41
	% heat to cooling water	46.7	40.4	33.1	31.02	31.08
10	Heat to exhaust gas(kcal/min)-Q_g	55.51	61.56	76.19	98.17	106.91
	% heat to exhaust gas	28.95	28.33	28.73	28.67	28.06
11	Heat unaccounted (kcal/min)-Q_u	12.85	23.45	39.84	57.36	66.74
	% of unaccounted heat	6.7	10.79	15.02	16.9	17.52

Table-3: Heat balance sheet –with Refrigerator at No load

1	Balance reading	0	0	0	0	0	0	0
	Time (hours)	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Speed RPM	1200	1200	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	36.0	41.8	43.0	43.2	43.2	43.3	43.5
4	Manometer reading(cm)	25.9	26.0	26.1	26.4	26.5	26.6	26.7
5	Time taken for collection of 2 lit of water in sec	6.0	6.0	6.0	6.0	6.1	6.0	6.1

6	Temperature of inlet water ^{0}C	28.8	30.0	30.0	30.0	30.0	30.5	30.5
7	Temperature of outlet water ^{0}C	30	31	31	32	32	33	33
8	Temp.rise of cooling water^{0}C	1.12	1.0	1.0	2.0	2.0	2.5	2.5
9	Temperature of exhaust gas ^{0}C	158	158	157	157	159	158	159
10	Room temperature ^{0}C	31	31	31	31	31	31	31

Table-4: Heat balance sheet calculated Results –with Refrigerator at No load-

1	BHP (kcal/min)	0	0	0	0	0	0	0
2	TFC (kg/hr)	0.835	0.719	0.699	0.695	0.695	0.694	0.691
3	SFC (kg/bhp-hr)	0	0	0	0	0	0	0
4	Air consumption(kg/hr)	46.51	46.69	46.87	47.41	47.59	47.78	47.95
5	Air fuel ratio	50:1	65:1	67:1	68:1	68:1	69:1	69:1
6	Mass flow rate of exhaust gas kg/hr	47.34	47.40	47.56	48.10	48.28	48.47	48.64
7	Heat input (kcal/min)-Q_s	150.3	129.4	125.8	125.1	125.1	124.9	124.3
8	Heat equivalent to BHP(kcal/min)	0	0	0	0	0	0	0
	%Heat to BHP(br.thr.eff)	0	0	0	0	0	0	0
9	Heat to cooling water(kcal/min)-Q_c	22.4	20.0	20.0	40.0	39.34	50.0	49.18
	% heat to cooling water	14.9	15.4	15.8	31.9	31.4	40.0	39.5
10	Heat to exhaust gas(kcal/min)-Q_g	27.05	27.08	26.96	27.27	27.8	27.7	28.0
	% heat to exhaust gas	18.07	20.93	21.43	21.80	22.22	22.17	22.52
11	Heat unaccounted (kcal/min)-Q_u	100.85	82.32	78.84	57.83	57.96	47.20	47.19
	% of unaccounted heat	67.0	63.61	62.67	46.22	46.33	37.79	37.94

Table-5: determination of cop of Refrigerator at No load on I.C Engine

1	Time in hours		Starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C		30	29.8	29.75	29.6	29.6	29.5	29.5
3	Temp. difference of water inside the refrigerator ^{0}C-t_d		0	0.2	0.25	0.4	0.4	0.5	0.5
4	Net heat removed (kcal/hr)-A		0	1.608	1.005	1.072	0.804	0.803	0.670
5	Average of exhaust gas quantity(kg/hr)-m_g		47.34	47.37	47.45	47.72	47.81	47.90	47.99
6	Average generator temp^{0}C	before	151	153	152.5	151.5	151.5	152.5	153
		after	109	117	116.5	116.5	117	116.5	117
7	Net heat absorbed (kcal/hr)-B		125.26	107.43	107.61	105.22	103.91	108.63	108.84
8	c.o.p(A/B)		0	0.0149	0.0092	0.0101	0.0077	0.0073	0.0061

Table-6: Heat balance sheet –with Refrigerator at 1/3 load (33.3%)

1	Balance reading	8	8	8	8	8	8	8
	Time (hours)	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Speed RPM	1200	1200	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	23.6	21.0	22.8	25.9	26.2	26.6	26.3
4	Manometer reading(cm)	25.9	26.0	26.1	26.3	26.5	26.5	26.5
5	Time taken for collection of 2 lit of water in sec	23.6	21.0	22.6	25.9	26.2	26.6	26.3
6	Temperature of inlet water ^{0}C	28.3	30.0	30.0	30.5	30.8	31.1	31.1
7	Temperature of outlet water ^{0}C	31.0	31.7	32.0	33.0	34.0	34.0	34.0
8	Temp.rise of cooling water^{0}C	2.67	1.75	2.0	2.44	3.17	2.89	2.89
9	Temperature of exhaust gas ^{0}C	261	262	261	259	260	258	258
10	Room temperature ^{0}C	31.5	31.5	31.5	31.5	31.5	31.5	31.5

Table-7: Heat balance sheet calculated Results –with Refrigerator at 1/3 load

1	BHP (kcal/min)	3.2	3.2	3.2	3.2	3.2	3.2	3.2
2	TFC (kg/hr)	1.273	1.431	1.318	1.160	1.147	1.130	1.142
3	SFC (kg/bhp-hr)	0.398	0.447	0.412	0.362	0.358	0.353	0.357
4	Air consumption(kg/hr)	46.51	46.69	46.87	47.23	47.59	47.59	47.59
5	Air fuel ratio	36.5:1	32.6:1	35.6:1	40.7:1	41.5:1	42.1:1	41.7:1
6	Mass flow rate of exhaust gas kg/hr	47.78	48.12	48.18	48.39	48.73	48.72	48.73
7	Heat input (kcal/min)-Q_s	229.0	257.6	237.2	208.8	206.5	203.4	205.5
8	Heat equivalent to BHP(kcl/min)	33.72	33.72	33.72	33.72	33.72	33.72	33.72
	% of Heat to BHP(kcl/min)	14.72	13.09	14.21	16.15	16.33	16.50	16.40
9	Heat to cooling water(kcal/min)-Q_c	57.2	37.5	40.0	46.4	60.3	54.2	57.8
	% heat to cooling water	24.9	8.3	16.8	22.2	29.2	26.6	28.1
10	Heat to exhaust gas(kcal/min)-Q_g	49.34	49.91	49.75	49.53	50.10	49.65	49.66
	% heat to exhaust gas	21.54	19.37	20.97	23.72	24.26	24.4	24.15
11	Heat unaccounted (kcal/min)-Q_u	88.74	138.5	113.7	79.09	62.3	65.8	64.32
	% of unaccounted heat	38.75	52.9	47.9	37.87	30.17	32.36	31.29

Table-8: determination of c.o.p of refrigerator at 1/3 load on I.C Engine

1	Time in hours		starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C		31.0	30.75	29.0	26.5	25.0	24.25	24.0
3	Temp. difference of water inside the refrigerator ^{0}C-t_d		0	0.25	2.0	4.5	6.0	6.75	7.0
4	Net heat removed (kcal/hr)-A		0	2.0108	8.0437	12.066	12.065	10.859	9.3844
5	Average of exhaust gas quantity(kg/hr)-m_g		47.78	47.95	47.98	48.08	48.25	48.25	48.25
6	Average generator	Before t_1	247	246.5	245	241.5	242.5	244	243

	temp ^{0}C	After t_2	174	184	182.5	182	183	183	183.5
7	Net heat absorbed (kcal/hr)-B		219.74	188.80	188.9	180.22	180.86	185.42	180.86
8	c.o.p(A/B)		0	0.0106	0.0425	0.0669	0.0667	0.0585	0.0518

Table-9: Heat balance sheet –with Refrigerator at 1/2 load (50.0%)

1	Balance reading	12	12	12	12	12	12	12
	Time (hours)	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Speed RPM	1200	1200	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	22.1	23.7	23.3	23.5	23.3	23.4	23.1
4	Manometer reading(cm)	24.7	25.0	25.0	25.0	25.1	25.2	25.2
5	Time taken for collection of 2 lit of water in sec	7.0	7.2	5.1	4.5	4.7	4.7	4.8
6	Temperature of inlet water ^{0}C	28.89	30.56	32.78	33.33	33.89	34.4	35.0
7	Temperature of outlet water ^{0}C	32	34	35	36	36	37	37.5
8	Temp.rise of cooling water^{0}C	3.11	3.44	2.22	2.67	2.11	2.60	2.5
9	Temperature of exhaust gas ^{0}C	305	295	294	295	294	294	294
10	Room temperature ^{0}C	31.5	31.5	31.5	31.5	31.5	31.5	31.5

Table-10: Heat balance sheet -calculated Results–with Refrigerator at 1/2 load

1	BHP (kcal/min)	4.8	4.8	4.8	4.8	4.8	4.8	4.8
2	TFC (kg/hr)	1.36	1.26	1.29	1.27	1.29	1.28	1.30
3	SFC (kg/bhp-hr)	0.283	0.264	0.268	0.266	0.268	0.267	0.270
4	Air consumption(kg/hr)	44.3	44.9	44.9	44.9	45.0	45.2	45.2
5	Air fuel ratio	32.6:1	35.4:1	34.8:1	35.1:1	34.9:1	35.2:1	34.8:1
6	Mass flow rate of exhaust gas kg/hr	45.71	46.16	46.16	46.17	46.29	46.53	46.55
7	Heat input (kcal/min)-Q_s	244.8	228.2	232.2	230.2	232.2	231.1	234.0
8	Heat equivalent to BHP(kcl/min)	50.58	50.58	50.58	50.58	50.58	50.58	50.58
	% of Heat to BHP(kcl/min)	38.2	35.6	36.2	35.9	36.2	36.0	36.5
9	Heat to cooling water(kcal/min)-Q_c	53.31	57.33	52.23	71.2	53.87	66.38	62.50
	% heat to cooling water	21.77	25.12	22.49	30.92	23.19	28.72	26.70
10	Heat to exhaust gas(kcal/min)-Q_g	56.25	54.73	54.56	54.74	54.68	54.96	54.98
	% heat to exhaust gas	42.50	23.93	23.49	23.73	23.54	23.78	23.49
11	Heat unaccounted (kcal/min)-Q_u	84.66	65.59	74.82	53.67	70.03	59.17	65.94
	% of unaccounted heat	34.58	28.78	32.22	23.31	31.46	25.60	28.10

Table-11: determination of c.o.p of refrigerator at 1/2 load on I.C Engine

1	Time in hours		starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C		31	30.75	28.5	26.5	24.75	23.0	21.5
3	Temp. difference of water inside the refrigerator ^{0}C-t_d		0	0.25	2.5	4.5	6.25	8.0	9.5
4	Net heat removed (kcal/hr)-A		0	2.0115	10.054	12.066	12.568	12.869	12.735
5	Average of exhaust gas quantity(kg/hr)-m_g		45.71	45.935	45.950	45.94	46.0	46.12	46.13
6	Average generator temp^{0}C	Before t_1	270	270	271	269	270	269.5	269
		After t_2	200	202	203.5	201	202	201	201.5
7	Net heat absorbed (kcal/hr)-B		201.58	196.78	195.0	196.0	197.06	199.0	196.16
8	c.o.p(A/B)		0	0.0102	0.0514	0.0613	0.0637	0.0647	0.0649

Table-12: Heat balance sheet –with Refrigerator at 2/3 load (66.6%)

1	Balance reading	16	16	16	16	16	16	16
	Time (hours)	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Speed RPM	1200	1200	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	17.6	17.5	17.4	17.5	17.7	17.9	18.6
4	Manometer reading(cm)	24.8	24.9	25.0	25.0	25.0	25.1	25.1
5	Time taken for collection of 2 lit of water in sec	5.0	5.0	5.1	5.1	5.0	5.1	5.1
6	Temperature of inlet water ^{0}C	28.4	29.5	29.5	29.5	30.0	30.0	31.0
7	Temperature of outlet water ^{0}C	30.0	31.0	31.0	32.0	32.0	32.0	34.0
8	Temp.rise of cooling water^{0}C	1.67	1.56	1.56	2.56	2.0	2.0	3.0
9	Temperature of exhaust gas ^{0}C	400	405	406	407	404	405	408
10	Room temperature ^{0}C	30	30	30	30	30	30	30

Table-13: Heat balance sheet -calculated Results–with Refrigerator at 2/3load

1	BHP (kcal/min)	6.4	6.4	6.4	6.4	6.4	6.4	6.4
2	TFC (kg/hr)	1.707	1.717	1.727	1.717	1.698	1.679	1.616
3	SFC (kg/bhp-hr)	0.266	0.268	1.269	1.268	1.265	1.262	0.252
4	Air consumption(kg/hr)	44.5	44.7	44.9	44.9	45.1	45.1	45.1
5	Air fuel ratio	26:1	26:1	26:1	26.1:1	26.5:1	26.9:1	27.9:1
6	Mass flow rate of exhaust gas kg/hr	46.20	46.41	46.62	46.61	46.79	46.77	46.70
7	Heat input (kcal/min)-Q_s	307.3	309.0	310.8	309.0	305.6	302.2	290.8
8	Heat equivalent to BHP(kcl/min)	67.44	67.44	67.44	67.44	67.44	67.44	67.44
	% of Heat to BHP(kcl/min)	21.9	21.82	21.69	21.82	22.06	22.31	23.19
9	Heat to cooling water(kcal/min)-Q_c	40.0	37.4	36.7	60.2	48.0	47.0	70.58
	% heat to cooling water	13.13	12.10	11.80	19.48	15.70	15.50	24.24
10	Heat to exhaust gas(kcal/min)-Q_g	76.92	78.31	78.88	79.07	78.74	78.92	79.43
	% heat to exhaust gas	25.03	25.34	25.38	25.59	25.76	26.11	27.31
11	Heat unaccounted (kcal/min)-Q_u	122.90	125.80	127.78	102.30	111.40	108.84	73.35
	% of unaccounted heat	40.0	40.72	41.11	33.10	36.40	36.0	25.22

Table-14: determination of c.o.p of refrigerator at 2/3load on I.C Engine

1	Time in hours		starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C		29.0	24.5	18.75	15.0	12.5	10.75	9.25
3	Temp. difference of water inside the refrigerator ^{0}C-t_d		0	4.5	10.25	14.0	16.5	18.25	19.75
4	Net heat removed (kcal/hr)-A		0	36.196	41.224	37.537	33.180	29.359	26.476
5	Average of exhaust gas quantity(kg/hr)-m_g		46.20	46.30	46.41	46.40	46.40	46.46	46.46
6	Average generator temp^{0}C	Before t_1	350	352.5	353	353	348.5	352	348.5
		After t_2	270	271	272	272	270	270	267.5
7	Net heat absorbed (kcal/hr)-B		232.84	237.72	236.83	236.77	229.47	240.11	237.08
8	c.o.p(A/B)		0	0.1522	0.174	0.1585	0.1445	0.1227	0.1116

Table-15: Heat balance sheet –with Refrigerator at 3/4 load (75%)

1	Balance reading	20	20	20	20	20	20	20
	Time (hours)	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Speed RPM	1200	1200	1200	1200	1200	1200	1200
3	Time taken for 10c.c of fuel consumption-sec	13.9	14.0	14.0	14.1	14.1	14.1	14.1
4	Manometer reading(cm)	23.7	24.0	24.2	24.3	24.4	24.5	24.6
5	Time taken for collection of 2 lit of water in sec	5.4	5.5	5.6	5.5	5.5	5.6	5.5
6	Temperature of inlet water ^{0}C	30	31.11	31.67	31.94	32.2	32.78	33.34
7	Temperature of outlet water ^{0}C	32	34	36	36	36	36.5	36.5
8	Temp.rise of cooling water^{0}C	2	2.89	4.33	4.06	3.8	3.72	3.26
9	Temperature of exhaust gas ^{0}C	458	462	460	466	468	468	467
10	Room temperature ^{0}C	30.5	30.5	30.5	30.5	30.5	30.5	30.5

Table-16: Heat balance sheet -calculated Results–with Refrigerator at 3/4load

1	BHP (kcal/min)	8	8	8	8	8	8	8
2	TFC (kg/hr)	2.162	2.147	2.147	2.131	2.131	2.131	2.131
3	SFC (kg/bhp-hr)	0.270	0.268	0.268	0.266	0.260	0.266	0.266
4	Air consumption(kg/hr)	41.66	43.1	43.46	43.64	43.82	43.99	44.18
5	Air fuel ratio	19.3:1	20:1	20.2:1	20.5:1	20.5:1	20.6:1	20.7:1
6	Mass flow rate of exhaust gas kg/hr	43.82	45.25	45.60	45.77	45.95	46.12	46.31
7	Heat input (kcal/min)-Q_s	389.16	386.46	386.46	383.58	383.58	383.5	383.5
8	Heat equivalent to BHP(kcl/min)	84.3	84.3	84.3	84.3	84.3	84.3	84.3
	% of Heat to BHP(kcl/min)	21.6	21.8	21.8	21.9	21.9	21.9	21.9
9	Heat to cooling water(kcal/min)-Q_c	44.4	63.0	92.7	88.5	82.9	79.7	71.1
	% heat to cooling water	11.4	16.3	24.0	23.0	21.6	20.7	18.5
10	Heat to exhaust gas(kcal/min)-Q_g	84.2	87.8	89.3	89.6	90.4	90.7	90.9

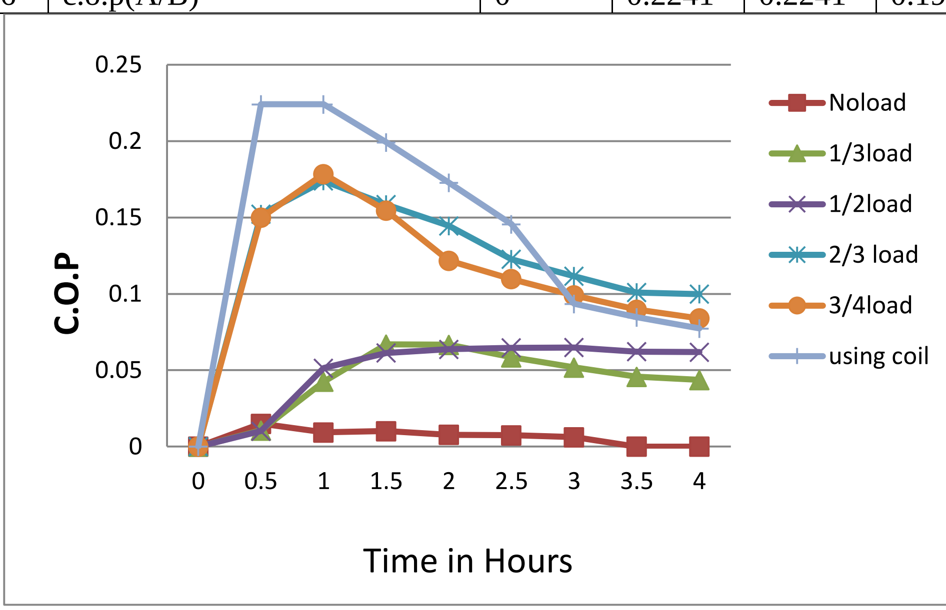
	% heat to exhaust gas	21.65	22.73	23.12	23.38	23.58	23.66	23.71
11	Heat unaccounted (kcal/min)-Q_u	171.1	151.4	120.0	121.0	125.9	128.7	137.2
	% of unaccounted heat	45.25	39.18	31.05	31.54	32.82	33.58	37.76

Table-17: determination of c.o.p of refrigerator at 3/4load on I.C Engine

1	Time in hours		starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C		28.5	24.5	17.75	15.0	12.5	10.5	9.0
3	Temp. difference of water inside the refrigerator ^{0}C-t_d		0	4.0	10.25	13.5	16.0	18.0	19.5
4	Net heat removed (kcal/hr)-A		0	32.174	41.224	36.197	32.175	28.957	26.142
5	Average of exhaust gas quantity(kg/hr)-m_g		43.82	44.53	44.71	44.79	44.88	44.97	45.06
6	Average generator temp^{0}C	Before t_1	377	391.5	397.0	401.0	409.5	411.0	411.5
		After t_2	311.0	315.0	315.0	318.0	316.0	318.0	318.5
7	Net heat absorbed (kcal/hr)-B		182.20	214.61	230.97	234.20	264.36	263.64	264.0
8	c.o.p(A/B)		0	0.1499	0.1784	0.1545	0.1217	0.1097	0.0990

Table-18: determination of c.o.p of refrigerator using coil (250 watts)

1	Time in hours	starting	0.5	1.0	1.5	2.0	2.5	3.0
2	Temp. of water inside the refrigerator ^{0}C	32.0	26.0	20.0	16.0	13.5	11.5	10.0
3	Temp. difference of water inside the refrigerator ^{0}C-t_d	0	6.0	12.0	16.0	18.5	19.5	22.0
4	Net heat removed (kcal/hr)-A	0	48.262	48.262	42.899	37.202	31.370	29.493
5	Net heat absorbed (kcal/hr)-B	215.31	215.31	215.31	215.31	215.31	215.31	215.31
6	c.o.p(A/B)	0	0.2241	0.2241	0.1992	0.1723	0.1456	0.0935



Graph: comparison of COP with Time in hours at different load conditions

Conversions used :

1w=3.6 x10^3 J/hour

250 w =250 x3.6x10^3 =900x10^3 J/hour

250 w=$\frac{900000}{4.18}$ =215311 cal/hour=215.311 kcal/hour

1 kcal =4.18 Joule

6. RESULTS AND CONCLUSIONS

The tests and results are found to be very much satisfactory. It is found that 100 litre capacity refrigerator can be functioned well using exhaust gas of a 10 HP engine without any additional equipment. With a well designed insulation and heat exchanger and selecting a better vapour absorption system. We can even run a higher capacity refrigerator. This gives a hope that the exhaust gases of an I.C engine of around 160 HP normally mounted on a refrigerated truck can be just sufficient to run a refrigeration system of 5 ton capacity

The results show that the coefficient of performance of the "Himalux" refrigerator of 100 litre capacity in both cases i.e 1.by using exhaust gas

2. By using electric power are almost same

The cop of machine is found to be less for the following reasons

1. The refrigerator chosen (which is available in the lab) a domestic Electrolux vapour absorption system which is originally a less efficient system compared to the vapour absorption system.

2. Absence of insulation increases heat losses. This leads to incomplete usage of exhaust heat. In the transport system it is always better to insulate the exhaust pipe line up to the generator.

3. The pipe line being of considerable length and process number of joints there are chances of transmission losses and leakages. As far as possible, reduce the length of exhaust pipe also with minimum number of bends.

4. Exhaust gas may cause corrosion on the generator parts. Hence generator parts are to be made of non-corrosive materials.

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