COMPARATIVE STUDY OF PERFORMANCE PARAMETERS OF COMBINE HARVESTERS

BY

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CERTIFICATE – I

This is to certify that this thesis entitled **"Comparative study of performance parameters of combine harvesters"** submitted for the degree of **Master of Technology** in the subject of **Farm Power and Machinery** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar,** is a bonafide research work carried out by **Dinesh Kumar** under my supervision and that no part of this dissertation has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that this thesis entitled **"Comparative study of performance parameters of combine harvesters"** submitted by **Dinesh Kumar** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** in partial fulfillment of the requirements for the degree of **Master of Technology** in the subject of **Farm Power and Machinery**, has been approved by the Student's Advisory Committee after an oral examination on the same.

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ABBREVIATIONS

%	Per-cent
ºC	Degree Celsius
A.R.A.I.	Automotive Research Association of India
BIS	Bureau of Indian Standard
D	Depreciation
Fig.	Figure
G	Gram
g/kW-h	Gram per kilowatt per hour
hp	Horse Power
Hrs	Hours
IS	Indian Standard
kW	Kilowatt
l/h	Litre per hour
N-m	Newton-meter
NRFMT&TI	North Region Farm Machinery Training and Testing Institute

N.S.	Non-Significant
Rs.	Rupees
SD	Standard Deviation
SEm	Standard Error of Mean
TAR	Total Accumulated Repair Cost
t_{cal}	Calculated value of t
t_{tab}	Tabulated value of t

CHAPTER – I

INTRODUCTION

Harvesting of wheat as well as paddy by combine harvester is common feature in most of the states in India. The combine harvester, or a combine, is a machine that accomplishes the tasks of harvesting, threshing, separating, cleaning of grain crops and then dumped into a truck or trailer for transport. Generally, in India there are two types of combines used tractor drawn and self-propelled combines, but now only self-propelled combines is used. In tractor-drawn combine, the combine is fitted on the tractor in such a way that it rest on the tractor rear axle as well as on extended portion of rear axle and header unit comes in front of tractor. Tractor's controls are raised to the combine platform with the help of the extended levers. The operator sits on the combine platform and operates the machine. The self-propelled combine is powered with 60 to 150 hp diesel engines. It is provided with a gearshift or variable-speed drives, such as the hydrostatic drive, to give desired field and road speeds. It is easy to handle and transport from field to field and over the highway. While transportation on highway, the header unit is removed from front and hitched behind the combine. About forty-five manufacturers make combines with different specifications and models in India. Most of the manufactures of combines are in Punjab. About 30 manufactures make self-propelled combine harvesters.

As a result of its increasing use, the test code was developed for the testing institutions for assessment of the performance of the combine on a uniform and rationalized basis. This test code is expected to fulfill this long felt need. The test code has two parts. Part-I of this code covers the terminology and part-II covers the method of various tests to be conducted to assess the performance of the combine including its prime mover, in case of self-propelled combine. Testing of combine harvesters are performed in accordance with IS: 8122-1994 Part-I & IS: 8122-2000 Part- II as amended from time to time by Bureau of Indian standard (BIS). This Indian standard (First Revision) was adopted by the bureau in Indian standard, after the draft finalized by the farm implements and machinery sectional committee had been approved by the food and agriculture division council. This standard was originally issued in 1981 and revision has been taken up for the following reasons: to change recommendations about fuels and lubricants used during the testing of combines, to modify servicing and preliminary setting after running in test, to modify test conditions of temperature for laboratory tests, to incorporate header lifting/hydraulic test end noise level tests, to harmonize break performance test and air-cleaner oil pull-over test with tractor test for the same parameters, to modify data sheets for recording of test data to meet the requirements of central motor vehicles rules and to update the standard(Mehta, 1995). In the preparation of this draft considerable assistance has been derived from the Central Farm Machinery Training and Testing Institute, Budni (M.P.). In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2: 1960 'Rules for rounding off numerical values (revised)'.

The testing fee of self-propelled combine harvester is Rs 353000. Total cost of testing the combine is around Rs 8-10 lacs, which included the field and labour charges during field operation. The testing of combine harvester is a long process which takes about 1.5-2 years. It is done in two seasons, Rabi and Kharif. It is a long, very costly and laborious process. The manufacturers of self-propelled combine harvesters purchase, prime mover or engines for their combine from some other manufacturer. Engine installed by the manufacturer of self-propelled combine harvesters were already tested as per the BIS standard, by Automotive Research Association of India, Pune (ARAI, Pune). The self-propelled combine harvesters are tested in North Region Farm Machinery Training & Testing Institute, Hisar (NRFMT &TI Hisar), as per the BIS standards, in this way the retesting of prime mover or engine is done. Three different makes of combine-harvesters used Kirloskar engine (Model-6R 1080) as prime mover, meaning there by the same model of engine was tested three times at NRFMT&TI (HISAR) during testing of combines. Engine of Ashok Leyland (Model-ALU-400) used in 22 different makes of combine harvesters as prime mover, meaning there by the same model of engine was tested twenty two times at NRFMT&TI (HISAR) during testing of combines.

The engines are tested at combine testing institutes, which increase the production and testing cost of combines. The testing of engine takes about 1.5-2 month, due to this there is delay in testing the combine harvesters. The same model of engine mounted on combines is tested again and again at same testing set-up in the combine testing institute. Testing cost of engine of combine results in extra expenditure of testing at the manufacturer and at the combine testing institute. Therefore, for reducing the burden of retesting of engines on testing institutions a need arises for comparative study of performance parameters of combine harvester for the benefits of users, entrepreneurs and the testing institutes.

The study was undertaken with the following objectives:

1. To study the specifications, performance data and test requirements of different makes of combine harvesters
2. To study the extent of labour, fuel and cost involved in the existing test requirements of the engine used on the combine harvester

3. To compare the existing engine performance data with the results obtained from the tests

CHAPTER – II

REVIEW OF LITERATURE

The review of literature collected on various aspects in relation to the present study is presented below:

Kalkat *et al*. (1993) studied the status of combine and other grain harvesting manufactured in Punjab. On the basis of the information secured thorough the survey, Patiala district was the major contributor for the production of grain combines and straw combines. Combine manufacturing units were located at Sirhand, Bhadson, Nabha and Patiala. Sangrur district was ranked second in the production of these machines with manufacturing units located at Surkam, Dhuri, and Malerkotia Handayaya etc.

Lin and Buckmaster (1996) evaluated an optimized engine-fluid power drive system to replace mechanical tractor take-off. Using a fluid power drive in place of a mechanical power take-off has received considerable interest in recent years, with the motivation of improving PTO safety. Fluid power has not been adopted primarily due to its inefficiency. To improve both, power source and transmission efficiency, a control strategy for optimizing tractor engine performance by controlling engine speed and fluid power displacement is proposed. A mathematical steady-state model was developed to evaluate the fuel efficiency of the proposed system. Simulation shows that operating an engine at its optimal state can yield a 7% improvement in average specific fuel consumption for the simulated engine. However, due to the low efficiency of the fluid power drive, the optimally control engine with a final drive would consume an average of 35.6% more fuel than with a mechanical drive. Further study shows that for the assumed load cycle such an engine coupled with an 88.8% efficient fluid power drive would consume a similar amount of fuel as the same engine with a 95% efficient mechanical.

Thakur *et al.* (2002) studied the utilization pattern of combine harvester in tarai region or Uttaranchal –A- case study. The survey was conducted to study the utilization of combine harvester in Sitrganj and Rudrapur block of disst. Udham Singh Nagar, Utranchal. About 85% of farmers used combine harvester to harvesting wheat and paddy crops in district. Major problem due to use of combine was loss of straw. About 94% of farmers burnt the straw left by Combine. The farmer got low market price for combine harvested crop due to poor grain quality. The major benefit or using Combine harvester was saving time, which developed to child care and social work. The Combine owners covered about 180-225 hectares in a season.

Ghassemzadeh and Mann (2003) developed a vision-aided tractor guidance simulator. To achieve a reasonable level of precision in tractor-based field operations, a tractor operator has to guide accurately, monitor and control both the tractor and the attached implement. Since guidance is the most time consuming task among the others, researchers have attempted to automate the guidance task. However, the use of automatic guidance and control in agricultural applications is not always appropriate. Transportation of the vehicle on a public road is an example of this. Some researchers therefore have focused on Vision-Aided methods to give some guidance aid to the driver rather than on eliminating the driver. To investigate the accuracy of such methods, a Vision-Aided tractor guidance belt-type simulator was developed. An experimental prototype of the simulator was constructed. To evaluate the prototype, a completely randomized factorial experiment was conducted with forward speed, heading angle, and camera tilt angle being the major factors under investigation. The simulator performed satisfactorily at 5 and 7km/h and mean deviations of 1.14 and 2.31cm were obtained respectively.

Manes *et al.* (2003) studied comparative performance of combine harvesters. The study was conducted to compare the technical features and field performance of two commercially available models of Combine harvesters namely: Tractor side mounted Combine (Cl) and Tractor riding type Combine (C2). Both the machines the rack and shoe loss for wheat and paddy were found to below 0.25 and .62% with grain breakage of 3.62 and 2.44% respectively. However grain breakage was low (0.80) % reported in machine C2 in case of paddy. Cleaning and threshing efficiency were more than 97 and 98% respectively. Better visibility and ease of operation were observed in case of side mounted combine.

Tahir *et al*. (2003) evaluated the techno-economic feasibility of using combine harvester. Techno-economic feasibility of using combine harvester (Class Denominator) was carried out by determining harvesting losses, timeliness of harvesting, field capacity, fuel consumption, and noise and dust pollution, frequency of repair/maintenance and operating cost of the machine. The results indicated that combine had an average harvesting loss of about 1.25% of wheat yield. Grain breakage losses (5.7%) were bit higher. The machine was able to harvest 2.5 to 3.0 acres in an hour. The fuel consumption of the combine was found to be 15 L of diesel per acre. As the machine was not equipped with a proper cab, dust and noise pollution posed threat to the operator’s health. The machine needed only two to three persons for its operation and costs about Rs 860/acre to the user. The combine is an efficient, economical, labor and time saving machine but its initial cost is quite high.

Grissoo *et al.* (2004) predicted tractor fuel consumption. Reports from the Nebraska Tractor Test Laboratory (NTTL) show improved fuel efficiency during the past 20 years. A

4.8% decrease in average annual specific volumetric fuel consumption for the data used in the ASAE Standards was shown. Using fuel consumption and power data from the NTTL reports, new equations for fuel consumption were established that predict fuel consumption for diesel engines during full and partial loads and under conditions when engine speeds are reduced from full throttle.

Thakur *et al.* (2004) studied the economics of custom of combine harvester in north western indo genetic planes of India -A- study. They conduct the study by dividing the required region in three different zones namely high, medium and low combining intensity zone. In high intensity zone the entrepreneur faced tough competition for the excess supply of combine harvesters from the state of Punjab and Haryana. In medium intensity zone, about 30% managers were interested to expand their business in low intensity zone; unit managers faced major constraints of bad weather and wet land conditions. The life of combine harvesters in study region was observed to vary from 1 to 20 years. Season wise operating hours of combine harvesters were 236.9 hrs in Kharif and 315.3 hrs in Rabi season.

Labeckas *et al.* (2009) presents the bench testing results of a four stroke, four cylinder, direct injection, unmodified, diesel engine operating on pure rapeseed oil (RO) and its 2.5 vol%, 5 vol%, 7.5 vol% and 10 vol% blends with ethanol (ERO), petrol (PRO) and both improving agents applied in equal proportions as 50:50 vol% (EPRO). The purpose of the research is to examine the effect of ethanol and petrol addition into RO on diesel engine emission characteristics and smoke opacity of the exhausts. The biggest NO_x emissions, 1954 and 2078 ppm, at 2000 min^{-1} speed generate blends PRO10 (9.72%) and EPRO5 (11.13%) against, 1731 and 1411 ppm, produced from ERO5 (12%) and ERO10 (13.2% oxygen) blends. The carbon monoxide, CO, emissions emitted from a fully loaded engine fuelled with three agent blends EPRO5–7.5 at maximum torque and rated speed are higher by 39.5–18.8% and 27.5–16.1% and smoke opacity lower by 3.3–9.0% and 24.1–17.6% comparing with RO case. When operating at rated 2200 min^{-1} mode, the carbon dioxide, CO_2, emissions are lower, 6.9–6.3 vol%, from blends EPRO5–7.5 relative to that from RO, 7.8 vol%, accompanied by a slightly higher emission of unburned hydrocarbons HC, 16 ppm, and residual oxygen contents O_2, 10.4–12.0 vol%, in the exhausts.

Murthy and Ramakrishna (2009) reported that, the behavior of various engine performance parameters like break torque, break power, indicated power, friction power, mechanical efficiency, mean effective pressure and specific fuel consumption are studied over its speed range which will helps us to do the performance comparison. Also the time distribution of parameters like engine speed, engine torque, engine break power, engine percent load, fan speed, ambient air and coolant temperature are graphically summarized using Histogram which will helps us to know the concentration areas of the particular parameter over its test period of time. It has been observed from the result that the maximum torque and maximum power developed by the engine is 307 Nm and 64.57 kW at the speed of 1332 rpm and 2450 rpm respectively. The maximum power loss observed is 36kW and the average pressured generated inside the cylinder is 400kN/m2. The maximum mechanical efficiency of the engine is observed at the speed of 1900 rpm. The engine speed is more concentrated between the range 2000 to 2250 rpm during its test period of time.

Robert *et al.* (2009) reported that the purpose of the tests is to collect data that can be used to assess the performance of tractors of different makes and models. For this reason, all tests are conducted under the same or similar test conditions and procedures. Tractor tests are generally conducted to assess the power-takeoff (PTO) performance, draw-bar performance, hydraulic-lift capacity, and hydraulic-system pressure and flow. In addition, sound-level measurements are taken at operator and bystander locations.

Coffman *et. al.* (2010) was tested fuel efficiency of a tractor with a continuously variable transmission. The relationship between fuel consumption and drawbar power was linear and there was no significant effect of the order in which the power levels were applied, it appears that the minimum number of power levels required for the test is two power levels representing the range of anticipated field load for each travel speed.

CHAPTER – III

MATERIAL AND METHODS

The principal objective of this investigation was "**Comparative study of performance parameters of combine harvesters"**. The study was planned and conducted in three phases. The methodology followed for matching the objectives of the study under consideration is reported in this chapter as under:

Phase-I

To study the specification, performance data and test requirements of different makes of combine harvesters. The study of first phase was carried out on the basis of the engine testing performance in the test reports of self-propelled combine harvester.

Phase-II

To study the extent of labor, fuel and cost involved in the existing test requirements of the engine used on the combine harvester. The study of second phase was carried out during the engine testing, conducted by NRFMT&TI (HISAR). The information taken from the institute involve the data on testing time, total fuel used, labor charges and total cost in testing the engine of combine harvester.

Phase III

To compare the existing engine performance data with the results obtained from the test reports. The study of third phase was carried out by comparing the testing performance parameters of engine tested in testing institutions.

Location of study:

The proposed study was conducted at North Region Farm Machinery Training and Testing institute (NRFMT&TI), Hisar.

3.1 Materials

Test report of all self-propelled combine harvesters, tested at NRFMT&TI (HISAR) since the inception of testing wing. Test report of engine tested at Automotive Research Association of India (ARAI) Pune, used in self-propelled combine harvesters as prime mover.

3.2 Methods

The major objective of study was to compare the existing engine performance data with the results of test reports released by testing institutes.

1.1.1 Engine performance test parameters reported under various tests in the test reports used for comparison purpose are:

i) Varying speed test

The varying speed test was conducted under natural condition (temp. range: 30±5 degree C). It repeated under high ambient condition (temp. range: 45±2 degree C) to assess engines performance under tropical climatic conditions. In this test, engine started for warming-up and after warming-up the engine run at maximum speed. The engine speed decreases after every five minute. The last reading was recorded at low ideal speed. The reading for engine power, torque, fuel consumption and specific fuel consumption were recorded after every five minutes. Maximum power and maximum torque was recorded in this test.

ii) Varying load test

The varying load test was conducted under natural condition (temp. range: 30±5 degree C). The reading for engine power, torque, fuel consumption and specific fuel consumption recorded at varying loads in this test.

iii) **Maximum power test**

The engine operated for a period of two hours after warmed-up, for power to become stabilized. The test carried out under natural condition (temp. range: 30±5 degree C). A minimum of six readings were recorded at 20 minutes interval of time during two hours test periods. The reading of engine power, torque, fuel consumption and specific fuel consumption recorded at varying loads in this test.

iv) Five hours rating test (High Ambient)

The engine run at 90% of maximum output for 4 hours under high ambient condition (temp. range: 45±2 degree C). The engine run at a load corresponding to maximum power for a period of 1 hour after 4 hours continuous running at 90% of maximum output. The reading of engine power, torque, fuel consumption and specific fuel consumption recorded at varying loads in this test.

3.2.2 Performance parameters of the engine to be compared are:

i. Power, kW
ii. Torque, N-m
iii. Fuel consumption, l/h
iv. Specific fuel consumption, g/kW-h

Engine performance parameters were recorded from the control panel of engine testing set-up. The engine power and torque were recorded from the control panel. The fuel consumption measured by the pipette method. Time taken for burning of 50g fuel was noted and from this hourly fuel consumption measured. The specific fuel consumption was calculated dividing the hourly fuel consumption by power.

3.2.3 Cost estimation of testing of the engine of combines at NRFMT&TI (Hisar):

Estimation of cost, carried out in accordance with IS: 9164-1979

The cost of testing the engine consists of charges and operating cost of testing bed, charges and operating cost of generator, labor charges and overhead charges. The charges of

Plate: 3.1 Self-propelled combine harvester fitted with Ashok Leyland engine

Plate: 3.2 Engine of combine mounted on testing-bed for testing

Plate: 3.3 Control panel for engine testing

Plate: 3.4 Generator used during engine testing

testing bed and generator are termed as fixed cost. Operating cost of testing bed and generator and labor charges are referred to as variables cost.

A summary of cost items is given below:

A) Fixed costs:

i. Depreciation:

This cost reflects the reduction in value of a machine with use (wear) and time. While actual depreciation would depend on the sale price of the machine after its use, on the basis of different computational method depreciation can be estimated. The straight line method for estimation of deprecation was used as under:

$$D = (P - S)/L$$

Where,

D = Depreciation cost average per year, Rs/yr

P = Purchase price of the machine, Rs

S = Residual value of the machine taken as 10% of purchase price, Rs

L= Useful life of the machine years

ii. Interest:

Annual charges of interest were calculated on the basis of the actual rate of interest payable.

Where,

I = Annual interest charge, Rs/yr

P = Purchase price of the machine, Rs

S = Residual value of the machine, Rs

i = Interest rate, %

iii. Insurances and taxes:

It is usually taken as 2.5% of the average purchase price of the machine.

iv. Housing cost:

It is estimated as 1.5% of the average purchase price of the machine.

B.) Variable costs:

i. Fuel: (actual fuel used in engine and in generator)

ii. Lubricant oil: (3% of total fuel used, as per IS: 9164-1979)

iii. Repair and maintenance: TAR = 0.120 x $(X)^{1.5}$

   a. TAR = total accumulated repair cost divided by purchased price of the machine expressed as percentage

   b. X = 100 times the ratio of the accumulated hours of use to the water out life.

iv. Wages and labor charges: (actual labor used)

C.) Overhead charges:

20% of total cost (fixed cost + variable cost)

(As per IS: 9164-1979)

3.3 Statistical Analysis

The statistical analysis was done by one-sample t-test using the SPSS statistical software. One-sample t-test was carried out to compare the means value of all performance parameters of Kirloskar engines (Model-6R 1080) tested at different testing institutes.

CHAPTER – IV

RESULTS

The present investigation was carried out on the comparative study of performance parameters of combine-harvesters. Objectives of the investigation were to study the specifications, performance and testing requirements, extent of labor, fuel and cost involved in testing the engine, and to compare the existing performance data with the results obtained from the tests. Three different makes of combine-harvesters received for testing used Kirloskar engine (Model-6R 1080) as prime mover, meaning there by the same model of engine was tested three times at NRFMT&TI (HISAR) during testing of the combines. The average values of testing performance of Kirloskar engine (Model-6R 1080) tested at NRFMT&TI (HISAR) were compared with the performance of same model of engine tested at Automotive Research Association of India (Pune). Engine of Ashok Leyland (Model-ALU-400) was used in 22 different makes of combine harvesters as prime mover, meaning there by the same model of engine was tested twenty two times at NRFMT&TI (HISAR) during testing of combines. The testing performances of Ashok Leyland engines (Model-ALU-400) were compared on the basis of mean values of test performance data. Results obtained during the investigation are reported below:

4.1 Kirloskar engine (Model-6R 1080)

4.1.1 Varying Speed Test

4.1.1.1 Power

Comparative performance results in terms engine power at different speeds, tested at different testing institutes are depicted in fig.4.1 & Table-4.1. Power performance of Kirloskar engines (Model-6R 1080) tested at different testing institutes obtained under varying speed test was similar as given in Table-4.1. The percentage of variation in the maximum power of engine tested at different testing institutes was very low (3.12%). The percentage of variations in power developed at speeds, 1000, 1200, 1400, 1600, 1800 & 2000 rpm were found to be 0.57, 0.87, 2.18, 0.30, 0.20 & 2.58% respectively. The calculated t values were 0.49, -0.78, -4.67, 0.58, -0.50, -5.67 and -9.07 at speed 1000, 1200, 1400, 1600, 1800, 2000 & 2200 rpm, respectively which were less than tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

4.1.1.2 Torque

Comparative performance results in terms of engine torque, tested at different testing institutes are shown in fig.4.2 & Table-4.1. Torque performance of Kirloskar engine (Model-6R 1080) tested at different testing institutes obtained under varying speeds was almost same. The percentage of variation was 0.56% at maximum torque of engine tested at different testing institutes which was quite low. The percentage of variations in torque developed at different speeds, 1200, 1400, 1600, 1800, 2000 & 2200 rpm were found to be 0.87, 0.95, 0.93, 0.32, 2.49 & 3.10% respectively. The calculated t values were 0.48, -0.76, -1.85, -1.97, -0.48, -5.61 and -9.18 at speeds 1000, 1200, 1400, 1600, 1800, 2000 & 2200 rpm, which were less than tabulated t value (9.93) at 1% level of significance.

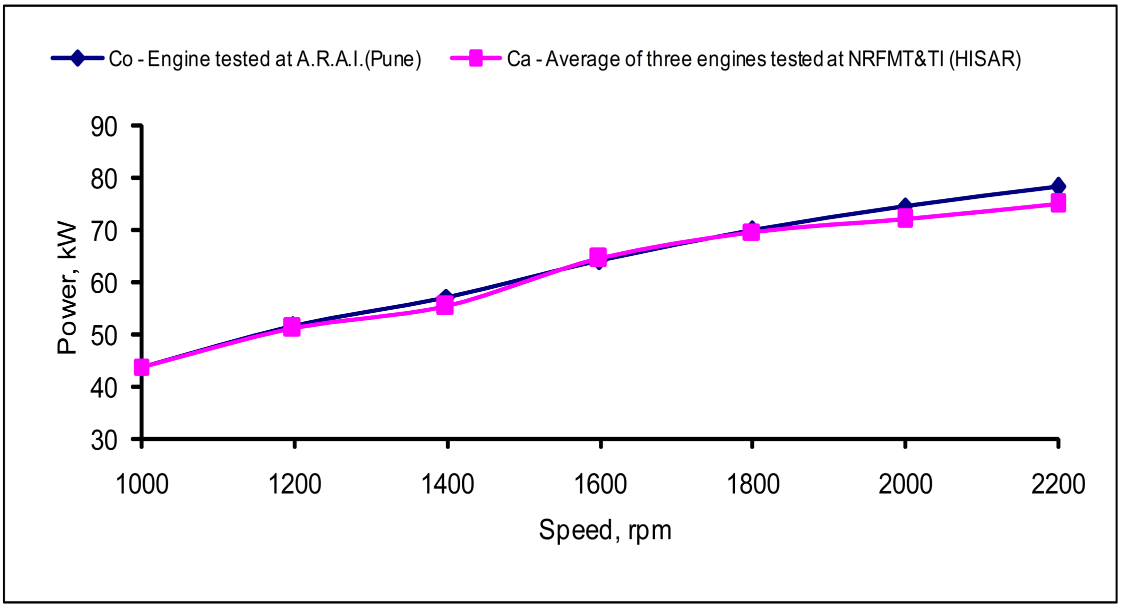


Fig.4.1 Comparative performance of engine power tested at different testing institutes at varying speeds

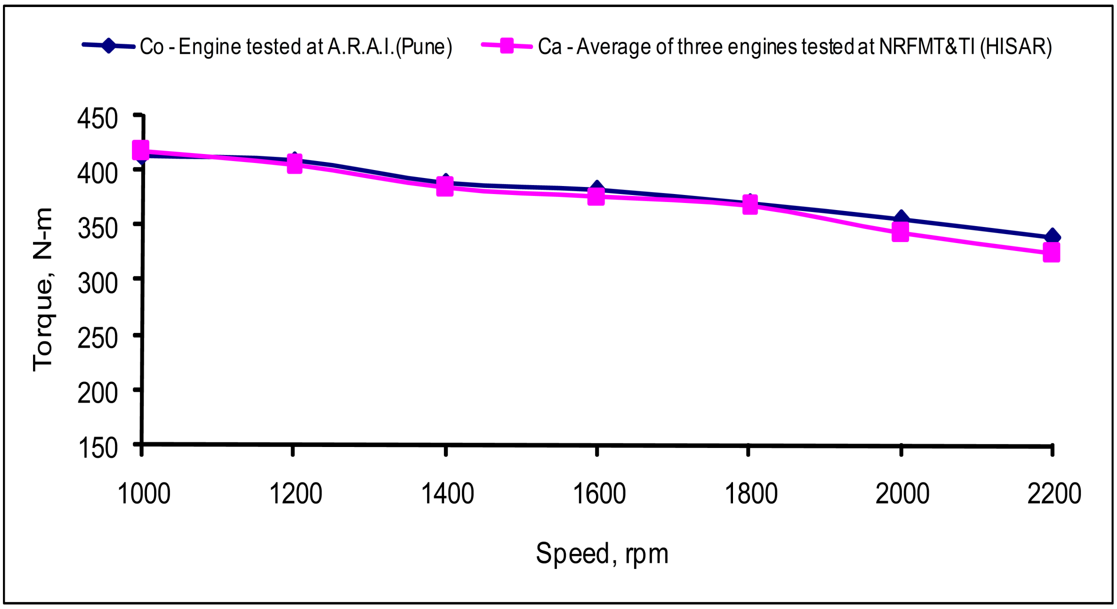


Fig.4.2 Comparative performance of engine torque tested at different testing institutes at varying speeds

4.1.1.3 Fuel consumption

Fuel consumptions performance of engines, tested at different testing institutes is reported in fig.4.3 and Table-4.1. Fuel consumption performance of Kirloskar engine (Model-6R 1080) tested at different testing institutes obtained under varying speeds was almost same. The percentage of variation in maximum fuel consumption of engine tested at different testing institutes was 0.98 %. The percentage of variations in fuel consumption at speeds, 1000, 1200, 1400, 1600, 1800 & 2000 rpm were found to be 1.07, 0.63, 1.71, 2.64, 2.78 & 1.84% respectively. The calculated t values were 1.88, 0.97, 0.46, 1.44, 2.92, 8.36 and 1.35 (Table-4.1) at speeds 1000, 1200, 1400, 1600, 1800, 2000 & 2200 rpm, which were less than the tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

Table-4.1 Comparative performance of kirloskar engine tested at different testing institutes in varying speed test

(t_{tab} = 9.93 at 1% level of significance, at 2 degree of freedom)

Speed (rpm)	C_0	Ca	Mean	S D	C V (%)	SEm	t_{cal}	Significance/ Non-significance
	Power kW							
1000	43.40	43.75	**43.58**	**0.25**	**0.57**	**0.22**	**0.49**	**N.S.**

1200	51.50	50.87	**51.19**	**0.45**	**0.87**	**0.39**	**-0.78**	**N.S.**
1400	57.00	55.27	**56.14**	**1.22**	**2.18**	**1.07**	**-4.67**	**N.S.**
1600	64.00	64.27	**64.14**	**0.19**	**0.30**	**0.17**	**0.58**	**N.S.**
1800	69.70	69.50	**69.60**	**0.14**	**0.20**	**0.12**	**-0.50**	**N.S.**
2000	74.50	71.83	**73.17**	**1.89**	**2.58**	**1.66**	**-5.67**	**N.S.**
2200	78.00	74.63	**76.32**	**2.38**	**3.12**	**2.09**	**-9.07**	**N.S.**
Torque N-m								
1000	414.65	417.96	**416.31**	**2.34**	**0.56**	**2.05**	**0.48**	**N.S.**
1200	410.03	404.99	**407.51**	**3.56**	**0.87**	**3.13**	**-0.76**	**N.S.**
1400	388.99	383.80	**386.40**	**3.67**	**0.95**	**3.22**	**-1.85**	**N.S.**
1600	382.17	377.16	**379.67**	**3.54**	**0.93**	**3.11**	**-1.97**	**N.S.**
1800	369.96	368.29	**369.13**	**1.18**	**0.32**	**1.04**	**-0.48**	**N.S.**
2000	355.89	343.15	**349.52**	**9.01**	**2.49**	**7.90**	**-5.61**	**N.S.**
2200	338.74	324.12	**331.43**	**10.34**	**3.10**	**9.07**	**-9.18**	**N.S.**
Fuel consumption l/h								
1000	12.93	13.11	**13.02**	**0.13**	**0.98**	**0.11**	**1.88**	**N.S.**
1200	14.48	14.70	**14.59**	**0.16**	**1.07**	**0.14**	**0.97**	**N.S.**
1400	15.58	15.72	**15.65**	**0.10**	**0.63**	**0.09**	**0.46**	**N.S.**
1600	17.14	17.56	**17.35**	**0.30**	**1.71**	**0.26**	**1.44**	**N.S.**
1800	19.77	20.45	**20.08**	**0.53**	**2.64**	**0.47**	**2.92**	**N.S.**
2000	21.73	22.60	**22.17**	**0.62**	**2.78**	**0.54**	**8.36**	**N.S.**
2200	23.87	24.50	**24.19**	**0.45**	**1.84**	**0.39**	**1.35**	**N.S.**
Specific fuel consumption g/kW-h								
1000	250.6	254.27	**252.43**	**2.59**	**1.03**	**2.28**	**1.44**	**N.S.**
1200	243.5	246.80	**245.15**	**2.33**	**0.95**	**2.05**	**2.32**	**N.S.**
1400	234.2	236.43	**235.31**	**1.57**	**0.67**	**1.38**	**1.02**	**N.S.**
1600	231.1	225.07	**228.08**	**4.26**	**1.87**	**3.74**	**-4.05**	**N.S.**
1800	242.9	243.23	**243.06**	**0.23**	**0.10**	**0.20**	**0.11**	**N.S.**
2000	252.2	261.10	**256.65**	**6.29**	**2.45**	**5.52**	**3.08**	**N.S.**
2200	271.1	274.77	**272.93**	**2.59**	**0.95**	**2.28**	**1.98**	**N.S.**

C_0 & Ca engines tested at A.R.A.I. (Pune), and at NRFMT&TI (HISAR) (average value of three different combines)

t_{cal} – Calculated value of t **SD- Standard Deviation**

N.S. –Non-Significante **CV- Co-efficient of Variation**

t_{tab} –Tabulated value of t **SEm- Standard Error of Mean**

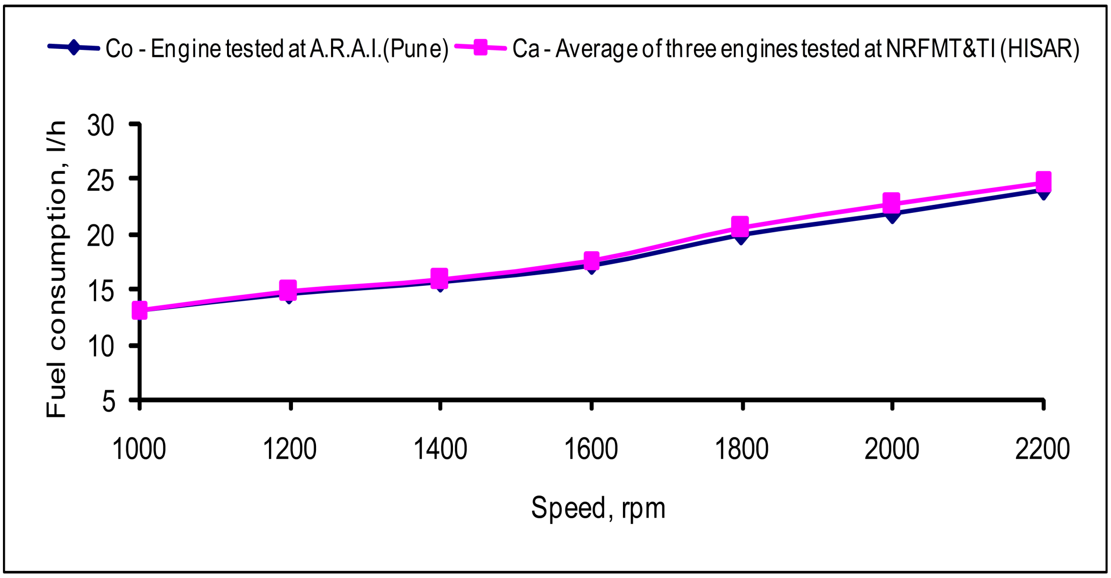


Fig.4.3 Comparative fuel consumption performance of engine tested at different testing institutes at varying speeds

Fig.4.4 Comparative specific fuel consumption performance of engine tested at different testing institutes at varying speeds

4.1.1.4 Specific fuel consumption

Specific fuel consumptions performances of engines, tested at different testing institutes are reported in fig.4.4 and Table-4.1. Performance of specific fuel consumption in Kirloskar engine (Model-6R 1080) tested at different testing institutes obtained under varying speed was similar as shown in Table-4.1. The percentage of variation in minimum fuel consumption was low (1.87%). The percentage of variation in specific fuel consumptions at speeds of 1000, 1200, 1400, 1800, 2000 & 2200 rpm were found to be 1.03, 0.95, 0.67, 0.10, 2.45 & 0.95%. The calculated t values were 1.44, 2.32, 1.02, -4.05, 0.11, 3.08 and 1.98 at speeds 1000, 1200, 1400, 1600, 1800, 2000 & 2200 rpm, which were less than the tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

4.1.2 Varying load test

4.1.2.1 Power

Comparative performance results in term of engine power at different loads, tested at different testing institutes are indicated in fig.4.5 and Table-4.2. Power performance of Kirloskar engine (Model-6R 1080) tested at different testing institute obtained under varying loads was almost similar as given in Table-4.2. The percentage of variations in maximum power at 100% load was only 3.10%. The percentage of variations in power at loads of, 85, 75, 50, & 10% were found to be 0.65, 0.89, 0.67 & 1.04% respectively. The calculated t values were -6.68, -1.23, -0.89, -1.04 and 0.73 at loads 100, 85. 75, 50 and 10%, which were less than tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

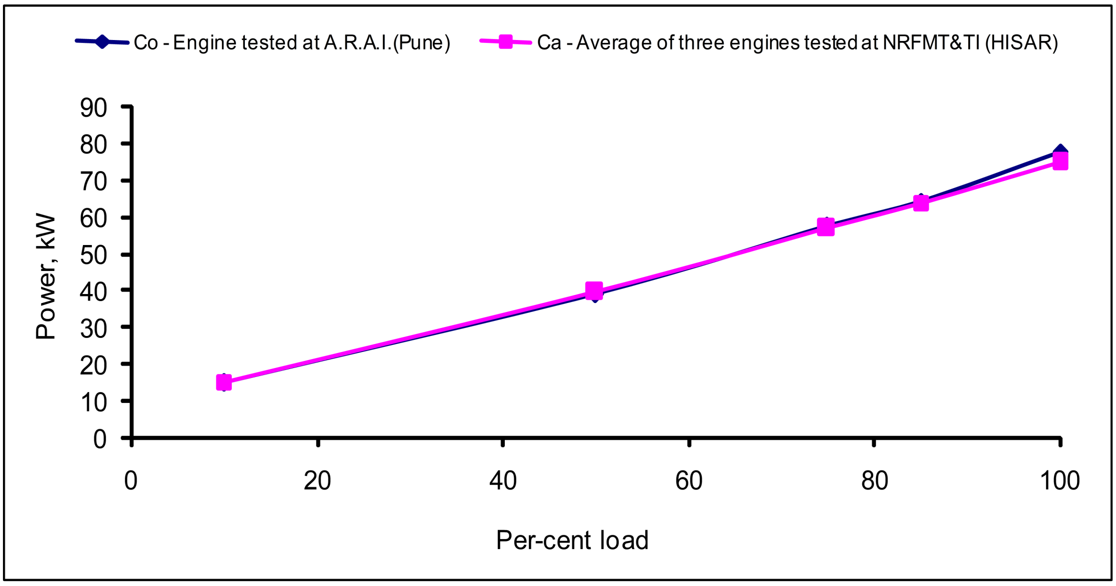


Fig.4.5 Comparative performance of engine power tested at different testing institutes under varying loads.

4.1.2.2 Torque

Comparative performance results in terms of engine torque, tested at different testing institutes are depicted in fig.4.6 and Table-4.2. Performance of torque in Kirloskar engine (Model-6R 1080) tested at different testing institute obtained under varying loads was similar. The percentage of variation in maximum torque was only 2.93%. The percentage of variations in torque at loads of, 85, 75, 50, & 10% were found to be 0.65, 1.07, 0.57 & 0.50%. The calculated t values were -3.77, -1.57, -1.26, 0.49 and 0.42 (Table-4.2) at loads 100, 85 75, 50 and 10%, which were less than tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

4.1.2.3 Fuel consumption

Fuel consumptions performances of engines, tested at different testing institutes are reported in fig.4.7 and Table-4.2. Performance of fuel consumption of Kirloskar engine (Model-6R 1080) tested at different testing institutes recorded under varying load test was almost same. The percentage of variation in maximum fuel consumption at 100 % load was only 2.25%. The percentage of variations in fuel consumptions at loads of, 85, 75, 50 & 10% were found to be 1.48, 1.76, 2.80 & 1.20% respectively. The calculated t values were 1.64, 1.22, 2.05, 2.06 and 1.72 at loads 100, 85. 75, 50 and 10%, which were less than tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

Table-4.2 Comparative performance of kirloskar engine tested at different testing institutes in varying load test

Load (%)	C0	Ca	Mean	S D	CV (%)	SEm	t_{cal}	Significance/ Non-significance
	Power kW							
100	77.70	74.37	**76.04**	**2.35**	**3.10**	**2.07**	**-6.68**	**N.S.**
85	64.25	63.66	**63.96**	**0.42**	**0.65**	**0.37**	**-1.23**	**N.S.**
75	57.30	56.58	**56.94**	**0.51**	**0.89**	**0.45**	**-0.89**	**N.S.**
50	38.90	39.27	**39.09**	**0.26**	**0.67**	**0.23**	**-1.04**	**N.S.**
10	14.80	15.02	**14.91**	**0.16**	**1.04**	**0.14**	**0.73**	**N.S.**
	Torque N-m							
100	338.51	324.75	**331.63**	**9.73**	**2.93**	**8.53**	**-3.77**	**N.S.**
85	284.27	281.65	**282.96**	**1.85**	**0.65**	**1.63**	**-1.57**	**N.S.**
75	254.21	250.39	**252.30**	**2.70**	**1.07**	**2.37**	**-1.26**	**N.S.**
50	169.47	168.12	**168.80**	**0.95**	**0.57**	**0.84**	**-0.49**	**N.S.**
10	64.48	64.94	**64.71**	**0.33**	**0.50**	**0.29**	**0.42**	**N.S.**
	Fuel consumption l/h							
100	23.83	24.60	**24.22**	**0.54**	**2.25**	**0.48**	**1.64**	**N.S.**
85	20.35	20.78	**20.57**	**0.30**	**1.48**	**0.27**	**1.22**	**N.S.**
75	17.44	17.88	**17.66**	**0.31**	**1.76**	**0.27**	**2.05**	**N.S.**
50	13.38	13.92	**13.65**	**0.38**	**2.80**	**0.33**	**2.06**	**N.S.**
10	10.53	10.71	**10.62**	**0.13**	**1.20**	**0.11**	**1.72**	**N.S.**
	Specific fuel consumption g/kW-h							
100	270.2	274.40	**272.30**	**2.97**	**1.09**	**2.61**	**2.38**	**N.S.**
85	275.3	277.53	**276.42**	**1.58**	**0.57**	**1.38**	**1.72**	**N.S.**
75	286.9	289.63	**288.27**	**1.93**	**0.67**	**1.69**	**1.14**	**N.S.**
50	306.5	307.23	**306.87**	**0.52**	**0.17**	**0.45**	**0.17**	**N.S.**
10	621.1	607.73	**614.42**	**9.45**	**1.54**	**8.29**	**-2.57**	**N.S.**

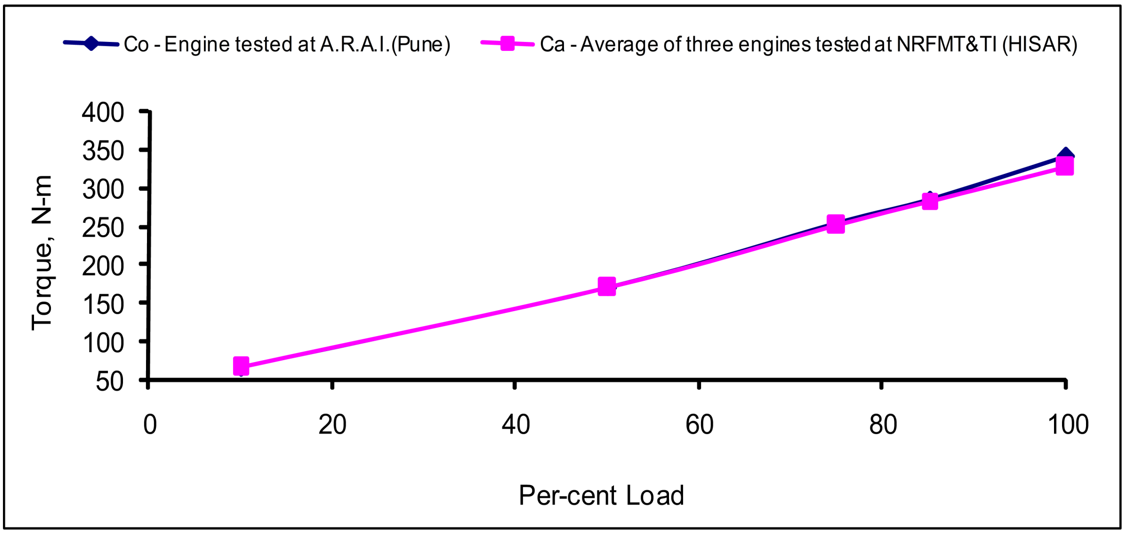


Fig.4.6 Comparative performance of engine torque tested at different testing institutes under varying loads

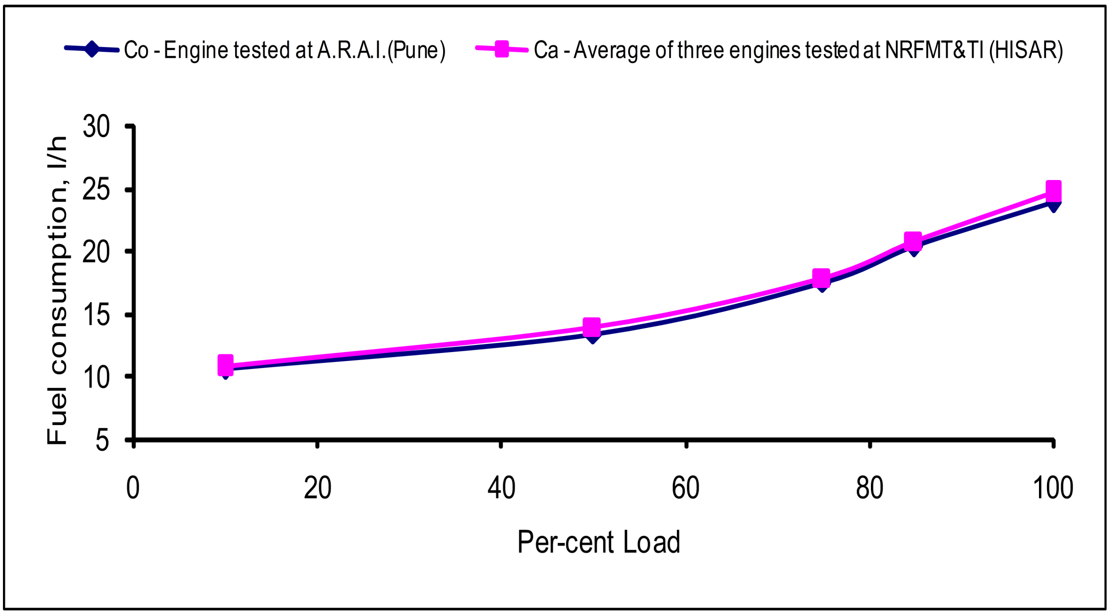


Fig.4.7 Comparative fuel consumption performance of engine tested at different testing institutes under varying loads

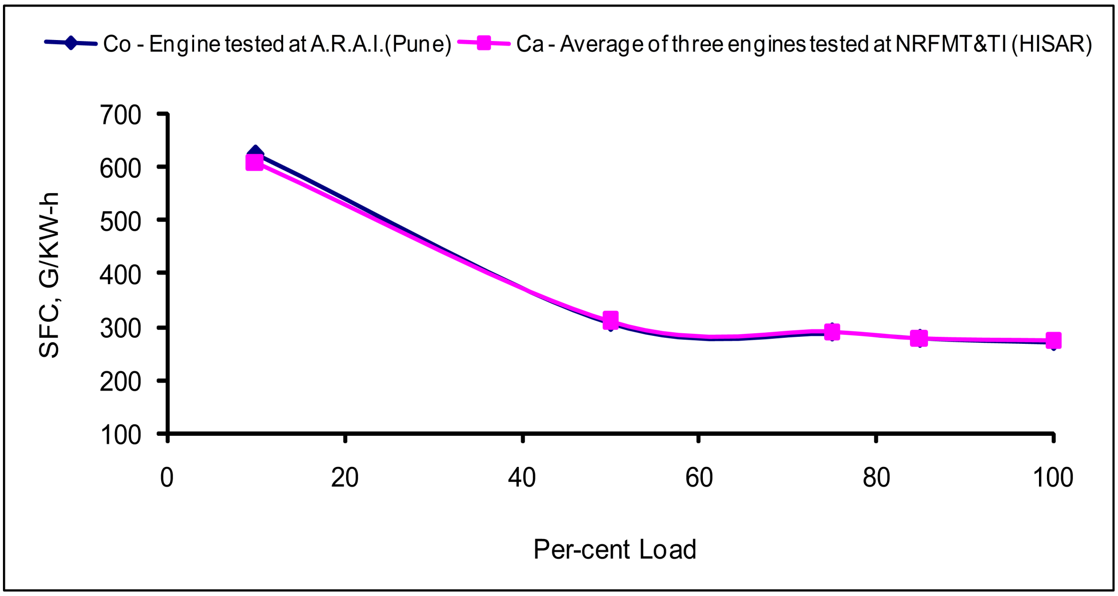


Fig.4.8 Comparative specific fuel consumption performance of engine tested at different testing institutes under varying loads

4.1.2.4 Specific fuel consumption

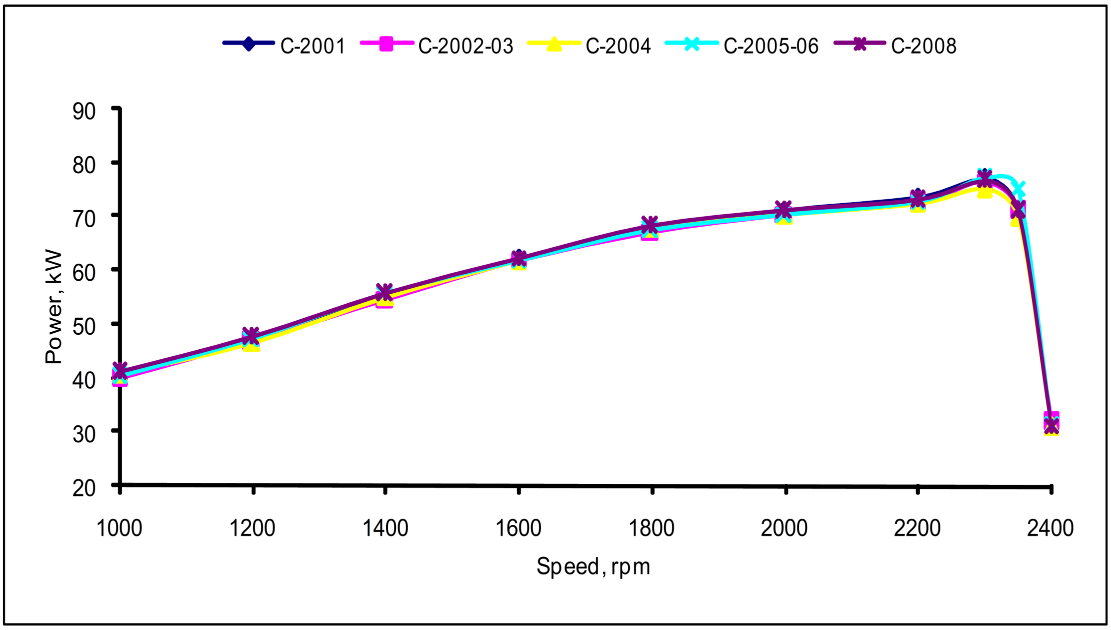
Specific fuel consumptions performances of engines, tested at different testing institutes are reported in fig.4.8 and Table-4.2. Specific fuel consumptions of Kirloskar engine (Model-6R 1080) tested at different testing institutes were found similar as shown in Table-4.2. The percentage of variation in specific fuel consumption at 100% load was only 1.09%. The percentage of variations in specific fuel consumption at loads of, 85, 75, 50 &10% were found to 0.57, 0.67, 0.17 & 1.54% respectively. The calculated t values were 2.38, 1.72, 1.14, 0.17 and -2.57 at loads 100, 85. 75, 50 and 10%, which were less than tabulated t value (9.93) at 1% level of significance and 2 degree of freedom.

4.2 Ashok Leyland Engine (Model ALU-400)

4.2.1 Varying speed test

4.2.1.1 Power

Power performance of engine (Model ALU-400) tested 22 times with combine harvesters at combine testing institute are depicted in fig.4.9 and Table-4.3. Average maximum value of power was 76.56 kW at 2300 rpm. The percentage of variation in maximum power of engine tested with 22 different combines was only 2.12%. The percentage of variation in power were 2.95, 1.41, 1.53, 1.06, 0.86, 1.16, 1.16, 2.72 and 2.73% (Table-4.3) at speeds of 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2350 and 2400 rpm respectively. Average values of power of Ashok Leyland engine (Model ALU-400) tested in different years 2001, 2002-03, 2004, 2005-06 and 2008 obtained under varying speeds, were found to be similar (fig.4.9). This shows that there was non-significant difference in performance of engine power, tested at combine testing institute.



C-2001 – Means value of engine testing performance, tested in 2001**(5)***
C-2002-03– Means value of engine testing performance, tested in 2002-03 **(3)***
C-2004– Mean value of engine testing performance, tested in 2004 **(4)***
C-2005-06– Means value of engine testing performance, tested in 2005-06 **(2)***
C-2008– Means value of engine testing performance, tested in 2008 **(8)***
* No. of engine tested

Fig.4.9 Engine power performance in Ashok Leyland engine (Model ALU-400), at varying speeds

4.2.1.2 Torque

Performance of torque in the engine (Model ALU-400) tested 22 times with combines are depicted in fig.4.10 and Table-4.3. Average maximum value of torque was 381.09 N-m at 1400 rpm. The percentage of variation in maximum torque of engine tested 22 times with combines was only 1.32% (Table-4.3). The percentage of variation in torque were 2.91, 1.38, 1.02, 0.91, 1.09, 1.13, 2.19, 2.77 and 2.79% at speeds of 1000, 1200, 1600, 1800, 2000, 2200, 2300, 2350 and 2400 rpm respectively. Average values of torque in Ashok Leyland engine (Model ALU-400) tested in different years 2001, 2002-03, 2004, 2005-06 and 2008 obtained under varying speeds, were found to be similar (fig.4.10). This shows that there was no difference in the performance of engine torque, tested at combine testing institute.

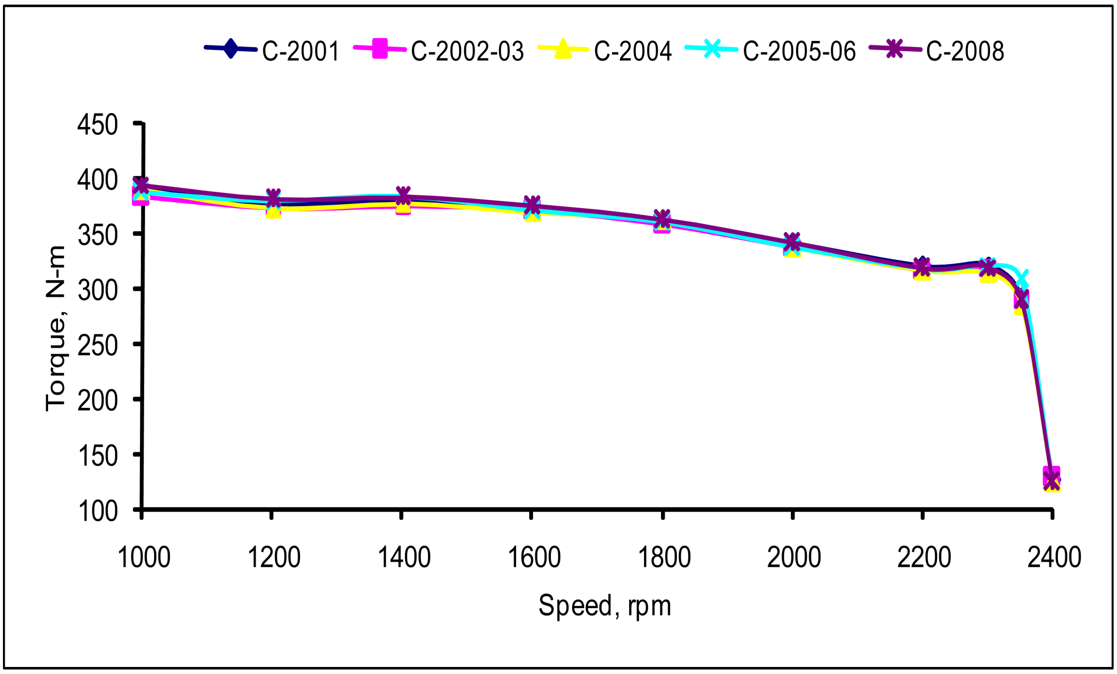


Fig.4.10 Engine torque performance in Ashok Leyland engine (Model ALU-400), at varying speeds

Table-4.3 Performances of various testing parameters of engine (Model-ALU 400) tested at combine testing institute under varying speed test

Speed, rpm	1000	1200	1400	1600	1800	2000	2200	2300	2350	2400
	Power, kW									
Mean	38.51	47.21	55.48	62.12	67.93	70.86	73.02	76.56	71.33	31.43
SD	1.14	0.67	0.84	0.64	0.58	0.82	0.85	1.63	1.92	0.84
CV	2.95	1.41	1.53	1.06	0.86	1.16	1.16	2.12	2.72	2.73
SEm	0.24	0.14	0.18	0.14	0.13	0.17	0.18	0.36	0.42	0.18
	Torque N-m									
Mean	367.91	375.27	381.09	370.93	360.54	338.50	317.11	318.03	290.01	125.13
SD	9.86	5.19	5.03	3.79	3.21	3.79	3.58	6.92	7.93	3.50
CV	2.91	1.38	1.32	1.02	0.91	1.09	1.13	2.19	2.77	2.79
SEm	2.17	1.04	1.01	0.76	0.62	0.76	0.73	1.38	1.59	0.69
	Fuel consumption l/h									
Mean	11.66	13.81	15.90	18.94	20.61	21.67	23.72	25.30	20.35	12.83
SD	0.36	0.47	0.54	0.54	0.69	0.67	0.56	0.51	0.58	0.43

CV	3.09	3.27	3.40	2.73	3.14	3.07	2.38	2.03	2.86	3.35
SEm	0.07	0.10	0.11	0.11	0.14	0.13	0.11	0.10	0.12	0.09
Specific fuel consumption g/kW-h										
Mean	239.01	242.39	233.63	252.64	251.38	253.40	269.11	273.85	239.30	338.52
SD	6.05	7.36	4.42	7.52	7.92	7.27	6.69	6.67	5.82	12.42
CV	2.53	3.03	1.89	2.97	3.15	2.87	2.49	2.43	2.43	3.79
SEm	1.21	1.55	0.88	1.50	1.58	1.45	1.34	1.33	1.16	3.24

4.2.1.3 Fuel consumption

Fuel consumption performances in Ashok Leyland engine (Model ALU-400), at varying speed are shown in fig.4.11 and Table-4.3. Average maximum fuel consumption was 25.30 l/h at 2300 rpm. The percentage of variation in maximum fuel consumption of engine tested 22 times with combines was only 2.03% (Table-4.3). The percentage of variation in fuel consumption were 3.09, 3.27, 3.40, 2.73, 3.14, 3.07, 2.38, 2.86 and 3.35% at speeds of 1000, 1200, 1400, 1600, 1800, 2000, 2200, 2350 and 2400 rpm respectively. Average values of fuel consumption in Ashok Leyland engine (Model ALU-400) tested in different years 2001, 2002-03, 2004, 2005-06 and 2008 obtained under varying speeds, were found to be similar as revealed from fig.4.11. This shows that there was non-significant difference in fuel consumption performance at varying speeds of engines, tested at combine testing institute.

4.2.1.4 Specific fuel consumption

Specific fuel consumption performances of Ashok Leyland engine (Model ALU-400), at varying speed is shown in fig.4.12 and Table-4.3. Average minimum specific fuel consumption was 233.63 g/kW-h at 1400 rpm. The percentage of variation in minimum specific fuel consumption of engine tested 22 times with combines was only 1.89%. The percentage of variation in specific fuel consumption were 2.53, 3.03, 2.97, 3.15, 2.87, 2.49, 2.43, 2.43 and 3.79% at speeds of 1000, 1200, 1600, 1800, 2000, 2200, 2300, 2350 and 2400 rpm respectively. Average values of specific fuel consumption in Ashok Leyland engine tested in different years 2001, 2002-03, 2004, 2005-06 and 2008 obtained under varying speeds, were found to be similar as indicated from fig.4.12. This indicates that there was no difference in specific fuel consumption performance at varying speeds of engines, tested at combine testing institute.

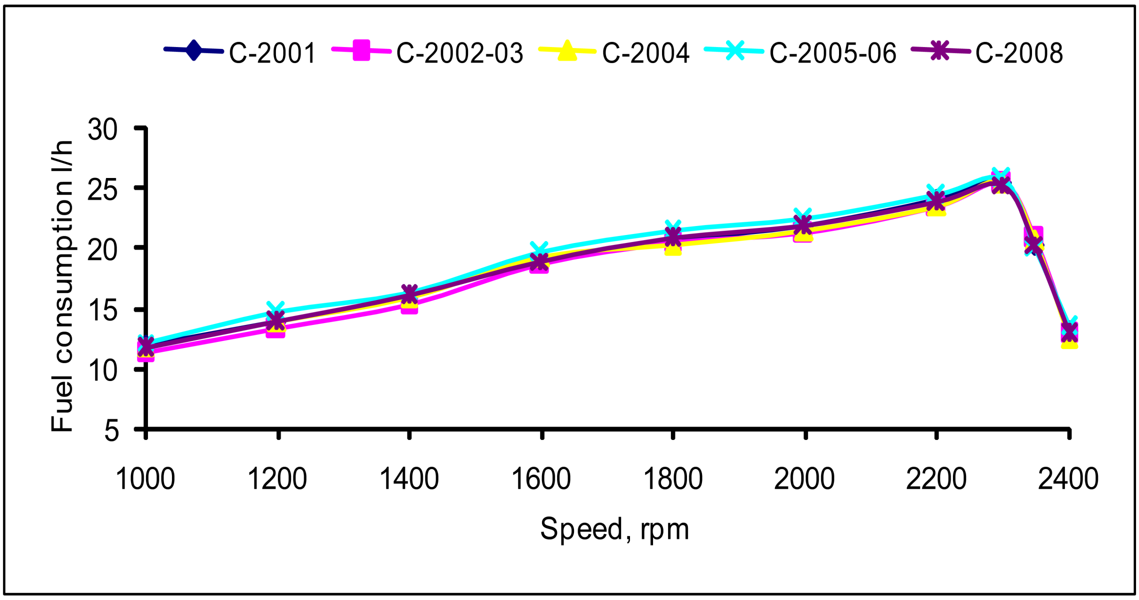


Fig.4.11 Fuel consumption performance in Ashok Leyland engine, at varying speeds

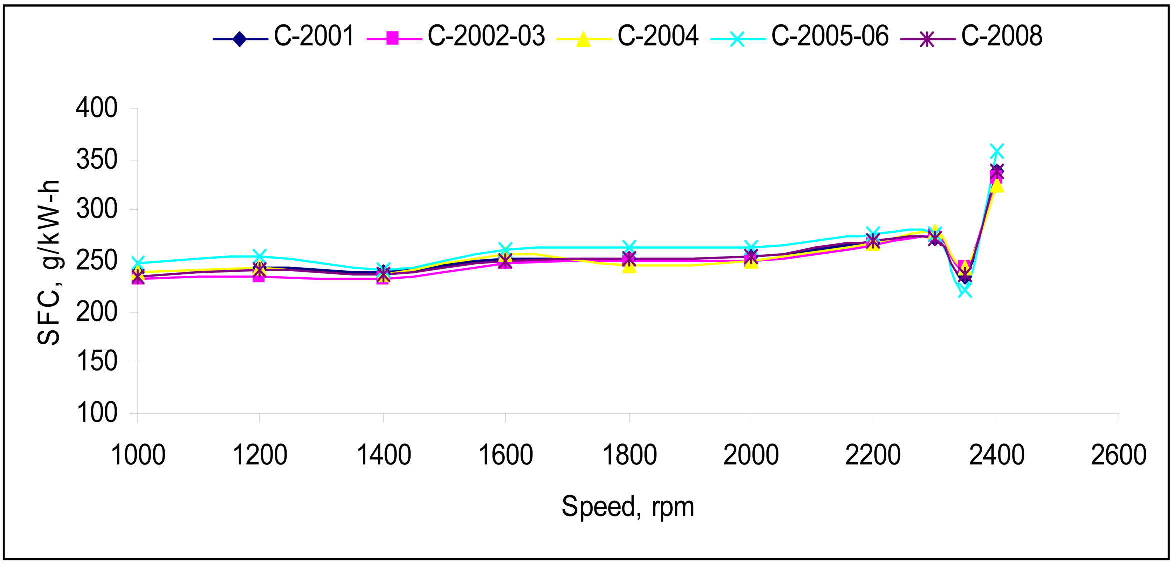


Fig.4.12 Specific fuel consumption performance in Ashok Leyland engine (Model ALU-400), at varying speeds

4.2.2 Varying load test

4.2.2.1 Power

Power performances results in the Ashok Leyland engine (Model ALU-400) tested with 22 different combines are depicted in fig.4.13 and Table-4.4. Average maximum value of power 76.32 kW was recorded at 100% load. The percentage of variation in maximum power was very low (2.20%). The percentages of variations in power were 2.29, 2.34, 2.10, 2.82 and 5.64% at loads of 85, 75, 50, 20 and 0% respectively. Fig.4.13 clearly indicated that average values of power of Ashok Leyland engine tested in different years obtained under varying loads, were found to be similar. It revealed that there was no difference in performance of power at varying loads in engine, tested at combine testing institute.

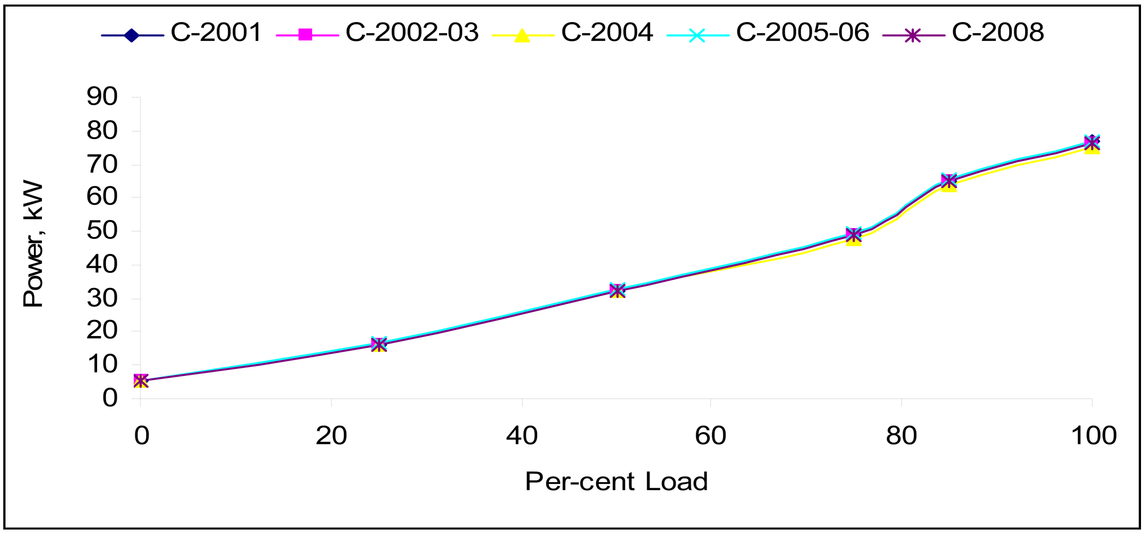


Fig.4.13 Engine power performance of Ashok Leyland engine (Model ALU-400), at varying loads

4.2.2.2 Torque

Fig.4.14 and table-4.4 revealed the performances of torque of Ashok Leyland engine (Model ALU-400) tested 22 times with combines. Average maximum value of torque 326.85 N-m was obtained at 100% load. The percentage of variation in maximum torque was only 2.88%. The percentages of variations in torque were 3.00, 2.93, 3.14, 2.97 and 5.73% at loads of 85, 75, 50, 20 and 0% respectively. Average values of torque in Ashok Leyland engine

(Model ALU-400) tested in different years were same obtained under varying loads. It means there was no difference in performance of torque at varying loads in engines, tested at combine testing institute.

Table-4.4 Performances of various testing parameters of engine tested at combine testing institute under varying load test

Load (%)	100	85	75	50	25	0
Power, kW						
Mean	76.32	64.89	48.64	32.34	16.21	5.43
SD	1.68	1.49	1.14	0.68	0.46	0.31
CV	2.20	2.29	2.34	2.10	2.82	5.64
SEm	0.34	0.30	0.23	0.14	0.09	0.07
Torque N-m						
Mean	326.85	275.96	209.19	139.50	69.51	23.36
SD	9.73	8.29	6.13	4.46	2.06	1.34
CV	2.88	3.00	2.93	3.14	2.97	5.73
SEm	1.95	1.66	1.23	0.93	0.41	0.27
Fuel consumption l/h						
Mean	25.07	21.37	16.01	10.61	7.49	6.34
SD	0.49	0.47	0.33	0.28	0.24	0.23
CV	1.96	2.19	2.04	2.65	3.18	3.62
SEm	0.10	0.09	0.07	0.06	0.05	0.06
Specific fuel consumption g/kW-h						
Mean	271.94	272.96	272.86	271.95	383.08	1022.39
SD	6.33	6.50	7.28	7.62	13.28	34.64
CV	2.33	2.38	2.67	2.80	3.46	3.39
SEm	1.27	1.30	1.46	1.52	3.18	6.93

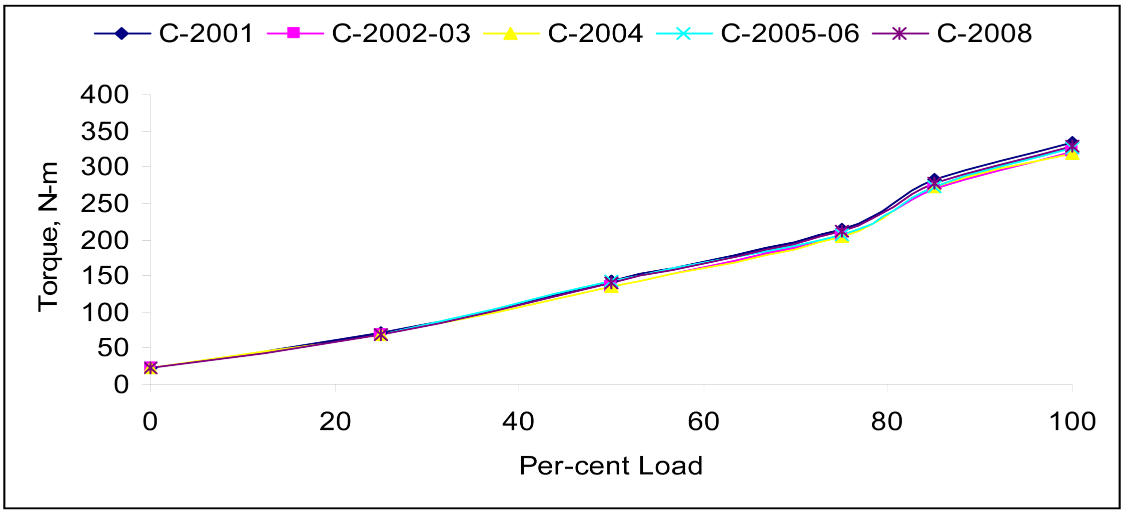


Fig.4.14 Engine torque performance in Ashok Leyland engine, at varying loads

4.2.2.3 Fuel consumption

Fuel consumption performance in Ashok Leyland engine (Model ALU-400), at varying loads are shown in fig.4.15 and Table-4.4. Average maximum value of fuel consumption 25.07 l/h was obtained at 100% load. The percentage of variation in maximum fuel consumption was only 1.96%. The percentages of variations in fuel consumption were 2.19, 2.04, 2.65, 3.18 and 3.62% at load of 85, 75, 50, 20 and 0% respectively. Average values of fuel consumption performance of Ashok Leyland engine tested in different years obtained under varying loads, were found to be similar (fig.4.15). This shows that there was non-significant difference in fuel consumption performance at varying loads in engines, tested at combine testing institute.

4.2.2.4 Specific fuel consumption

Specific fuel consumptions performances in Ashok Leyland engine (Model ALU-400), at varying load are shown in fig.4.16 and Table-4.4. Average minimum value of specific fuel consumption was obtained 271.94g/kw-h at 100% load. The percentage of variation in minimum specific fuel consumption was only 2.33%. The percentages of variations in specific fuel consumption were 2.38, 2.67, 2.80, 3.46 and 3.39% at loads of 85, 75, 50, 20 and 0% respectively. Average values of specific fuel consumption of Ashok Leyland engine tested in different years obtained under varying loads were similar. This shows that there was no difference in specific fuel consumption performance at varying loads in engines, tested at combine testing institute.

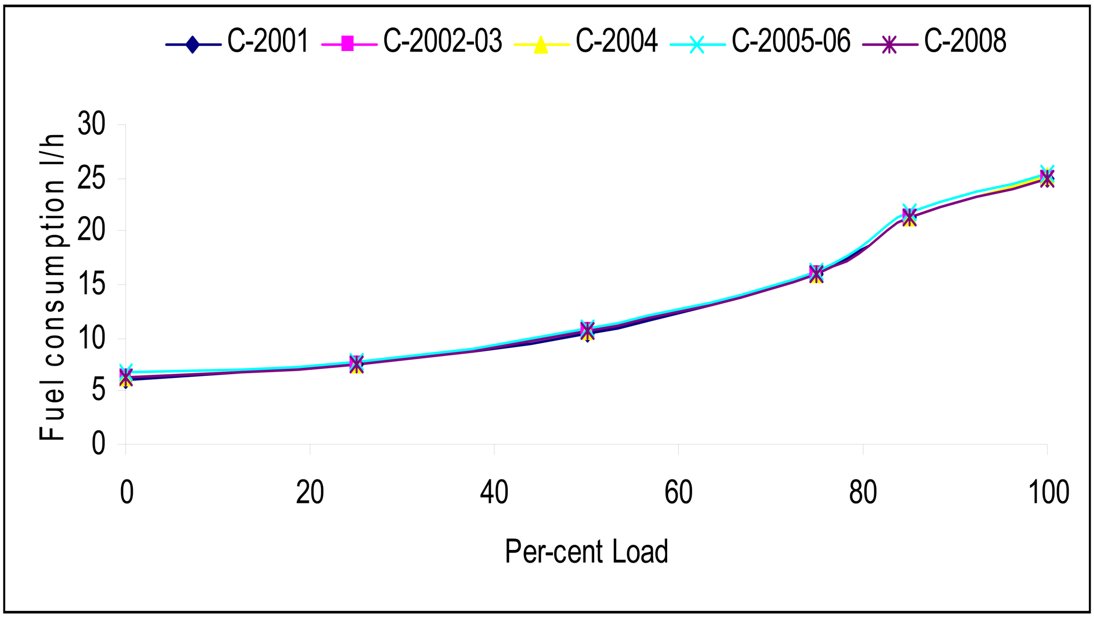


Fig.4.15 Fuel consumption performance in Ashok Leyland engine (Model ALU-400), at varying loads

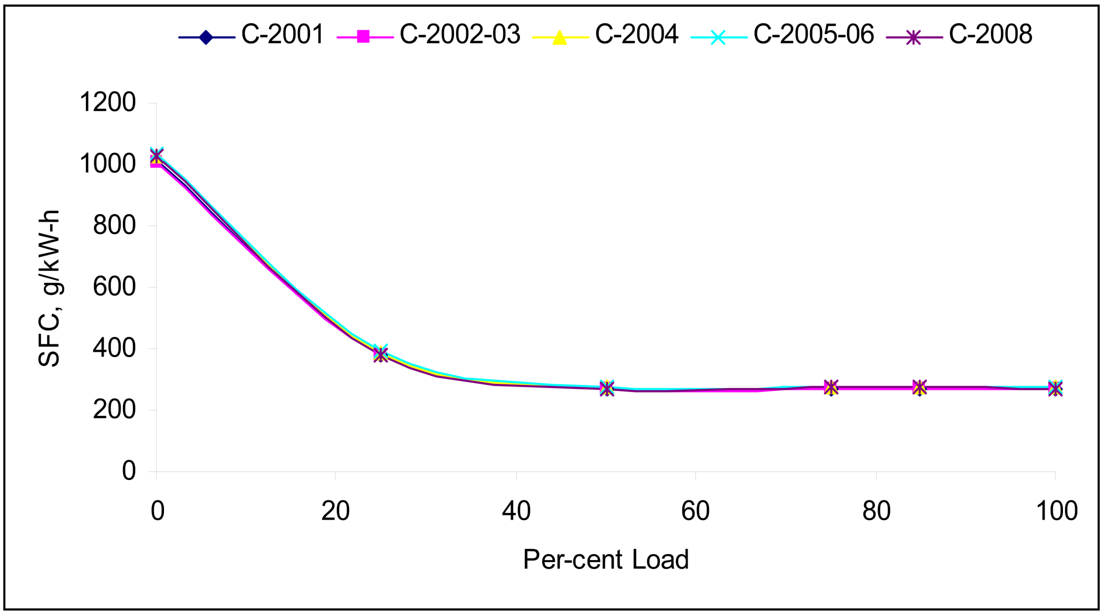


Fig.4.16 Specific fuel consumption performance in Ashok Leyland engine (Model ALU-400), at varying loads

4.2.3 Maximum power test

4.2.3.1 Power

Power performance results in Ashok Leyland engine (Model ALU-400), tested 22 times with combines in maximum power test are shown in fig.4.17 and Table-4.5. Average values of power in Ashok Leyland engine (Model ALU-400), tested 22 times at NRFMT&TI (Hisar), at normal and part throttle setting were 76.27 & 57.27kW at corresponding average speed of 2283 and 1606 rpm respectively. The percentage of variations in power under normal and part throttle setting were found to be 2.13 & 1.89% respectively (Table-4.5).

Fig.4.17 Power performance in Ashok Leyland engine (Model ALU-400), in maximum power test

Fig.4.18 Torque performance in Ashok Leyland engine (Model ALU-400), in maximum power test

4.2.3.2 Torque

Performance of engine torque in Ashok Leyland engine (Model ALU-400), tested 22 times with combines in maximum power test are shown in fig.4.18 and Table-4.5. Average value of torque in Ashok Leyland engine at normal and part throttle setting were 311.74 & 364.40 N-m at corresponding average speed of 2283 and 1606 rpm respectively. The percentage of variations in torque under normal and part throttle setting were found to be 3.12 & 2.61% respectively (Table-4.5).

4.2.3.3 Fuel consumption

Fuel consumption performance in Ashok Leyland engine (Model ALU-400), tested 22 times with combines at maximum power test are shown in fig.4.19 and Table-4.5. Average value of fuel consumption performance of Ashok Leyland engine at normal and part throttle setting were 24.74 & 16.78l/h at corresponding average engine speed of 2283 and 1606 rpm respectively. The percentage of variations in fuel consumption under normal and part throttle setting were found to be 2.81 & 3.16% respectively (Table-4.5).

4.2.3.4 Specific fuel consumption

Specific fuel consumption performance in Ashok Leyland engine (Model ALU-400), tested 22 times with combines at maximum power test are illustrated in fig.4.20 and Table-4.5. Mean values of specific fuel consumption in Ashok Leyland engine at normal and part throttle setting were 273.91 & 240.89 g/kW-h at corresponding average speed of 2283 and 1606 rpm respectively. The percentage of variations in specific fuel consumption under normal and part throttle setting were found to be 2.41 & 3.36% respectively (Table-4.5).

Fig.4.19 Fuel consumption performance of Ashok Leyland engine (Model ALU-400), in maximum power test

Table-4.5 Performances of various testing parameters of engine tested at combine testing institute under maximum power test

	Speed (rpm)		**Power (kW)**		**Torque (N-m)**		**Fuel consumption (l/h)**		**Specific fuel consumption (g/kW-h)**	
	Normal	**Part throttle**	**Normal**	**Part throttle**	**Normal**	**Part throttle**	**Normal**	**Part throttle**	**Normal**	**Part throttle**
Mean	2283.4	1606.2	76.27	57.51	311.74	364.40	24.74	16.78	273.91	240.89
SD	38.09	31.75	1.62	1.09	9.74	8.53	0.70	0.59	6.60	8.10
CV	1.67	1.98	2.13	1.89	3.12	2.61	2.81	3.16	2.41	3.36
SEm	8.10	6.76	0.32	0.23	2.07	2.04	0.15	0.15	1.32	1.62

Fig.4.20 Specific fuel consumption performance of Ashok Leyland engine (Model ALU-400), in maximum power test

4.2.4 Five hours rating test (High ambient)

4.2.4.1 Power

Power performance of Ashok Leyland engine (Model ALU-400), tested 22 times at NRFMT&TI(Hisar) in five hours rating test are shown in fig.4.21 and Table-4.6. Average value of power of engine tested in five hours rating test at engine loaded to 90% of maximum power was 68.80 kW. The percentage of variation in power at engine loaded to 90% of maximum power was only 2.58%. Average value of power of engine, at engine loaded to maximum power was 76.33 kW (Table-4.6). The percentage of variation of power at engine loaded to maximum power was only 2.18%.

Fig.4.21 Power performance of Ashok Leyland engine (Model ALU-400), in five hours rating test

Fig.4.22 Torque performance of Ashok Leyland engine (Model ALU-400), in five hours rating test

4.2.4.2 Torque

Performance of torque in Ashok Leyland engine (Model ALU-400), tested 22 times at NRFMT&TI(Hisar) in five hours rating test are shown in fig.4.22 and Table-4.6. Average value of torque of engine tested in five hours rating test at engine loaded to 90% of maximum power was 288.27 N-m. The percentage of variation in torque at engine loaded to 90% of maximum power was only 2.83 % (Table-4.6). Average value of torque in engine, at engine loaded to maximum power was 307.24 N-m. The percentage of variation of torque at engine loaded to maximum power was only 3.09%.

Fig.4.23 Fuel consumption performance of Ashok Leyland engine (Model ALU-400), in five hours rating test

4.2.4.3 Fuel consumption

Fuel consumption performance of Ashok Leyland engine (Model ALU-400), tested 22 times at NRFMT&TI(Hisar) in five hours rating test are shown if fig.4.23 and Table-4.6. Average value of fuel consumption of engine in five hours rating test at engine loaded to 90% of maximum power was 22.38 l/h. The percentage of variation in fuel consumption at engine loaded to 90% of maximum power was only 3.71%. Average value of fuel consumption in engine, at engine loaded to maximum power was 24.77 l/h (Table-4.6). The percentage of variation in fuel consumption at engine loaded to maximum power was only 3.04%.

Table-4.6 Performances of various testing parameters of engine (Model-ALU 400) tested at combine testing institute under five hours rating test (High Ambient)

	Engine loaded to 90% of maximum power					Engine loaded to maximum power				
	Speed (rpm)	Power (kW)	Torque (N-m)	Fuel consumption (l/h)	Specific fuel consumption (g/kWh)	Speed (rpm)	Power (kW)	Torque (Nm)	Fuel consumption (l/h)	Specific fuel consumption (g/kWh)
Mean	2316.68	68.80	288.27	22.38	277.21	2316.68	76.33	307.24	24.77	276.79
SD	38.80	1.78	8.17	0.83	9.19	38.80	1.67	9.48	0.75	8.42
CV	1.67	2.58	2.83	3.71	3.11	1.67	2.18	3.09	3.02	3.04
SEm	8.26	0.38	1.63	0.18	1.84	8.26	0.33	1.92	0.16	1.68

4.2.4.4 Specific fuel consumption

Specific fuel consumption performance of Ashok Leyland engine (Model ALU-400), tested 22 times at NRFMT&TI(Hisar) in five hours rating test are shown in fig.4.24 and Table-4.6. Average value of specific fuel consumption in engine in five hours rating test at engine loaded to 90% of maximum power was 277.21 g/kW-h. The percentage of variation in specific fuel consumption at engine loaded to 90% of maximum power was only 3.11%. Average value of specific fuel consumption in engine, at engine loaded to maximum power was 276.79 g/kW-h. The percentage of variation in specific fuel consumption at engine loaded to maximum power was only 3.04% (Table-4.6).

Fig.4.24 Specific fuel consumption performance of Ashok Leyland engine (Model ALU-400), in live hours rating test

iv.3 Complete process of engine testing and cost involved in engine testing:

iv.3.1 Complete process of testing the engine of combine harvester, at North Region Farm machinery Training and Testing Institute, Hisar is reported in the following table:

Sr. No.	Process of engine testing	Date (s)	Hours of the day		Time taken (Hrs.)	Man power required
			Starting time	Finishing time		
1.	Dismantling the engine from combine harvester	23-2-09	9:00	17:00	8	Three helpers, two mates and one technician
2.	Mounting the engine on testing –bed	24-2-09	9:00	17:00	8	Three helpers, two mates, one technician assistant and one assistant engineer
		25-2-09	9:00	17:00	8	

3.	Attachment of all accessories and sensors with engine	26-2-09	9:00	17:00	8	Two helpers, two mates, one technician, one technical assistant and one assistant engineer
		27-2-09	9:00	17:00	8	
		28-2-09	9:00	17:00	8	
4.	Alignment of engine with sensor, control panel and calibration of dynamometer etc.	02-3-09	9:00	17:00	8	Two helpers, two mates, one technician, one technical assistant and one assistant engineer
		03-3-09	9:00	17:00	8	
		4-3-09	9:00	17:00	8	
5.	Checking of working condition of sensors, control panel and dynamometer	05-03-09	9:00	17:00	8	Two helpers, two mates, one technician, one technical assistant, one assistant engineer and senior testing engineer
6.	Engine testing started varying speed test (ambient), Maximum power test, varying load test	06-03-09	11:35	17:40	6 hrs 10 min	Two helpers, two mates, one technician, one technical assistant, one assistant engineer and senior testing engineer
7.	Engine testing, varying speed	07-03-09	10:20	12:30	2 hrs 10 min	Two helpers, two mates, one technician, one technical assistant, one assistant engineer and senior testing engineer
8	Engine testing, Five hours rating test (high ambient)	09-3-09	12:35	17:40	8	Two helpers, two mates, one technician, one technical assistant, one assistant engineer and senior testing engineer
9	Dismantling the engine from testing bed and wear assessments	12-3-09 13-3-09	9:00 9:00	17:00 17:00	8 8	Three helpers, two mates and one technician
10	Mounting the engine on combine harvester	14-3-09	9:00	17:00	8	Three helpers, two mates and one technician
11	Preparation of detailed report of engine testing	15-3-09-- 31-3-09	9:00	17:00	8	One technical assistant, one assistant engineer, one senior testing engineer and one steno (typist)

iv.3.2 Total time in complete engine testing

Process of engine testing	**Time taken (days)***
Engine mounted on testing-bed	2

Attachment of sensor and their alignment with engine, and checking for the good running condition of the accessories	6
Testing the engine	4
Detachment of engine	3
Total testing time	15
Time taken in preparation of details report of engine testing	15
Total time (Testing time + report preparation time)	30

**Day- 8 hours of working*

4.3.3 Cost estimation of engine testing

Sr. No.	**Particulate**	**Cost of testing setup (Rs./15day)**	**Cost of generator (Rs./15day)**
A.	Fixed cost		
1.	Depreciation	2932.05	134.69
2.	Interest rate	1944.49	89.32
3.	Insurance and taxes	324.80	14.88
4.	Housing	243.06	11.16
5.	Total fixed cost	5444.40	250.05
B.	Variable cost		
1.	Fuel charge	-	13625.50
2.	Oil charges	-	2334
3.	Repair and maintenance	607.65	27.91
4.	Wages and labor charges	93000	-
6.	Total variable cost	93607.65	15976.41
C.	Total cost of operation	115290.51	
D.	Overhead charges	23058.10	
E.	**Total cost of testing engine**	**138348.61**	

Total fixed cost of engine testing, at NRFMT&TI (Hisar) was Rs. 5694.45(appendix-IV). Total variable cost of the engine testing, at NRFMT&TI (Hisar) was Rs. 109576.06. Overhead charges for engine testing were Rs. 23058.10. Total cost of complete testing of engine of combine, at NRFMT&TI (Hisar) was Rs. 1.38 lacs (appendix-IV).

iv.4 Specification and performance of combine harvester

4.4.1 Specification

Specifications of different makes of self-propelled combine harvesters are illustrated in appendix-I, (C). All the different makes of combine harvester had different specifications of harvesting and threshing system.

iv.4.2 Field performance of combine harvesters

Total processing losses of paddy crop were 2.54% (average of 25 combines), which was within the permissible limit of Bureau of Indian Standard (BIS). Average threshing and cleaning efficiency for paddy crop were 99.07% and 98.08% respectively (Appendix-I, D), which were in the permissible limit of Bureau of Indian Standard (BIS). Total processing losses of wheat crop were 2.31% (average of 25 combines), which was within the permissible limit of Bureau of Indian Standard (BIS). Average threshing and cleaning efficiency for wheat crop were 99.09% and 97.97% respectively (Appendix-I, E), which were in the permissible limit of Bureau of Indian Standard (BIS).

CHAPTER – V

DISCUSSION

Testing of combine harvester is a long, costly and laborious process, it is done in two season Rabi and Kharif. The testing fee of self-propelled combine harvester is Rs 353000. Total cost of testing the combine is around Rs 8-10 lacs, which included the lab test, field test, and labour charges during field operation. The present study was carried out for reducing the high cost investment, labor and time on retesting of engine of combine-harvesters, as the engines used by different makes of combine harvesters were already tested by A.R.A.I.(Pune) as per the recommendations of Bureau of Indian Standard (BIS). Results of present investigation are discussed below:

iv.1. Kirloskar engine (Model- 6R 1080)

iv.1.1 Comparison of various testing parameters of Kirloskar engine (Model- 6R 1080) in different tests, tested at different testing institutes

iv.1.1.1 Engine power

It is evident from fig.4.1, that power of Kirloskar engine (Model ALU-400), tested at different testing institutes obtained at varying speed, had non-significant difference. The percentage of variation in maximum power of engine was only 3.12%, meaning there by all the engines tested in different periods gave almost same power. The engines were tested under different weather conditions and in different years, so this slight variation is possible. In varying speed test at 1000, 1200, 1400, 1600, 1800 & 2000, the percentage of variations ranged from 0.20 to 2.58% (Table-4.1), thus this slight variation also indicated that there was no significant difference in the performance of engine power at varying speeds. Bureau of Indian Standard (BIS) recommend 2-3% variation in power performance during the engine testing. From fig.4.5 it is evident that power in Kirloskar engine (Model ALU-400) recorded under varying loads was almost same. The percentages of variations in power at all modes of loads were found to be ranged from 0.65 to 3.10 % (Table-4.2) this variation was within the prescribed limit. The calculated values of t for means values of power in Kirloskar engines (Model ALU-400), tested at different testing institutes were less than the tabulated value of t (9.93) at 1% level of significance and 2 degree of freedom. This clearly shows that performances of power in Kirloskar engine (Model ALU-400) obtained under varying speeds and varying loads were similar. This clearly shows that performances of power in Kirloskar engine (Model ALU-400) obtained under varying speeds and varying loads were similar.

5.1.1.2 Engine torque

It can be observed from fig.4.2 that performance of torque in Kirloskar engine (Model ALU-400), tested at different testing institutes was almost same under varying speeds. The percentage of variations in engine torque at all modes of speeds ranged from 0.21 to 3.10 % (Table-4.1), this variation was non-significant. It is also clear that torque performance of same model of engine tested in both the testing institutes was found to quite similar in varying speed test. From fig.4.6, it can be observed that performance of engine torque was similar at both the testing institutes. Engine performance in terms of torque development in both the testing institutes recorded was same at different loads. The percentage of variations in torque at all modes of loads ranged from 0.50 to 2.93 % (Table-4.2), this variation was non-significant. The calculated values of t for means values of torque in Kirloskar engines (Model ALU-400), tested at different testing institutes were less than the tabulated value of t (9.93) at 1% level of significance and 2 degree of freedom. This clearly shows that performances of torque in Kirloskar engine (Model ALU-400) tested at different testing institutes, obtained under varying speeds and varying loads were similar.

5.1.1.3 Fuel consumption

It can be seen from Fig.4.3 that fuel consumption performance of Kirloskar engine (Model ALU-400), tested at different testing institutes were similar at varying speeds. The percentage of variation in fuel consumption at different speed ranged from 0.63 to 2.78 % (Table-4.1), which were quite low. These results clearly indicate that there was no use in repeating the tests. From fig.4.7, it can be observed that the performance of fuel consumptions in Kirloskar engine (Model ALU-400), tested at different testing institutes were similar at varying loads. Moreover, lower values of percentage of variation in fuel consumption i.e. 0.93 to 2.31% (Table-4.2), also indicates that the repeated testing of engine with combines should not be done as this will save time, labor, fuel and unnecessary expenditure on lab testing of combine engines at testing institute. The calculated values of t for means values of fuel consumption in Kirloskar engines (Model ALU-400), tested at different testing institutes were less than the tabulated value of t (9.93) at 1% level of significance and 2 degree of freedom.

5.1.1.4 Specific fuel consumption

It is evident in fig.4.4 that performance of specific fuel consumption in Kirloskar engine (Model ALU-400), tested at different testing institutes were similar at varying speeds. The percentage of variation in specific fuel consumption at different speeds ranged from 0.29 to 2.81% (Table-4.1), which were quite low. Performance of specific fuel consumption in Kirloskar engine (Model ALU-400), tested at different testing institutes were similar at varying loads as given in fig.4.8. The percentage of variation in specific fuel consumption at different loads ranged from 0.25 to 2.31% (Table-4.2). The calculated values of t for means values of specific fuel consumption in Kirloskar engines (Model ALU-400), tested at different testing institutes were less than the tabulated value of t (9.93) at 1% level of significance and 2 degree of freedom. This clearly shows that performances of specific fuel consumption in Kirloskar engine (Model ALU-400) tested at different testing institutes, obtained under varying speeds and varying loads were similar.

iv.2 Ashok Leyland engine (Model ALU-400)

5.2.1 Performance of various testing parameters of engine under different tests

iv.211 Engine power

It can be observed from fig.4.9 that power performance of engines tested in different years, at combine testing institute was same under varying speeds. The percentage of variations in power performance at different speeds ranged from 0.86 to 2.95% (Table-4.3). This shows that there was non-significant difference in the performance of power of Ashok Leyland engine at different speeds. It is quite clear from fig.4.13 that performance of power of engines tested in different years, at NRFMT&TI (Hisar) were found similar in varying load test. The percentage of variations in power of engine at different loads ranged from 2.20 to 5.64% (Table-4.4). It means there was insignificant difference in the performance of power under varying loads. Bureau of Indian Standard (BIS) recommend 2-3% variation in the power performance during the engine testing. Fig.4.17 indicates that the performance of power in engines tested 22 times at combine testing institute was similar under normal and part throttle setting in maximum power test. It is clear from fig.4.21 that performance of power in engines tested 22 times at combine testing institute was almost same in five hours rating test. The percentage of variation in power at engine loaded to 90% of maximum power was only 2.58% (Table-4.6) in five hours rating test. The percentage of variation in power at engine loaded to maximum power was only 2.18% in five hours rating test. Performance of power of engine in all the tests was similar.

iv.212 Engine torque

It is quite clear from fig.4.10 that torque performance of engines tested in different years at NRFMT&TI (Hisar) were found similar under varying speeds. The percentage of variations in torque at different speeds ranged from 0.91 to 2.97% (Table-4.3), this difference was non-significant. It can be observed from fig.4.14 that performance of torque of engines tested in different years at NRFMT&TI (Hisar) was same in varying load test. The percentage of variations in torque of engine at different loads ranged from 2.88 to 5.73% (Table-4.4), which was non-significant. Fig.4.18 shows that the performance of torque in engines tested

22 times was similar under normal and part throttle setting in maximum power test. It is clear from fig.4.22 that performance of torque in engines tested 22 times was almost same in five hours rating test. The percentage of variation in torque at engine loaded to 90% of maximum power was only 2.83% (Table-4.6) in five hours rating test. The percentage of variation in torque at engine loaded to maximum power was only 3.09% in five hours rating test. Performance of torque in engines tested at NRFMT&TI (Hisar) under different tests was similar.

iv.213 Fuel consumption

It is evident from fig.4.11 that fuel consumption performance of engines tested in different years at NRFMT&TI (Hisar) was same under varying speeds. The percentage of variations in fuel consumption at different speeds ranged from 2.03 to 3.40% (Table-4.3), this variation was non-significant. It can be observed from fig.4.15 that performances of fuel consumption in engines tested in different years at NRFMT&TI (Hisar) were found similar under varying load test. The percentage of variations in fuel consumption of engine at different loads ranged from 1.96 to 3.62% (Table-4.4), which was non-significant. Fig.4.19 shows that the performance of fuel consumption in engines tested 22 times was similar under normal and part throttle setting in maximum power test. It is quite clear from fig.4.23 that performance of fuel consumption in engines tested 22 times at combine testing institute was almost same in five hours rating test. The percentage of variation in fuel consumption at engine loaded to 90% of maximum power was only 3.71% (Table-4.6) in five hours rating test. The percentage of variation in fuel consumption at engine loaded to maximum power was only 3.02% in five hours rating test. Fuel consumption performance of engines tested at NRFMT&TI (Hisar) under various tests was same.

iv.214 Specific fuel consumption

It is evident from fig.4.12 that specific fuel consumption performance of engines tested in different years at NRFMT&TI (Hisar) was found similar under varying speeds. The percentage of variations in specific fuel consumption at different speeds ranged from 1.89 to 3.79% (Table-4.3), this variation was non-significant. It can be observed from fig.4.16 that performance of specific fuel consumption in engines tested in different years at NRFMT&TI (Hisar) were similar under varying load test. The percentage of variations in specific fuel consumption of engine at different loads ranged from 2.33 to 3.39% (Table-4.4). Fig.4.20 shows that the performance of specific fuel consumption in engines tested 22 times was similar under normal and part throttle setting in maximum power test. It is clear from fig.4.24 that performance of specific fuel consumption in engines tested 22 times at combine testing institute was almost same in five hours rating test. The percentage of variation in specific fuel consumption at engine loaded to 90% of maximum power was only 3.11% (Table-4.6) in five hours rating test. The percentage of variation in specific fuel consumption at engine loaded to maximum power was only 3.04% in five hours rating test. Performance of specific fuel consumption of engine in all the tests was similar.

iv.3 Cost of complete engine testing at combine testing institute

Total fixed cost of engine testing, at NRFMT&TI (Hisar) was Rs. 5694.45 whereas variable was Rs. 109576.06. Overhead charges for engine testing were Rs. 23058.10. Total cost of complete testing of engine mounted on combine was Rs. 1.38 lacs.

iv.4 Specification and field performance of combine harvesters

All the different makes of combine harvester had different specifications of harvesting and threshing system. Different manufacturer of combine harvester make combines of different specifications. The field performance parameters, viz. total processing losses, threshing efficiency and cleaning efficiency were within the specified limit of Bureau of Indian Standard (BIS).

CHAPTER – VI

SUMMARY AND CONCLUSIONS

The main objectives of the study was to compare the existing engine performance data with the results obtained from the test reports and to study the cost involved in testing the engines of self-propelled combine harvesters. The results of the investigation are summarized and concluded as follows:

The manufacturers of self-propelled combine harvesters purchase, prime mover or engines for their combine from some other manufacturer. Engines mounted on self-propelled combine harvesters were already tested as per the BIS standard, by Automotive Research Association of India, Pune (ARAI, Pune). The self-propelled combine harvesters are tested in North Region Farm Machinery Training & Testing Institute, Hisar (NRFMT&TI Hisar), as per the BIS standards, in this way the testing of engine is repeated. For reducing the burden of retesting of engines on testing institutions a need arises for comparative study of performance parameters of combine harvester for the benefits of users, entrepreneurs and the testing institutes.

Kirloskar engine (Model 6R-1080) was used in three different makes of combines during different years, meaning thereby the same model of engine was tested three times with combines at NRFMT&TI (Hisar). The average mean values of engine performance data, tested at NRFMT&TI (Hisar) were compared with the engine performance of same model tested at A.R.A.I. (Pune) as per the Bureau of Indian Standard (BIS). One-sample t-test was carried out to compare the mean values of engine performance results under different tests prescribed in the test report. The calculated t values for all engine performance parameters viz. power, torque, fuel consumption and specific fuel consumption were less than tabulated values of t in varying speed and varying load test. This clearly concluded that mean values of power, torque, fuel consumption and specific fuel consumption in Kirloskar engines (Model 6R 1080) obtained under varying speed and varying loads in different testing institutes were similar. There was no significant effect on engine testing performance parameters of engine tested in different period and at different testing institutes. So there is no need to repeat these tests when the testing of combine harvesters is undertaken by the testing institutes.

Ashok Leyland engine (Model ALU-400) used in 22 different makes of combine harvesters was tested 22 times with the combines during different durations at NRFMT&TI (Hisar), meaning thereby the same engine was tested repeatedly. The performances parameters of Ashok Leyland engines were compared on the basis of mean values of their performance data. The performances of all the testing parameters in Ashok Leyland engines (Model ALU-400) obtained under various tests viz. varying speed test, varying load test, maximum power test and five hours rating test (High Ambient) were similar. The percentages of variations in all the testing parameters were found to be very low in various tests. There was no significant effect on the engine performance parameters under different tests of the engine, tested during different periods/seasons at NRFMT&TI (HISAR). These results clearly revealed that repeated testing of engine of combines should be avoided as similar performance results are obtained during different testing periods.

Total fixed cost of engine testing of combine harvester, at NRFMT&TI (Hisar) was Rs. 5694.45. Total variable cost of the engine testing, was Rs. 109576.06, while overhead charges for engine testing were Rs. 23058.10. The total cost of engine testing of combine harvester, at NRFMT&TI (Hisar) during the year 2009-10 was Rs. 1.38 lacs.

Testing of Kirloskar and Ashok Leyland makes of engines used on combine harvesters at NRFMT&TI (Hisar) resulted in an extra expenditure of 1.38 lacs. This is an extra expenditure for the combine manufacturers as these engine had already been tested at A.R.A.I.(Pune) as per the BIS test codes. Moreover, retesting of these engines at combine testing institutes, results in unavoidable delays. Therefore, the existing test requirement needs to be reviewed at the testing institute level to economize the cost of combine testing as well as avoid unnecessary delays.

Recommendation

No need of retesting engines mounted on combines by testing institute authorized by government of India or state government, when engine mounted on combine is new one and manufactured by a standard registered company having Engine no., Chassis no. and Model. For this a certificate must be taken from combine manufacturer that engine installed on combine is new one and of standard make.

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APPENDIX-I

A: Specification of kirloskar engine

Model	**6R-1080**
Type	**4-stroke, water cooled, DI diesel engine**
Maximum speed at No load	**2340**
Rated speed	**2200**
Low idle speed	**650±50**
Number of cylinder +	**Six**
Disposition	**Vertical, inline**
Bore/stroke	**105/120**
Compression ratio	**17.6:1**

B: Specification of Ashok Leyland engine

Model	**ALU-400**
Type	**4-stroke, water cooled, DI diesel engine**
Maximum speed at No load	**2370**
Rated speed	**2200**
Low idle speed	**450-500**
Number of cylinder	**Six**
Disposition	**Vertical, inline**
Bore/stroke	**107.18/120.65**
Compression ratio	**16:1**

C: SPECIFICATION OF COMBINE HARVESTERS

Item	Code
Make	1
Model	2
Type	3
Dia of reel (mm)	4
Width of reel (mm)	5
Range of reel speed corresponding to 1800 rpm of engine (rpm)	
Maximum	6
Medium	7
Minimum	8
Working width of cutter bar with shoes (mm)	9
Effective cutter bar width (mm)	10
No. of knifes	11
Spacing of knife quards (mm)	12
Knife stroke (mm)	13
Strokes per minute	14
Knife speed corresponding to 1800 rpm of engine (m/sec.)	15
Threshing drum type, wheat/ paddy	16
Threshing drum width, wheat/paddy (mm)	17
Threshing drum outside dia, wheat/ paddy (mm)	18
Range of threshing drum speed corresponding to 1800 rpm of engine (rpm)	
Minimum, wheat/paddy	19
Maximum, wheat/paddy	20
Overall width of concave, wheat/ paddy (mm)	21

Code	Combine harvesters												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	Hira	Hind	Shaktiman	Roop	Dasmesh	Manjit	RAMA	Mohindra	Kartar	Harmeet	Sunstar	Bhoday	K.S
2	785	999	AS-930	887	7100	986	930	7700	4400	985	678	1070	9300
3	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled
4	874	905	933	924	949	933	960	950	882	936	1024	1029	1036
5	3740	4140	4200	4175	3550	3445	3530	3455	3810	3804	3745	4144	4086
6	52	47	54	66	38	46	36	37	40	37	40	51	59
7	-	38	31	-	-	-	-	-	-	-	-	-	-
8	41	31	18	26	28	32	21	20	30	33	33	21	20
9	3900	4300	4300	4280	3925	3710	3700	3660	4030	4050	4040	4313	4310
10	3850	4240	4225	4260	3770	3640	3655	3585	3950	3975	3795	4280	4265
11	52	56	58	56	48	50	50	47	54	54	54	57	58
12	71	75	80	75	75	75	73-79	75-80	70-80	70-80	75	75	75
13	99	90	92	90	90	80	88	75	80	91	100	95	95
14	978	850	850	879	940	850	924	910	884	870	870	920	864
15	1.70	1.46	1.46	1.39	1.39	1.244	0.765	1.237	1.383	1.39	1.385	1.34	1.368
16	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B. / P.T	R.B./ P.T.	R.B. / P.T
17	10201020	1220/ 1220	1270/ 1250	1265/ 1270	970/ 990	1125 / 1015	1015 / 1015	1017 / 985	1272 / 1275	1278 / 1268	1273 / 1265	1270 / 1265	1252 / 1272
18	615/ 615	590/ 570	600/ 590	595/ 460	585/ 600	580 / 465	598 / 463	593 / 455	595 / 479	595 / 470	593 / 601	600 / 609	565 / 605
19	693/ 693	517/ 517	546/ 546	566/ 566	680/ 680	678 / 668	653 / 653	525 / 525	671 / 671	710 / 710	566/ 566	720 / 680	568 / 614
20	952/ 952	1100	1186/ 1186	869/ 869	870/ 870	840 / 840	900 / 900	902 / 905	877 / 877	900 / 800	920 / 840	973 / 850	1062 / 1042

	Combine harvesters												
Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
21	1025/ 1030	1285	1280/ 1280	1285/ 1275	1025/ 1025	1020 / 1117	1033 / 1039	1026 / 1020	1285 / 1285	1280 / 1280	1275 / 1275	1285 / 1285	1275 / 1275
22	1000/ 1010	1260/ 1270	1260/ 1260	1270/ 1255	1000/ 1010	1010 / 900	1000 / 957	1014 / 935	1272 / 1267	1250 / 1260	1260 / 1260	1265 / 1265	1250 / 1250
23	0.665/ 0.57	0.743/ 0.730	0.737/ 0.806	0.765/ 0.746	0.48/ 0.48	0.61 / 0.55	0.55 / 0.51	0.60 / 0.52	0.60 / 0.52	0.77 / 0.64	0.78 / 0.73	0.81 / 0.76	0.73 / 0.77
24	21.5-37.4/ 11.8-35.7	9.5-36.5	9.2-33.8/ 8-32.5	6-30/ 8-32	21.5-37.4/ 11.8-35.7	22-52 / 18-51.6	16.7-35.25 / 16.8-42	9.2-44.9 / 12.33-42.2	12-32 / 34-54	16-31 / 22-32	15-30 / 21-32	14-31 / 21-23	8-40 / 2-38
25	12.5-17.6/ 20-21.5	5-9	8-18.5/ 6.2-17.5	8-28/ 10.26	12.5-17.6/ 20-21.5	14-37 / 16.3-42	8-29.6 / 15.2-38	7-50.2 / 15.3-39.5	14-24 / 24-47	8-19 / 22-41	7-32 / 15-30	9-35/ 17-33	7-25 / 12-39
26	4	5	5	6	5	5	5	5	5	5	5	5	5
27	3620	3830	3800	3825	3800	3835	3495	3693	3780	3970	3965	3975	3836
28	240	235	240	195	240	240	240	236	235	230	233	236	235
29	4.33	4.98	5.035	5.13	4.33	3.68	3.355	3.486	4.44	4.57	4.55	4.58	4.283
30	140/ 140	140/ 140	160/ 160	145/ 145	150/ 150	148 / 151.5	156 / 151	143 / 145.5	135 / 125	150 / 150	145 / 145	153 / 151	151 / 152
31	2	2	2	2	2	1	1	1	1	1	2	2	2
32	1240/ 755	1310/ 760	1240/ 760	1240/ 760	1235/ 958	1029	995	988	1215	1240	1253 / 608	1235 / 756	1242 / 885
33	960/ 960	1215/ 1215	1212/ 1212	1223/ 1220	960/ 757	960	962	964	1210	1215	962 / 960	961 / 960	1218 / 1218
34	1.03/ 0.68	1.28/ 0.714	1.35/ 0.912	1.36/ 0.792	1.6/ 0.63	0.9	0.859	0.863	1.35	1.351	1.04 / 0.48	1.028 / 0.604	1.357 / 0.973
35	30/ 30	30/ 30	40/ 40	30/ 30	55/ 55	18 / 31	13 / 32	16 / 32	55 / 35	28 / 25	28 / 32	25 / 29	22 / 35
36	1	1	1	1	1	1	1	1	1	1	1	1	1
37	1230	1310/ 1325	1240	1240	1250	957	962	1000	1210	1215	1211	12-14	1238
38	960	1215	1215	1225	965	640	473	963	620	655	653	658	1218
39	1.08	1.28/ 1.46	1.386	1.357	1.00	0.55	0.384	0.78	0.66	0.702	0.701	0.704	1.363
40	310	185/ 185	185	288	595	286	420	285	380	130	291	282	281

Code	Combine harvester											
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	Hira	Vishal	Sansar	SYAN	Gurunanak	Malkit	Gurunanak	Gill	Sonalika	Preet	Preet	Panjab
2	985	408 supreme	930	998	985	Malkit-997	785	2001	9614	Preet-849	Preet-989	930
3	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled	Self propelled
4	1000.5	898	1012	974	1038	1012	1021	928	928	983	1033	928
5	4125	4242	4225	3813	4240	4270	3585	4200	3244	3467	4125	3590
6	43	74	49	39	63	60	63	50	39	55	45	41
7	-	-	-	-	38	-	37	37	-	-	-	-
8	28	23	16	30	23	32	27	26	30	29	29	37
9	4360	4371	4365	3950	4313	4640	3930	4300	3460	3675	4360	3860
10	4350	4338	4272	3882	4302	4340	3650	4267	3380	3655	4280	3680
11	58	58	56	53	57	57	51	58	46	51	58	49
12	75	75	75	75	75	75	76	76	74	76	75	75
13	90	93	89	78	97	95	98	89	80	99	92	83
14	910	958	879	717	972	888	840	939	814	1000	920	817
15	1.445	1.527	1.341	0.932	1.61	1.488	1.450	1.39	1.085	1.60	1.37	1.13
16	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.	R.B. / P.T.
17	1245 / 1250	1270 / 1270	1265 / 1270	1267 / 1246	1270 / 1275	1270 / 1265	1012 / 1020	1273 / 1270	1025 / 1010	1016 / 1020	1280 / 1270	1135 / 1135
18	590 / 602	598 / 598	595 / 614	592 / 594	590 / 595	595 / 610	590 / 608	560 / 600	598 / 602	595 / 615	590 / 610	594 / 592
19	606 / 606	537 / 537	550 / 550	646 / 646	568 / 568	550 / 550	567 / 567	678 / 678	653 / 653	525 / 525	681 / 681	714 / 714
20	1117 / 1117	1016 / 1016	1178 / 1178	754 / 754	1010 / 1010	910 / 910	1011 / 1011	871 / 871	1010 / 1010	1177 / 1177	1070 / 1070	910 / 910

Code	Combine harvester											
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
21	1278 / 1278	1290 / 1272	1282 / 1274	1292 / 1286	1280 / 1285	1283 / 1283	1027 / 1032	1282 / 1282	1032 / 1030	1028 / 1030	1283 / 1285	1156 / 1154
22	1256 / 1256	1253 / 1248	1262 / 1254	1278 / 1274	1258 / 1264	1257 / 1255	1010 / 1006	1258 / 1262	1016 / 1017	1016 / 1010	1263 / 1285	1137 / 1135
23	0.760 / 0.671	0.744 / 0.754	0.718 / 0.658	0.749 / 0.745	0.755 / 0.666	0.722 / 0.722	0.600 / 0.540	0.697 / 0.751	0.576 / 0.506	0.591 / 0.587	0.733 / 0.752	0.615 / 0.653
24	12.5-32 / 15-41	14-30 / 2-52	11-31 / 8-38	13-42 / 18-45	17-31 / 16-39	14-32 / 23-29	19-30 / 15-32.5	6-32 / 6-32	20-47 / 11-32	17-35 / 13-39	22-50 / 15-43	10-37 / 8-32
25	10-15 / 8-18	6-20 / 24-50	11-27 / 10-26	6-14 / 7-25	5-15 / 9-16	7-17 / 19-22	5-7 / 7.5-19	5-30 / 5-23	20-36 / 6-8	11-18 / 10-15	14-30 / 11-20	7-40 / 6-35
26	5	5	5	5	5	5	4	5	4	4	5	5
27	3590	3955	3802	3900	3585	3846	3590	3790	3665	3860	3900	3670
28	233	235	236	230	240	238	236	240	234	238	237	202
29	3.98	4.41	4.2	4.381	4.2084	5.06	3.841	4.331	3.255	-	5.17	4.442
30	142 / 145	141 / 141	151 / 151	136 / 136	148 / 148	145 / 145	140 / 140	145 / 145	147 / 147	140 / 140	150 / 150	145 / 145
31	2	2	2	2	2	1	1	2	2	1	2	2
32	1244 / 709	1238 / 630	1240 / 713	1224 / 633	1240 / 715	1320 / 750	1240 / 725	764 / 1243	1256 / 609	1240 / 756	1240 / 760	1230 / 1082
33	1216 / 1216	1214 / 1214	1215 / 1215	1215 / 1216	1215 / 1215	1215 / 1215	960 / 955	1212 / 1212	962 / 960	960 / 960	1210 / 1210	1085 / 735
34	1.54 / 0.720	1.305 / 0.620	1.314 / 0.717	1.282 / 0.656	1.315 / 0.726	1.395 / 0.714	1.02 / 0.586	0.802 / 1.322	1.04 / 0.48	1.028 / 0.604	1.31 / 0.77	1.212 / 0.587
35	34 / 18	22 / 41	35 / 40	20 / 28	17 / 35	35 / 22	20 / 35	28 / 32	20 / 35	28 / 34	25 / 65	35 / 35
36	1	1	1	1	1	1	1	1	1	1	1	1
37	1242	1392	1238	1210	1243	1317	1240	757 / 757	1248	1238	1240	1228
38	1215	1213	1213	1266	1215	1215	960	1215 / 1215	1223	960	1210	1246
39	1.303	1.473	1.306	1.336	1.321	1.393	1.03	0.771 / 0.791	1.319	1.009	1.29	1.366
40	272	625	264	304	272	238	264	279 / 279	274	272	275	306

D: Average field performance of 25 different makes of combines for paddy harvesting

Combines	Pre-harvest loss (%)	Header loss (%)	Total collectable losses (%)	Total non-collectable losses (%)	Total processing losses (%)	Threshing efficiency (%)	Cleaning efficiency (%)
C1	1.055	0.756	1.323	1.204	2.311	99.01	97.97
C2	1.054	0.818	1.422	1.416	2.670	98.97	98.09
C3	1.124	0.855	1.421	1.303	2.700	99.11	98.16
C4	1.206	0.892	1.131	1.277	2.361	99.38	98.14
C5	1.010	0.765	1.288	1.326	2.359	99.05	98.07
C6	1.169	0.884	1.454	1.385	2.734	99.20	98.32
C7	0.820	0.824	1.545	1.246	2.552	99.07	97.79
C8	0.713	0.867	1.253	1.125	2.303	99.05	98.04
C9	0.644	0.780	1.346	1.266	2.280	98.99	98.02
C10	0.728	0.805	1.238	1.254	2.431	99.31	98.16
C11	0.744	0.831	1.589	1.434	2.718	99.02	98.03
C12	0.607	1.006	1.458	1.475	2.793	99.16	98.24
C13	0.639	0.829	1.739	1.363	2.735	99.03	98.09
C14	0.522	0.700	1.709	1.391	2.723	99.00	98.08
C15	0.763	0.743	1.637	1.346	2.690	99.02	98.01
C16	0.593	0.784	1.789	1.496	2.930	99.07	98.08
C17	0.358	1.010	2.038	1.457	2.945	99.08	98.40
C18	0.355	0.818	1.589	1.471	2.914	98.99	98.09
C19	0.351	0.796	1.392	1.229	2.390	99.03	98.00
C20	0.482	0.873	1.309	1.234	2.417	99.23	98.33
C21	0.563	0.718	1.314	1.204	2.339	99.01	97.90
C22	0.404	0.988	1.389	1.229	2.296	98.93	98.04
C23	0.433	0.916	1.144	1.236	2.348	99.01	97.96
C24	0.348	0.756	1.167	1.259	2.340	99.05	98.00
C25	0.352	0.926	1.149	1.142	2.276	98.98	97.96
Mean	**0.681**	**0.838**	**1.433**	**1.311**	**2.542**	**99.07**	**98.08**
S. D.*	**0.282**	**0.085**	**0.227**	**0.107**	**0.229**	**0.10**	**0.13**
C.V.**	**41.315**	**10.137**	**15.840**	**8.162**	**9.023**	**0.11**	**0.14**
S.E.M.***	**0.056**	**0.017**	**0.045**	**0.021**	**0.046**	**0.02**	**0.02**

**** S. D. - Standard deviation***
***** C.V. – Co-efficient of variation***
****** S.E.M. – Standard error of mean***

E: Average field performance of 25 different makes of combines for wheat harvesting

Combines	Pre-harvest loss (%)	Header loss (%)	Total collectable losses (%)	Total non-collectable losses (%)	Total processing losses (%)	Threshing efficiency (%)	Cleaning efficiency (%)
C1	0.710	0.470	1.256	1.442	2.650	99.54	98.07
C2	0.808	1.112	1.530	1.392	2.790	99.07	98.25
C3	0.580	0.530	1.272	1.166	2.410	99.26	98.29
C4	0.717	0.493	1.349	1.225	2.442	99.16	97.96
C5	0.424	1.352	1.164	1.168	2.314	99.11	98.14
C6	0.433	0.673	1.441	1.248	2.509	98.95	97.83
C7	0.466	0.583	1.186	1.224	2.184	99.08	98.03
C8	0.337	0.232	1.262	1.184	2.282	98.99	98.15
C9	0.527	0.919	1.142	1.164	2.162	99.14	97.71
C10	0.509	0.877	1.202	1.248	2.388	99.06	97.96
C11	0.394	0.608	1.314	1.092	2.266	99.07	97.61
C12	0.404	0.383	1.148	1.112	2.240	99.14	98.09
C13	0.306	0.471	1.101	1.117	2.128	99.12	97.94
C14	0.344	0.643	1.282	1.221	2.394	99.05	98.01
C15	0.367	0.542	1.134	1.128	2.219	99.13	97.84
C16	0.262	0.408	1.090	1.298	2.215	98.86	97.86
C17	0.367	0.258	1.299	1.306	2.303	99.05	97.92
C18	0.395	1.216	1.181	1.233	2.269	99.07	98.10
C19	0.318	0.661	1.144	1.131	2.231	99.05	98.05
C20	0.331	0.427	1.336	1.214	2.141	99.10	98.01
C21	0.295	0.975	1.204	1.124	2.335	99.13	98.08
C22	0.367	1.013	1.120	1.163	2.126	99.16	97.79
C23	0.243	0.783	1.079	1.139	2.165	98.93	98.01
C24	0.477	0.830	1.193	1.216	2.281	99.00	97.62
C25	0.687	0.735	1.386	1.198	2.383	98.97	98.06
Mean	**0.443**	**0.688**	**1.233**	**1.206**	**2.313**	**99.09**	**97.97**
S. D.*	**0.152**	**0.292**	**0.115**	**0.085**	**0.161**	**0.12**	**0.17**
C.V.**	**34.431**	**42.387**	**9.307**	**7.059**	**6.949**	**0.12**	**0.17**
S.E.M.***	**0.030**	**0.058**	**0.023**	**0.017**	**0.032**	**0.02**	**0.03**

APPENDIX-II

A: Performances of various testing parameters of kirloskar engine in varying speed test

Speed rpm	Date of tests				Mean (C1,C2 &C3)	S D	C V (%)	S Em
	11.1.02 -13.1.02	03.7.02 -09.7.02	11.3.03 -13.3.03	13.9.04 -15.9.04				
	Control	Different makes of combine						
	C0	C1	C2	C3				
	Power kW							
1000	43.40	45.13	42.90	43.21	**43.75**	**1.21**	**2.73**	**0.70**
1200	51.50	52.30	50.80	49.50	**50.87**	**1.40**	**2.76**	**0.81**
1400	57.00	56.00	54.80	55.00	**55.27**	**0.64**	**1.12**	**0.37**
1600	64.00	65.12	63.50	64.20	**64.27**	**0.81**	**1.26**	**0.47**
1800	69.70	69.90	68.70	69.90	**69.50**	**0.69**	**1.00**	**0.40**
2000	74.50	72.40	70.90	72.20	**71.83**	**0.81**	**1.16**	**0.47**
2200	78.00	75.10	73.90	74.90	**74.63**	**0.64**	**0.89**	**0.37**
	Torque Nm							
1000	414.65	431.18	409.87	412.83	**417.96**	**11.54**	**2.78**	**6.67**
1200	410.03	416.40	404.46	394.11	**404.99**	**11.15**	**2.72**	**6.44**
1400	388.99	388.85	379.18	383.36	**383.80**	**4.85**	**1.19**	**2.80**
1600	382.17	382.17	373.98	375.34	**377.16**	**4.39**	**1.25**	**2.53**
1800	369.96	371.02	364.65	369.20	**368.29**	**3.28**	**0.98**	**1.89**
2000	355.89	345.86	338.69	344.90	**343.15**	**3.89**	**1.12**	**2.25**
2200	338.74	326.14	320.93	325.28	**324.12**	**2.79**	**0.83**	**1.61**
	Fuel consumption l/h							
1000	12.93	13.10	13.28	12.95	**13.11**	**0.17**	**1.26**	**0.10**
1200	14.48	15.10	14.32	14.68	**14.70**	**0.39**	**2.66**	**0.23**
1400	15.58	16.11	15.95	15.11	**15.72**	**0.54**	**3.42**	**0.31**
1600	17.14	18.10	17.45	17.12	**17.56**	**0.50**	**2.84**	**0.29**
1800	19.77	20.35	20.90	20.11	**20.45**	**0.41**	**1.98**	**0.23**
2000	21.73	22.65	22.40	22.75	**22.60**	**0.18**	**0.80**	**0.10**
2200	23.87	25.45	23.96	24.10	**24.50**	**0.82**	**3.36**	**0.48**
	Specific fuel consumption g/kWh							
1000	250.6	258.3	254.9	249.6	**254.27**	**4.38**	**1.72**	**2.53**
1200	243.5	249.4	246.5	244.5	**246.80**	**2.46**	**1.00**	**1.42**
1400	234.2	239.7	237.3	232.3	**236.43**	**3.78**	**1.60**	**2.18**
1600	231.1	227.6	222.4	225.2	**225.07**	**2.60**	**1.16**	**1.50**

1800	242.9	248.5	243.2	238.0	**243.23**	**5.25**	**2.16**	**3.03**
2000	252.2	256.1	266.1	261.1	**261.10**	**5.00**	**1.91**	**2.89**
2200	271.1	275.4	277.6	271.3	**274.77**	**3.20**	**1.16**	**1.85**

C0 & Ca engines tested at A.R.A.I. (Pune), and at NRFMT&TI (HISAR)
(average value of three different combines)
t_{cal} – Calculated value of t
N.S. –Non-Significant
t_{tab} –Tabulated value of t

B: Performances of various testing parameters of kirloskar engine in varying load test

Load (%)	Date of tests				Mean (C1,C2 &C3)	S D	C V (%)	SEm
	11.1.02 -13.1.02	**03.7.02 -09.7.02**	**11.3.03 -13.3.03**	**13.9.04 -15.9.04**				
	C0	**C1**	**C2**	**C3**				
	Power kW							
100	77.70	75.10	73.42	74.60	**74.37**	**0.86**	**1.16**	**0.50**
85	64.25	64.46	62.81	63.72	**63.66**	**0.83**	**1.30**	**0.48**
75	57.30	58.05	55.25	56.43	**56.58**	**1.41**	**2.48**	**0.81**
50	38.90	39.27	37.18	38.36	**38.27**	**1.05**	**2.74**	**0.61**
10	14.80	15.60	14.52	14.95	**15.02**	**0.54**	**3.62**	**0.31**
	Torque Nm							
100	338.51	323.97	318.85	331.42	**324.75**	**6.32**	**1.95**	**3.65**
85	284.27	281.72	278.77	284.47	**281.65**	**2.85**	**1.01**	**1.65**
75	254.21	249.06	245.94	256.18	**250.39**	**5.25**	**2.10**	**3.03**
50	169.47	166.59	164.46	173.30	**168.12**	**4.61**	**2.74**	**2.66**
10	64.48	64.92	63.06	66.84	**64.94**	**1.89**	**2.91**	**1.09**
	Fuel consumption l/h							
100	23.83	25.46	23.96	24.39	**24.60**	**0.77**	**3.14**	**0.45**
85	20.35	21.35	20.13	20.87	**20.78**	**0.61**	**2.96**	**0.35**
75	17.44	18.25	17.50	17.90	**17.88**	**0.38**	**2.10**	**0.22**
50	13.38	14.35	13.45	13.95	**13.92**	**0.45**	**3.24**	**0.26**
10	10.53	11.09	10.37	10.67	**10.71**	**0.36**	**3.38**	**0.21**
	Specific fuel consumption g/kW-h							
100	270.2	274.3	277.5	271.4	**274.40**	**3.05**	**1.11**	**1.76**
85	275.3	277.5	279.8	275.3	**277.53**	**2.25**	**0.81**	**1.30**
75	286.9	285.1	290.6	293.2	**289.63**	**4.14**	**1.43**	**2.39**
50	306.5	298.8	313.2	309.7	**307.23**	**7.51**	**2.44**	**4.34**
10	621.1	599.4	617.3	606.5	**607.73**	**9.01**	**1.48**	**5.20**

APPENDIX-III

A. Power in Ashok Leyland engine (Model ALU-400), at varying speed test

Speed rpm		**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2300**	**2350**	**2400**
Combines	**Dates of test(s)**	**Power, kW**									
C1	12.2.01 - 15.2.01	37.34	46.52	54.50	61.90	67.70	70.25	72.81	75.68	70.50	31.70
C2	3.8.01 - 8.8.01	40.14	48.00	56.13	62.85	68.85	71.77	74.23	79.10	72.40	32.15
C3	10.8.01 - 14.8.01	38.77	47.16	55.45	61.60	68.20	71.22	73.65	76.50	71.75	31.50
C4	8.9.01 - 10.9.01	36.40	46.75	54.95	61.50	67.20	70.60	72.40	74.80	70.15	31.35
C5	18.9.01 - 21.9.01	38.85	47.85	56.45	62.65	68.15	71.65	74.45	79.20	71.85	32.45
C6	2.12.02 - 4.12.02	36.75	46.25	54.10	61.15	66.90	70.10	72.28	75.10	70.88	33.55
C7	1.7.03 - 4.7.03	38.66	47.30	55.10	62.86	67.30	70.40	72.75	77.77	71.45	30.60
C8	14.7.03 - 18.7.03	38.45	46.67	54.96	61.86	67.82	71.18	73.25	76.85	70.65	31.85
C9	8.9.04 - 10.9.04	39.65	47.25	55.73	62.45	68.30	69.95	71.65	74.11	69.20	29.88
C10	27.9.04 - 29.9.04	38.24	46.21	55.15	61.27	68.25	70.65	73.15	75.85	70.33	32.26
C11	1.10.04 - 3.10.04	37.35	45.90	54.10	60.90	67.10	69.80	71.80	73.90	69.55	30.77
C12	7.10.04 – 9.10.04	39.37	47.15	55.73	62.36	68.13	71.26	73.77	77.25	70.37	31.37
C13	12.8.05 - 16.8.05	36.45	47.65	55.25	62.30	67.20	69.70	72.35	75.90	79.13	31.63
C14	24.11.06 - 30.11.06	39.45	47.30	56.70	61.45	67.85	71.20	73.65	78.33	71.65	30.65
C15	13.6.08 - 15.6.08	37.92	46.96	55.11	62.10	68.35	71.45	73.35	76.75	72.25	31.60
C16	25.6.08 - 28.6.08	39.34	47.66	55.85	62.45	67.80	70.30	72.60	75.80	71.44	30.72
C17	10.7.08 - 14.7.08	38.25	47.15	55.25	62.30	67.90	71.85	73.85	77.53	71.14	32.15
C18	21.7.08 - 26.7.08	39.45	47.65	56.65	62.75	68.45	71.75	73.19	78.70	70.60	30.90
C19	29.7.08 - 2.8.08	39.18	47.76	55.10	62.32	68.77	69.44	71.55	74.50	70.20	30.38
C20	20.8.08 - 22.8.08	40.45	48.66	57.35	63.15	69.00	72.25	74.35	79.20	72.45	32.45
C21	27.8.08 - 31.8.08	38.87	47.96	56.35	62.950	67.95	71.60	72.85	76.45	71.25	30.40
C22	4.9.08 - 7.9.08	37.85	46.95	54.65	61.50	67.20	70.57	72.50	74.90	70.13	31.24
Mean		**38.51**	**47.21**	**55.48**	**62.12**	**67.93**	**70.86**	**73.02**	**76.56**	**71.33**	**31.43**
Standard Deviation		**1.14**	**0.67**	**0.84**	**0.64**	**0.58**	**0.82**	**0.85**	**1.63**	**1.92**	**0.84**
Coefficient of Variation		**2.95**	**1.41**	**1.53**	**1.06**	**0.86**	**1.16**	**1.16**	**2.12**	**2.72**	**2.73**
Standard Error of Mean		**0.24**	**0.14**	**0.18**	**0.14**	**0.13**	**0.17**	**0.18**	**0.36**	**0.42**	**0.18**

B: Torque in Ashok Leyland engine (Model ALU-400), at varying speed test

Speed rpm		**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2300**	**2350**	**2400**
Combines	**Dates of test(s)**	**Torque N-m**									
C1	12.2.01 - 15.2.01	356.75	370.38	378.93	369.63	359.34	335.59	316.20	315.16	286.62	126.19
C2	3.8.01 - 8.8.01	383.50	380.17	387.05	375.30	365.45	342.85	322.37	328.58	294.35	127.99
C3	10.8.01 - 14.8.01	370.41	375.48	379.41	367.83	362.00	340.22	319.85	317.78	291.71	125.40
C4	8.9.01 - 10.9.01	347.77	372.21	385.00	367.24	356.69	337.26	314.42	310.72	285.20	124.80
C5	18.9.01 - 21.9.01	371.18	380.97	385.24	374.10	361.73	342.28	323.32	328.99	292.11	129.18
C6	2.12.02 - 4.12.02	351.11	368.23	379.20	365.15	355.10	334.87	313.90	311.96	288.17	133.56
C7	1.7.03 - 4.7.03	369.36	371.59	379.02	375.36	357.22	336.31	315.94	323.05	290.49	121.82
C8	14.7.03 - 18.7.03	367.36	371.58	376.07	369.39	359.98	340.03	318.11	319.23	287.23	126.79
C9	8.9.04 - 10.9.04	378.82	376.19	380.32	372.91	362.53	334.16	311.16	307.85	281.34	118.95
C10	27.9.04 - 29.9.04	365.35	367.91	376.36	365.86	362.26	337.50	317.68	315.08	285.93	128.42
C11	1.10.04 - 3.10.04	356.85	365.45	369.20	363.65	356.16	333.44	311.81	306.98	282.76	122.49
C12	7.10.04 – 9.10.04	376.15	375.40	380.32	372.37	361.62	340.41	320.37	320.89	286.10	124.88
C13	12.8.05 - 16.8.05	348.25	373.38	377.05	372.01	356.69	332.96	314.20	315.29	321.71	125.92
C14	24.11.06 - 30.11.06	376.91	376.59	386.94	366.94	360.14	340.13	319.85	325.38	291.30	122.01
C15	13.6.08 - 15.6.08	362.29	373.89	376.09	370.82	362.79	341.32	318.54	318.82	293.74	125.80
C16	25.6.08 - 28.6.08	375.86	379.46	381.14	372.91	359.87	335.83	315.29	314.87	290.45	122.29
C17	10.7.08 - 14.7.08	365.45	375.40	379.05	372.01	360.40	343.23	320.72	322.06	289.23	127.99
C18	21.7.08 - 26.7.08	376.91	379.38	386.60	374.70	363.32	342.75	317.85	326.92	287.03	123.01
C19	29.7.08 - 2.8.08	374.33	380.25	386.02	372.13	365.02	331.72	310.73	309.47	285.40	120.94
C20	20.8.08 - 22.8.08	386.46	387.42	391.38	377.09	366.24	345.14	322.89	328.99	294.55	129.18
C21	27.8.08 - 31.8.08	371.37	380.85	384.55	375.90	360.67	342.04	316.37	317.57	289.67	121.02
C22	4.9.08 - 7.9.08	361.62	373.81	378.95	367.24	356.69	337.12	314.85	311.13	285.12	124.36
Mean		**367.91**	**375.27**	**381.09**	**370.93**	**360.54**	**338.50**	**317.11**	**318.03**	**290.01**	**125.13**
Standard Deviation		**9.86**	**5.19**	**5.03**	**3.79**	**3.21**	**3.79**	**3.58**	**6.92**	**7.93**	**3.50**
Coefficient of Variation		**2.91**	**1.38**	**1.32**	**1.02**	**0.91**	**1.09**	**1.13**	**2.19**	**2.77**	**2.79**
Standard Error of Mean		**2.17**	**1.04**	**1.01**	**0.76**	**0.62**	**0.76**	**0.73**	**1.38**	**1.59**	**0.69**

C: Fuel consumption in Ashok Leyland engine (Model ALU-400), at varying speed test

Speed rpm		1000	1200	1400	1600	1800	2000	2200	2300	2350	2400
Combines	Dates of test(s)	Fuel consumption l/h									
C1	12.2.01 - 15.2.01	12.01	13.40	15.63	18.11	20.46	21.97	24.02	24.78	20.45	13.16
C2	3.8.01 - 8.8.01	12.13	14.30	16.60	19.46	21.31	22.51	24.31	25.89	20.41	13.39
C3	10.8.01 - 14.8.01	11.35	13.78	15.87	18.67	20.11	21.10	23.90	25.45	21.13	12.65
C4	8.9.01 - 10.9.01	11.29	13.47	15.38	18.73	19.99	20.83	22.87	24.35	19.37	12.83
C5	18.9.01 - 21.9.01	12.09	14.43	16.81	19.67	21.43	22.73	24.13	25.93	19.63	13.11
C6	2.12.02 - 4.12.02	10.95	12.99	14.98	18.76	20.34	20.93	23.45	24.97	20.66	13.17
C7	1.7.03 - 4.7.03	11.23	13.12	15.25	18.12	19.87	21.27	23.10	25.66	21.34	12.59
C8	14.7.03 - 18.7.03	11.34	13.67	15.65	18.67	20.67	21.39	23.56	25.34	20.31	12.65
C9	8.9.04 - 10.9.04	11.71	13.39	15.71	18.53	20.45	21.23	23.42	25.08	19.65	12.76
C10	27.9.04 - 29.9.04	12.10	13.40	16.06	18.93	19.56	20.87	22.98	25.11	20.67	11.90
C11	1.10.04 - 3.10.04	11.65	14.14	16.24	19.56	19.78	20.65	23.34	26.04	20.78	12.23
C12	7.10.04 – 9.10.04	11.35	14.09	14.86	19.40	20.85	22.34	24.04	25.25	21.03	12.67
C13	12.8.05 - 16.8.05	12.13	14.30	16.20	19.55	21.18	22.20	24.15	25.18	19.41	13.39
C14	24.11.06 - 30.11.06	12.03	14.76	16.38	19.47	21.56	22.45	24.54	26.10	20.67	13.49
C15	13.6.08 - 15.6.08	11.47	13.45	15.45	18.75	20.12	21.90	23.35	24.98	19.96	12.45
C16	25.6.08 - 28.6.08	11.64	13.74	15.85	18.79	20.36	21.47	23.47	25.32	20.56	12.85
C17	10.7.08 - 14.7.08	11.65	13.88	15.65	18.71	20.45	21.30	23.85	25.12	21.15	12.75
C18	21.7.08 - 26.7.08	11.93	14.24	16.57	19.69	21.78	22.53	24.47	25.25	20.19	13.18
C19	29.7.08 - 2.8.08	12.23	14.56	16.82	19.39	21.62	22.37	24.87	25.96	20.27	13.39
C20	20.8.08 - 22.8.08	11.37	13.53	16.00	18.12	19.98	21.87	23.14	25.21	20.50	11.85
C21	27.8.08 - 31.8.08	11.59	13.75	16.29	19.38	21.56	22.06	23.87	25.49	19.80	13.10
C22	4.9.08 - 7.9.08	11.19	13.50	15.46	18.23	19.99	20.83	22.92	24.10	19.65	12.76
Mean		**11.66**	**13.81**	**15.90**	**18.94**	**20.61**	**21.67**	**23.72**	**25.30**	**20.35**	**12.83**

Standard Deviation	**0.36**	**0.47**	**0.54**	**0.54**	**0.69**	**0.67**	**0.56**	**0.51**	**0.58**	**0.43**
Coefficient of Variation	**3.09**	**3.27**	**3.40**	**2.73**	**3.14**	**3.07**	**2.38**	**2.03**	**2.86**	**3.35**
Standard Error of Mean	**0.07**	**0.10**	**0.11**	**0.11**	**0.14**	**0.13**	**0.11**	**0.10**	**0.12**	**0.09**

D: Specific fuel consumption in Ashok Leyland engine (Model ALU-400), at varying speed test

Speed rpm		**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2300**	**2350**	**2400**
Combines	**Dates of test(s)**	**Specific fuel consumption g/kW-h**									
C1	12.2.01 - 15.2.01	246.7	238.6	237.6	242.4	250.4	259.1	273.3	270.6	240.3	343.9
C2	3.8.01 - 8.8.01	238.5	246.8	235.0	256.5	256.4	259.9	271.3	271.2	239.6	345.1
C3	10.8.01 - 14.8.01	239.6	242.1	237.1	251.1	244.3	245.5	268.9	275.6	244.0	332.7
C4	8.9.01 - 10.9.01	237.4	238.7	226.9	252.3	246.5	244.4	261.7	269.7	228.8	339.1
C5	18.9.01 - 21.9.01	239.3	249.8	226.7	260.1	260.5	262.8	268.5	271.3	229.4	334.7
C6	2.12.02 - 4.12.02	234.1	232.7	229.4	254.2	251.9	247.4	268.8	275.5	241.5	325.2
C7	1.7.03 - 4.7.03	231.8	229.8	229.3	238.8	244.6	250.3	263.1	273.4	247.4	340.9
C8	14.7.03 - 18.7.03	237.3	242.7	235.9	250.1	252.5	249.0	266.5	273.2	238.2	329.1
C9	8.9.04 - 10.9.04	234.9	234.8	233.6	245.8	248.1	251.5	270.8	280.4	235.3	323.8
C10	27.9.04 - 29.9.04	249.1	240.2	241.3	256.0	237.4	244.7	260.3	274.3	248.5	315.6
C11	1.10.04 - 3.10.04	245.3	255.2	243.7	266.1	244.2	245.1	269.3	291.9	247.5	329.3
C12	7.10.04 – 9.10.04	232.3	247.6	230.9	257.7	253.5	259.7	270.0	270.8	247.6	334.6
C13	12.8.05 - 16.8.05	254.7	248.6	228.9	260.0	261.1	263.9	276.5	274.9	233.2	350.7
C14	24.11.06 - 30.11.06	240.5	258.5	236.3	262.5	263.3	261.2	276.1	276.1	239.0	364.6
C15	13.6.08 - 15.6.08	233.2	237.3	232.3	250.2	243.9	253.9	263.7	269.7	238.9	326.4
C16	25.6.08 - 28.6.08	237.3	238.9	235.1	249.3	248.8	253.0	267.8	276.7	239.4	346.6
C17	10.7.08 - 14.7.08	239.8	243.9	234.7	248.8	249.5	245.6	267.6	268.4	246.3	328.6
C18	21.7.08 - 26.7.08	238.5	247.6	232.3	260.0	263.6	260.2	277.0	265.8	236.9	353.4
C19	29.7.08 - 2.8.08	246.1	252.6	237.9	257.8	260.5	266.9	288.0	288.7	239.2	345.2
C20	20.8.08 - 22.8.08	234.9	230.4	231.1	237.7	239.9	250.8	257.9	263.7	234.4	312.5
C21	27.8.08 - 31.8.08	231.3	237.5	229.5	255.1	262.9	255.3	271.5	276.2	232.2	347.0

C22	4.9.08 - 7.9.08	235.6	238.2	234.4	245.6	246.5	244.5	261.9	266.6	237.1	338.4
Mean		**239.01**	**242.39**	**233.63**	**252.64**	**251.38**	**253.40**	**269.11**	**273.85**	**239.30**	**338.52**
Standard Deviation		**6.05**	**7.36**	**4.42**	**7.52**	**7.92**	**7.27**	**6.69**	**6.67**	**5.82**	**12.42**
Coefficient of Variation		**2.53**	**3.03**	**1.89**	**2.97**	**3.15**	**2.87**	**2.49**	**2.43**	**2.43**	**3.79**
Standard Error of Mean		**1.21**	**1.55**	**0.88**	**1.50**	**1.58**	**1.45**	**1.34**	**1.33**	**1.16**	**3.24**

E: Power in Ashok Leyland engine (Model ALU-400), at varying loads

Percent load		**100%**	**85% of load obtained at max. power**	**75% of load obtained in (ii)**	**50% of load obtained in (ii)**	**25% of load obtained in (ii)**	**Minimum load**
Combines	**Date of test(s)**	**Power kW**					
C1	12.2.01 - 15.2.01	75.48	64.16	48.42	32.08	16.04	6.01
C2	3.8.01 - 8.8.01	79.10	67.24	50.13	32.82	16.81	5.60
C3	10.8.01 - 14.8.01	76.30	64.86	48.64	32.43	16.21	5.40
C4	8.9.01 - 10.9.01	74.68	62.68	47.61	31.74	15.37	4.95
C5	18.9.01 - 21.9.01	79.20	67.32	50.49	32.76	16.83	5.20
C6	2.12.02 - 4.12.02	75.05	63.79	47.84	31.90	15.65	5.10
C7	1.7.03 - 4.7.03	77.55	65.92	49.44	32.96	16.48	5.40
C8	14.7.03 - 18.7.03	76.65	65.15	48.86	32.48	16.29	5.50
C9	8.9.04 - 10.9.04	74.10	63.99	47.24	31.49	15.75	5.00
C10	27.9.04 - 29.9.04	75.65	63.40	48.23	32.15	16.28	6.16
C11	1.10.04 - 3.10.04	73.60	62.56	46.92	31.28	15.64	4.90
C12	7.10.04 – 9.10.04	77.15	65.58	49.18	32.79	16.39	5.58
C13	12.8.05 - 16.8.05	75.90	64.52	48.29	32.26	16.13	5.37
C14	24.11.06 - 30.11.06	78.43	66.67	50.20	32.93	16.67	5.56
C15	13.6.08 - 15.6.08	76.25	64.81	48.61	32.41	16.50	5.20
C16	25.6.08 - 28.6.08	75.80	64.43	48.32	32.22	16.11	5.40
C17	10.7.08 - 14.7.08	77.53	65.90	49.73	32.95	16.48	5.78

C18	21.7.08 - 26.7.08	77.90	66.22	49.56	33.11	16.55	5.30
C19	29.7.08 - 2.8.08	74.50	62.93	47.49	31.66	15.83	5.40
C20	20.8.08 - 22.8.08	79.20	67.32	50.49	33.86	16.93	4.96
C21	27.8.08 - 31.8.08	76.15	64.73	46.85	32.36	16.38	5.60
C22	4.9.08 - 7.9.08	74.59	63.40	47.55	30.90	15.35	5.70
Mean		**76.32**	**64.89**	**48.64**	**32.34**	**16.21**	**5.43**
Standard Deviation		**1.68**	**1.49**	**1.14**	**0.68**	**0.46**	**0.31**
Coefficient of Variation		**2.20**	**2.29**	**2.34**	**2.10**	**2.82**	**5.64**
Standard Error of Mean		**0.34**	**0.30**	**0.23**	**0.14**	**0.09**	**0.07**

F: Torque in Ashok Leyland engine (Model ALU-400), at varying loads

Percent load		**100%**	**85% of load obtained at max. power**	**75% of load obtained in (ii)**	**50% of load obtained in (ii)**	**25% of load obtained in (ii)**	**Minimum load**
Combines	**Date of test(s)**	**Torque N-m**					
C1	12.2.01 - 15.2.01	343.16	291.69	218.76	145.84	72.92	25.20
C2	3.8.01 - 8.8.01	341.58	289.34	217.76	145.17	72.59	24.83
C3	10.8.01 - 14.8.01	332.78	281.86	212.15	141.43	70.72	23.46
C4	8.9.01 - 10.9.01	324.72	273.01	207.01	138.01	69.30	20.90
C5	18.9.01 - 21.9.01	328.99	277.64	209.73	139.82	69.91	22.60
C6	2.12.02 - 4.12.02	327.96	268.77	209.07	139.38	69.69	21.54
C7	1.7.03 - 4.7.03	313.05	268.09	198.57	133.05	66.52	23.56
C8	14.7.03 - 18.7.03	319.23	275.35	209.51	135.67	67.94	22.35
C9	8.9.04 - 10.9.04	317.85	273.17	207.63	137.09	67.34	23.40
C10	27.9.04 - 29.9.04	325.08	276.32	203.24	139.16	68.98	22.54
C11	1.10.04 - 3.10.04	306.98	258.93	197.70	129.47	65.23	21.30
C12	7.10.04 – 9.10.04	325.89	277.01	209.75	133.50	69.25	25.80
C13	12.8.05 - 16.8.05	315.29	268.00	202.00	139.00	67.00	24.98
C14	24.11.06 - 30.11.06	335.38	278.07	208.80	146.54	71.67	22.10

C15	13.6.08 - 15.6.08	328.82	269.50	212.62	139.75	69.87	24.89
C16	25.6.08 - 28.6.08	324.87	276.14	207.10	138.07	69.03	22.34
C17	10.7.08 - 14.7.08	332.06	275.25	211.69	141.13	70.56	23.34
C18	21.7.08 - 26.7.08	326.92	273.88	208.41	138.94	69.47	24.19
C19	29.7.08 - 2.8.08	319.47	271.55	203.66	135.77	67.89	23.76
C20	20.8.08 - 22.8.08	345.99	294.09	218.57	149.05	73.52	24.40
C21	27.8.08 - 31.8.08	333.57	283.53	220.65	143.77	70.38	23.68
C22	4.9.08 - 7.9.08	321.11	269.94	207.71	139.47	69.44	22.65
Mean		**326.85**	**275.96**	**209.19**	**139.50**	**69.51**	**23.36**
Standard Deviation		**9.73**	**8.29**	**6.13**	**4.46**	**2.06**	**1.34**
Coefficient of Variation		**2.88**	**3.00**	**2.93**	**3.14**	**2.97**	**5.73**
Standard Error of Mean		**1.95**	**1.66**	**1.23**	**0.93**	**0.41**	**0.27**

G: Fuel consumption in Ashok Leyland engine (Model ALU-400), at varying loads

Percent load		**100%**	**85% of load obtained at max. power**	**75% of load obtained in (ii)**	**50% of load obtained in (ii)**	**25% of load obtained in (ii)**	**Minimum load**
Combines	**Date of test(s)**	**Fuel consumption l/h**					
C1	12.2.01 - 15.2.01	24.38	20.70	15.44	10.36	7.38	6.33
C2	3.8.01 - 8.8.01	25.49	21.77	16.35	10.83	7.52	6.12
C3	10.8.01 - 14.8.01	25.15	21.48	16.43	10.69	7.44	6.04
C4	8.9.01 - 10.9.01	24.35	20.67	15.42	9.90	7.37	5.97
C5	18.9.01 - 21.9.01	25.63	21.69	16.34	10.79	7.45	6.35
C6	2.12.02 - 4.12.02	24.29	20.58	15.48	10.22	7.26	6.16
C7	1.7.03 - 4.7.03	25.37	21.56	16.17	10.78	7.49	6.27
C8	14.7.03 - 18.7.03	25.34	21.44	16.15	10.77	7.58	6.48
C9	8.9.04 - 10.9.04	24.88	21.15	15.86	10.57	7.39	6.36
C10	27.9.04 - 29.9.04	25.03	21.28	15.96	10.64	7.32	6.22
C11	1.10.04 - 3.10.04	25.74	21.78	16.41	10.94	7.97	6.39
C12	7.10.04 – 9.10.04	25.06	21.30	15.98	10.55	7.33	6.13

C13	12.8.05 - 16.8.05	24.98	21.23	15.92	10.42	7.61	6.59
C14	24.11.06 - 30.11.06	25.90	22.32	16.51	11.21	8.05	7.03
C15	13.6.08 - 15.6.08	24.78	21.12	15.80	10.53	7.47	6.37
C16	25.6.08 - 28.6.08	25.12	21.19	16.01	10.68	7.34	6.14
C17	10.7.08 - 14.7.08	24.92	21.18	15.89	10.59	7.60	6.70
C18	21.7.08 - 26.7.08	24.95	21.21	15.91	10.60	7.30	6.20
C19	29.7.08 - 2.8.08	25.68	22.13	16.37	10.91	8.02	7.00
C20	20.8.08 - 22.8.08	25.16	22.09	16.04	10.59	7.35	6.24
C21	27.8.08 - 31.8.08	25.28	21.49	16.22	10.74	7.37	6.31
C22	4.9.08 - 7.9.08	24.04	20.83	15.63	10.19	7.19	6.14
Mean		**25.07**	**21.37**	**16.01**	**10.61**	**7.49**	**6.34**
Standard Deviation		**0.49**	**0.47**	**0.33**	**0.28**	**0.24**	**0.23**
Coefficient of Variation		**1.96**	**2.19**	**2.04**	**2.65**	**3.18**	**3.62**
Standard Error of Mean		**0.10**	**0.09**	**0.07**	**0.06**	**0.05**	**0.06**

H: Specific fuel consumption in Ashok Leyland engine (Model ALU-400), at varying loads

Percent load		**100%**	**85% of load obtained at max. power**	**75% of load obtained in (ii)**	**50% of load obtained in (ii)**	**25% of load obtained in (ii)**	**Minimum load**
Combines	**Date of test(s)**	**Specific fuel consumption g/kW-h**					
C1	12.2.01 - 15.2.01	267.6	267.3	264.2	267.6	381.2	1034.6
C2	3.8.01 - 8.8.01	267.0	268.2	270.2	273.4	370.6	1035.4
C3	10.8.01 - 14.8.01	273.1	274.4	279.9	273.1	380.3	996.7
C4	8.9.01 - 10.9.01	270.1	273.2	268.3	258.4	397.3	999.2
C5	18.9.01 - 21.9.01	268.1	266.9	268.1	272.9	366.7	1011.7
C6	2.12.02 - 4.12.02	268.1	267.3	268.1	265.4	384.3	1030.7
C7	1.7.03 - 4.7.03	271.0	271.0	271.0	271.0	376.5	997.0
C8	14.7.03 - 18.7.03	273.9	272.6	273.8	274.7	385.5	991.1
C9	8.9.04 - 10.9.04	278.2	273.8	278.2	278.1	388.7	1053.9
C10	27.9.04 - 29.9.04	274.1	278.1	274.2	274.2	372.5	996.6

C11	1.10.04 - 3.10.04	289.8	288.4	289.8	289.8	422.2	1080.4
C12	7.10.04 – 9.10.04	269.1	269.1	269.2	266.6	370.5	990.2
C13	12.8.05 - 16.8.05	272.7	272.6	273.1	267.6	390.9	1016.7
C14	24.11.06 - 30.11.06	273.6	277.4	272.5	282.0	400.1	1047.5
C15	13.6.08 - 15.6.08	269.2	270.0	269.3	269.2	375.1	1114.9
C16	25.6.08 - 28.6.08	274.6	272.5	274.5	274.6	377.5	992.0
C17	10.7.08 - 14.7.08	266.3	266.3	264.7	266.3	382.1	997.4
C18	21.7.08 - 26.7.08	265.4	265.4	266.0	265.2	365.4	999.2
C19	29.7.08 - 2.8.08	285.6	291.4	285.6	285.5	419.7	1074.0
C20	20.8.08 - 22.8.08	263.2	271.9	263.2	259.1	359.7	1042.3
C21	27.8.08 - 31.8.08	275.0	275.1	286.8	275.0	372.8	993.5
C22	4.9.08 - 7.9.08	267.0	272.2	272.3	273.2	388.1	997.5
Mean		**271.94**	**272.96**	**272.86**	**271.95**	**383.08**	**1022.39**
Standard Deviation		**6.33**	**6.50**	**7.28**	**7.62**	**13.28**	**34.64**
Coefficient of Variation		**2.33**	**2.38**	**2.67**	**2.80**	**3.46**	**3.39**
Standard Error of Mean		**1.27**	**1.30**	**1.46**	**1.52**	**3.18**	**6.93**

I: Performance of Ashok Leyland engines (Model ALU-400) in maximum power test (Two hours)

Combines	Date of test(s)	Speed (rpm)		Power (kW)		Torque (N-m)		Fuel consumption (l/h)		Specific fuel consumption (g/kW-h)	
		Normal	Part throttle	Normal	Part throttle	Normal	Part throttle	Normal	Part throttle	Normal	Part throttle
C1	12.2.01 - 15.2.01	2360	1552	75.34	57.40	324.35	369.2	25.70	16.44	269.6	237.7
C2	3.8.01 - 8.8.01	2280	1550	79.10	56.71	317.13	378.3	23.94	16.20	262.7	237.5
C3	10.8.01 - 14.8.01	2350	1558	76.10	55.60	295.93	352.0	24.50	15.80	284.4	235.3
C4	8.9.01 - 10.9.01	2270	1602	74.80	56.70	329.13	367.0	25.39	16.40	269.2	240.5
C5	18.9.01 - 21.9.01	2258	1640	78.11	57.80	316.92	364.8	23.53	17.20	260.1	247.3
C6	2.12.02 - 4.12.02	2265	1625	75.10	58.10	302.02	364.7	23.35	17.09	270.5	244.8
C7	1.7.03 - 4.7.03	2295	1570	77.17	57.30	300.57	364.7	25.10	16.20	278.6	234.2
C8	14.7.03 - 18.7.03	2286	1592	75.95	56.40	306.77	354.3	25.30	16.50	280.4	242.3
C9	8.9.04 - 10.9.04	2375	1651	74.10	58.25	302.15	337.0	24.50	15.96	270.9	227.5

C10	27.9.04 - 29.9.04	2290	1601	75.25	60.90	318.33	369.6	25.47	17.25	277.3	235.1
C11	1.10.04 - 3.10.04	2305	1601	73.50	57.90	310.50	362.2	24.72	16.07	273.2	230.3
C12	7.10.04 – 9.10.04	2275	1570	77.25	57.80	312.53	367.2	24.59	17.50	265.3	251.8
C13	12.8.05 - 16.8.05	2250	1602	75.90	56.30	310.83	351.5	24.00	15.60	272.2	230.5
C14	24.11.06 - 30.11.06	2234	1625	78.13	57.60	309.21	353.5	25.30	16.40	280.6	236.3
C15	13.6.08 - 15.6.08	2251	1650	76.45	56.90	324.70	362.8	24.94	17.30	270.8	252.2
C16	25.6.08 - 28.6.08	2271	1580	75.30	57.20	326.17	374.2	25.39	17.40	271.1	252.9
C17	10.7.08 - 14.7.08	2300	1620	77.53	57.50	314.04	379.7	25.48	16.13	279.0	232.7
C18	21.7.08 - 26.7.08	2303	1651	78.40	58.30	302.43	353.0	24.30	17.46	276.3	248.4
C19	29.7.08 - 2.8.08	2300	1622	74.50	58.50	298.67	360.8	25.40	17.40	283.6	246.2
C20	20.8.08 - 22.8.08	2202	1640	79.10	58.10	318.47	355.0	23.90	17.60	270.3	251.7
C21	27.8.08 - 31.8.08	2295	1610	76.25	57.30	300.57	364.7	24.30	16.20	279.3	234.9
C22	4.9.08 - 7.9.08	2250	1620	74.70	57.60	316.77	356.9	25.25	17.30	280.6	249.4
Mean		**2283.41**	**1606.28**	**76.27**	**57.51**	**311.74**	**364.40**	**24.74**	**16.78**	**273.91**	**240.89**
Standard Deviation		**38.09**	**31.75**	**1.62**	**1.09**	**9.74**	**8.53**	**0.70**	**0.59**	**6.60**	**8.10**
Coefficient of Variation		**1.67**	**1.98**	**2.13**	**1.89**	**3.12**	**2.61**	**2.81**	**3.16**	**2.41**	**3.36**
Standard Error (mean)		**8.10**	**6.76**	**0.32**	**0.23**	**2.07**	**2.04**	**0.15**	**0.15**	**1.32**	**1.62**

J: Performance of Ashok Leyland engines (Model ALU-400) in five hours rating test (High Ambient)

Combines	Date of test(s)	Engine loaded to 90% of maximum power					Engine loaded to maximum power				
		Speed (rpm)	Power (kW)	Torque (N-m)	Fuel consumption (l/h)	Specific fuel consumption (g/kW-h)	Speed (rpm)	Power (kW)	Torque (N-m)	Fuel consumption (l/h)	Specific fuel consumption (g/kW-h)
C1	12.2.01 - 15.2.01	2328	68.75	291.9	21.21	265.6	2328	75.28	324.22	25.83	279.3
C2	3.8.01 - 8.8.01	2262	70.01	305.2	21.73	257.2	2262	78.90	318.81	24.14	273.5
C3	10.8.01 - 14.8.01	2399	68.28	286.9	22.96	268.6	2399	76.20	299.21	24.30	274.2
C4	8.9.01 - 10.9.01	2278	67.14	287.0	22.10	272.7	2278	74.60	323.78	25.39	282.0
C5	18.9.01 - 21.9.01	2278	71.10	279.0	20.94	244.0	2278	79.10	309.94	23.53	256.5
C6	2.12.02 - 4.12.02	2236	67.59	287.0	21.17	249.5	2236	75.10	303.80	23.25	259.5
C7	1.7.03 - 4.7.03	2339	69.72	279.5	22.60	265.6	2339	77.47	298.51	25.30	270.6
C8	14.7.03 - 18.7.03	2378	68.89	276.3	22.30	268.2	2378	76.65	296.46	25.30	277.5

C9	8.9.04 - 10.9.04	2337	66.60	281.7	22.82	263.9	2337	74.11	305.02	24.50	273.9
C10	27.9.04 - 29.9.04	2298	67.91	293.4	22.87	269.0	2298	75.45	313.07	25.27	277.5
C11	1.10.04 - 3.10.04	2325	66.33	291.5	21.70	270.0	2325	73.70	305.77	24.82	279.0
C12	7.10.04 – 9.10.04	2288	69.53	300.9	21.87	260.6	2288	77.25	316.52	24.69	268.8
C13	12.8.05 - 16.8.05	2330	67.77	289.3	22.90	260.0	2330	75.30	307.16	24.00	269.1
C14	24.11.06 - 30.11.06	2318	70.32	285.6	23.20	263.3	2318	78.13	298.00	25.30	268.3
C15	13.6.08 - 15.6.08	2256	68.81	304.5	21.56	259.6	2256	76.45	322.28	24.74	268.1
C16	25.6.08 - 28.6.08	2328	68.04	296.1	23.80	269.8	2328	75.60	316.54	25.39	278.2
C17	10.7.08 - 14.7.08	2340	69.51	292.9	23.56	264.8	2340	77.23	308.67	25.28	271.2
C18	21.7.08 - 26.7.08	2318	70.56	287.7	21.56	253.2	2318	78.40	297.59	24.70	261.0
C19	29.7.08 - 2.8.08	2329	66.69	280.8	23.12	277.2	2329	74.10	294.95	25.40	284.0
C20	20.8.08 - 22.8.08	2313	71.01	282.7	23.50	244.2	2313	78.90	301.95	23.20	253.6
C21	27.8.08 - 31.8.08	2339	68.81	279.5	22.60	272.1	2339	76.45	297.69	25.30	278.2
C22	4.9.08 - 7.9.08	2350	67.41	282.5	22.30	271.1	2350	74.90	299.23	25.25	279.3
Mean		**2316.68**	**68.80**	**288.27**	**22.38**	**277.21**	**2316.68**	**76.33**	**307.24**	**24.77**	**276.79**
Standard Deviation		**38.80**	**1.78**	**8.17**	**0.83**	**9.19**	**38.80**	**1.67**	**9.48**	**0.75**	**8.42**
Coefficient of Variation		**1.67**	**2.58**	**2.83**	**3.71**	**3.11**	**1.67**	**2.18**	**3.09**	**3.02**	**3.04**
Standard Error (mean)		**8.26**	**0.38**	**1.63**	**0.18**	**1.84**	**8.26**	**0.33**	**1.92**	**0.16**	**1.68**

APPENDIX-IV

Cost estimation of engine testing at combine testing institute.

Purchasing cost of testing bed=Rs. 751049 (purchased in 1988)

Present cost of testing-bed= Rs. 2850000 (approximately)

Useful life = 10 years

Purchasing cost of generator = Rs. 34500

Useful life = 10 years

Cost estimation

Fixed costs:

I. Testing set-up operating cost:

i) Depreciation:

Depreciation (D) = (P-S)/L

= (Rs 751049- Rs 37552.45)/10

D = Rs. 71349.65/year

= Rs. 195.47/day

= Rs. 195.47*15

Where; D = depreciation cost, average per year,

P = purchase price of machine

S = salvage vale of the machine (taken as 5% of purchase price)

L = Useful life of the machine in years

For fifteen days, D = Rs. 2932.05 (As minimum fifteen days are required for the testing)

ii) Interest rate:

I = (P+S)/2x (i/100) Assume, i=12%

= (Rs 751049+ Rs 37552.45)/2x12/100

= Rs 47316.08 year

For fifteen days, I = Rs. 1944.49

iii) Insurance and taxes:

Take 2% of average purchase price, (A) = 2% of (P+S)/2

A = 2% of (Rs 751049+ Rs 37552.45)/2

For fifteen days, A = Rs. 324.8

iv) Housing:

Take 1.5% of average purchase price

= 1.5% (Rs.7510149+ Rs.37552.45)/2

For fifteen days = Rs. 243.06

II. Generator Set

i) Depreciation:

D = (Rs.34500 - Rs.1725)/10

= Rs. 3277.5/year

= Rs. 8.77/days,

For fifteen days, D = Rs. 134.69

ii) Interest:

I = (P+S)/2 x i/100

Assume, i=12%

I = (Rs.34500 + Rs.1725)/2 * (12/100)

I = Rs. 2173.5/year,

For fifteen days, I = Rs. 89.32

iii) Insurance and taxes:

Take 2% of average purchase price (A)

A = 2% of (P+S)/2

A = Rs. 362.25/year,

For fifteen days = Rs. 14.88

iv) Housing:

1.5% of average purchase price (A)

= 1.5% (34500-1725)/2

= Rs. 271.68/year,

For fifteen days, Rs. 11.16

Total fixed cost: Fixed cost of testing bed + Fixed cost of generator

Fixed cost = Rs. 5444.40 + Rs. 250.05

= Rs. 5694.45

Variable Cost

A) Fuel used in testing the engine

Type of test	**Duration of test**	**Date**	**Fuel used (Litre)***	**Cost (Rs.)**
Varying speed test	11:35-13:30 (1 hr. 55 min.)			
1. Natural ambient	10:20-13:30 (2 hrs. 10 min.)	06.03.09	44.02	1540.7
2. High ambient		07.03.09	54.31	1900.85
Max. power test	13:35-15:35 (2 hrs.)	06.03.09	58.65	2052.75
Varying load test	15:45-17:45 (2 hrs.)	06.03.09	48.54	1698.92
Five hours rating test				
1. 90% max. output	10:35-14:35 (4 hrs.)	08.03.09	109.88	3845.80
2. Load corresponding to max. power	14:45-15.45 (1 hr.)	08.03.09	28.89	1011.50
		Total	344.29	12050.50
Fuel used in generator, operating for 13 hrs.			45.00	1575.00
		Total	389.29	13625.50

* Rs. 35/- per litre

B) Oil used:

Take, 3% of total fuel used

Oil used = Fuel used x (3/100)

= 389.29 x (3/100)

= 11.67 litre

Cost = Rs. 2334

C) Repair and maintenance cost

i). For testing set-up

TAR = 0.120 x $(X)^{1.5}$ = 0.120x $(10)^{1.5}$

Where, TAR = total accumulated repair cost divided by purchased price of the machine expressed as percentage

X = 100 times the ratio of the accumulated hours of use of the wear out life.

= 0.120x31.62=3.75% of average purchase price

= 3.75% of (Rs. 751049+ Rs. 37552.45)/2 = (3.75 x Rs. 394300.725)/100

= Rs. 14786.27/year

= Rs. 40.51/day

For fifteen days = Rs. 607.65

ii). For generator:

TAR = 0.120 x $(10)^{1.5}$ = 3.75% of average purchase price

= 3.75% of (Rs. 34500+ Rs. 1725)/2 = (3.75x Rs. 18112.5)/100

= Rs. 679.21/year

For fifteen days = Rs. 27.91

D) Wages and labor charges

Man power used in testing the engine (for 15 days)	**Wages/charges (Rs.)**
Assist Engineer (one)	14000
Technical Assistant (one)	11000
Technician (one)	7000
Mate (two)	12000
Helper (two)	8000
Total Total	52000
Man power used in preparation of test report (15 days)	
Senior testing engineer (one)	16000

Assist. Engineer (one)	14000
Technical Assistant (one)	11000
Total	41000
Total wages and labor charges	93000

Total variable cost: A+B+C+D = Rs. 13625.50 + Rs. 2334 + Rs. 93000 + Rs. 635.56

= Rs. 109596.06

Total cost of operation = Fixed cost + Variable cost

= Rs. 5694.45 + Rs. 109596.06

= Rs. 115290.51

Overhead charges:

Take, 20% of total cost of operation

= 20% of Rs.115290.51

= Rs. 23058.10

Total cost of testing of engine = Fixed costs + Variable cost + Overhead charges

= Rs. 5694.45 + Rs. 109596.06 + Rs. 23058.10

= Rs. 138348.61

ABSTRACT

Title of Thesis	:	**Comparative study of performance parameters of combine harvesters**
Full Name of the Degree Holder	:	**DINESH KUMAR**
Admission Number	:	2007AE86M
Title of the Degree	:	**Master of Technology**
Name of Discipline	:	Farm Power and Machinery

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Degree Awarding University	:	CCS Haryana Agricultural University Hisar-125 004 (Haryana), India
Year of Award of Degree	:	2010
Major Subject	:	Farm Power and Machinery
Total Number of Pages in Thesis	:	40+ii
Number of Words in Abstract	:	497
Key words	:	**Ashok Leyland engine, Kirloskar engine, testing parameters, power, torque, fuel consumption, specific fuel consumption**

(An abstract of the thesis submitted to CCS Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of Master of Technology in Farm Power and Machinery)

The investigation was carried out on the comparative study of performance parameters of combine-harvesters. The main objectives of the study were to compare the existing engine performance data with the results obtained from the test report released by testing institutes and to study the extent of labor, fuel and cost involved in testing the engine. Kirloskar engine (Model 6R-1080) used in three different makes of combine harvesters, was tested three times with combines at NRFMT&TI (Hisar) during different years. Although this model of engine was already tested at A.R.A.I.(Pune) as per the BIS codes. The average mean values of engine performance data, tested at NRFMT&TI (Hisar) were compared with the engine performance obtained at A.R.A.I. (Pune). Ashok Leyland engine (Model ALU-400) used in 22 different makes of combine harvesters was tested 22 times with combines at NRFMT&TI (Hisar) in different years. The testing performances of Ashok Leyland engines used in 22 different combines were compared on the basis of mean values of performance data. Four testing performance parameters of engine viz. power (kW), torque (N-m), fuel consumption (l/h) and specific fuel consumption (g/kW-h) were selected to compare the engine performance, as given in the engine test report of the combine harvester. Mean values of all the performance parameters in Kirloskar engines (Model 6R 1080) obtained under varying speed and varying loads in different testing institutes were similar. The percentages of variations in all the testing parameters were found to be very low in varying speed and varying load test. There was no significant effect on performance parameters of the engine tested during different periods and different testing institutes. So, there was unnecessary expenditure in conducting testing of Kirloskar engines (Model 6R 1080) again at combine testing institute with no fruitful contribution to the results already obtained at A.R.A.I.(Pune). Performance of all testing parameters in Ashok Leyland engines (Model ALU-400) obtained under varying speed and varying load tests were also similar. There was no significant effect on engine performance parameters in varying speed and varying load tests in engines tested during different periods, at NRFMT&TI (HISAR). Performance of all the testing parameters in Ashok Leyland engines (Model ALU-400) obtained in maximum power test and five hours rating test were similar. The percentages of variations in all the performance parameters were found to be very low in maximum power test and five hours rating test. There was non-significant difference in engine performance parameters under maximum power test and five hours rating test of engine tested during different periods, at NRFMT&TI (HISAR). Total cost of complete testing of engine of combine harvester, at NRFMT&TI (Hisar) observed was Rs. 1.38 lacs. Retesting of Kirloskar and Ashok Leyland engines used on combine harvesters, resulted in extra expenditure of Rs.1.38 lacs on testing and also unavoidable delays. Therefore this practice needs to be reviewed at the testing institute level to economize the cost of combine testing. Retesting of engines of combines at testing institutes may be discontinued to save time, labor, energy and money.

MAJOR ADVISOR **SIGNATURE OF THE STUDENT**

HEAD OF THE DEPARTMENT

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I, **Dinesh Kumar,** Admn. No. **2007AE86M** undertakes that I give copy right to the CCS HAU, Hisar of my thesis entitled **“Comparative study of performance parameters of combine harvesters”**.

I also undertake that, patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCSHAU, Hisar.

(Dinesh Kumar)