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UNIDO/IO
ENGLISH
FEBRUARY 1986

15417

India.

APPLICATION OF ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES, IIP, DEHRA DUN

DP/IND/82/001

INDIA

FINAL REPORT *

Prepared for the Government of India,
by the United Nations Industrial Development Organization,
acting as Executing Agency for the United Nations Development Programme

Based on the work of Mr. Stanislaw Radzimirski
Expert in Combustion Studies in SI Engines
under the post 11-03

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

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C O N T E N T S

ABSTRACT

The title of the post was "Expert in Combustion Studies in S.I. Engines" in the Project IND/82/001, Application of Alternative Fuels for Internal Combustion Engines", duration of the mission- 3 months beginning from 3rd December, 1985, assisted organisation- Indian Institute of Petroleum, Dehra Dun, India. The present mission was a continuation of the six months' mission held in the first half of 1985.

The programme of author's works comprised:

i) development of two-stroke engines for neat methanol operation,

ii) development of systems for the reduction of charge losses into the exhaust in two-stroke engines,

iii) training of IIP technical personnel in S.I. engine design, testing and development.

The performances of Bajaj scooter two-stroke engines converted for neat methanol operation during the first mission were further improved, in particular fuel consumption was considerably reduced. Studies of the abnormal combustion in the engine and road tests of the scooter were continued. The inlet/scavenging system developed and patented during the first author's mission was improved with regard to its efficiency. Another system for the reduction of fuel losses was devised, its functional model fabricated and tested on the engine bench. This system consisting in selective exhaust gas extraction combined with introduction of the extracted gas in-to the transfer ports(called Selective Exhaust Gas Recirculation) proved efficient in reducing the hydrocarbons emissions. The detailed programme of works to be carried out at IIP on both the methanol engines and the systems for the reduction of fuel losses was worked out.

The training of IIP technical personnel took place in the form of consultancies, group discussions and on-the-job basis.

I. INTRODUCTION

The title of the post was "Expert in Combustion Studies in S.I. Engines " DP/IND/001/11-03/31.9.B in the project IND/82/001 „Application of Alternative Fuels for Internal Combustion Engines", duration of the mission-3 months beginning from the 3rd December, 1985, duty station- Dehra Dun, India, assisted organization- Indian Institute of Petroleum.

The present mission was a continutation of the 6 month' mission held by the author in the first half of 1985. Its main purpose was to develop and establish suitable technologies for the use of methanol in two-stroke spark-ignited engines for two-and three- wheelers, in particular to continue works started earlier in keeping with the recommendations given in "Final Report " dated June, 1985 and duties of the expert outlined in "Job Description" DP/IND/82/001/11-03/31.9.B revised 27 September, 1985.

The duties laid down in the above mentioned"Job Description" were as follows:

"The expert will be required to assist the Indian Institute of Petroleum (IIP) in the following specific jobs:

1) Planning of the research activities related to experimental and analytical studies on two-stroke S.I. engines. This would include design and development of suitable systems for fuel introduction, modification of other engine systems and guidance with regard to combustion and emission studies on 2-stroke engines from the point of view of alcohol fuel atilization. Also to assist in development of techniques/methods to evaluate comburation requirements, delivery ratio, trapping efficiency etc.

ii) Training of IIP engineers on the above subject through lectures and group discussions. The expert will be also expected to prepare a final report, setting out the findings of the mission and recommendations to the Government on further action which might to be taken"

II. WORK PROGRAMME

On the basis of expert duties outlined in "Job Description ", the recommendations given in the author's"Final Report " of the previous mission, author's findings after the arrival in the field and IIP requests resulting from the programme of the project works, the following programme of author's works was laid down (see also the author's "Preliminary Report", Annex 1)

i) Neat methanol application in two-stroke engines,
ii) Reduction of fresh charge losses in two-stroke engines,
iii) Training of IIP project engineers in engine design, testing and development, in particular on-the- job basis, and consultancy for IIP and Indian industry in the area of two-and four-stroke SI engines and alternative fuels(depending on the request).

The outlined work programme was fulfilled despite difficulties in carrying out engine modifications and experiments resulting in the first place from frequent break downs of the equipment (gas analysers, dynamometers etc), limited facilities of IIP workshop and power cuts.

III. NEAT METHANOL APPLICATION IN TWO-STROKE ENGINES

1. STATUS OF WORKS

During the author's first mission at IIP three two-stroke engines of the most popular Indian scooter make Bajaj 150 were converted for neat methanol operation and subjected to comprehensive tests on the engine bench, lubrication tests and fuel tests. The detailed description of the carried out works and their results are given in the author's "Final Report" (June,1985) in Chapter IV and Annex 3,4/1,4/2,5 . The introduced modifications were minor(fuel system,spark plug, settings) and they by no means disturb the main advantage of two-stroke engines i.e. simplicity. The introduced changes in the carburettor floats were treated as temporary for testing until proper floats would be developed. After the author's departure IIP purchased teflon floats from Italy and fixed them in the engines.

These floats have proved fully resistant to methanol. The engines were run on a fuel composed of 90% vol. methanol and 10% vol. petrol. Castor oil(2%) was used for lubrication. The main features of the converted engines as compared with those running on ordinary petrol were:

- higher engine power at wide open throttle,
- better fuel economy resulting from higher thermal efficiency and leaner air-fuel mixture,
- lower carbon monoxide emissions resulting from leaner mixture,
- very satisfactory scooter driveability, cold driveability included, with the exception of cold startability which was poor at ambient temperatures below 10°C,
- higher wear of top piston rings and unsatisfactory engine cleanliness,
- the same compression ratio because abnormal combustion in methanol engines made it not possible to increase this parameter in order to improve the thermal efficiency.

The main recommendations given by the author in the "Final Report" (June, 1985) with regard to further development works on neat methanol application in small two-stroke spark-ignition engines were as follows:

i) convert at least one other two-stroke engine model for operation on neat methanol to confirm results achieved during the works on Bajaj 150 and widen the experience,

ii) study the abnormal combustion and lean operation and find suitable measures to ensure problem-free operation with higher compression ratios and leaner mixtures in order to improve fuel economy and reduce emissions,

iii) improve cold startability of methanol engines by optimising the carburattor starting system and/or fuel composition,

iv) study measures to reduce top ring wear(oils, optimization of cooling system, materials)

The problem iv) being dealt with by Mr. Edmond Vieilledent, expert in lubrication requirements of two-stroke engines, the author concentrated in his works during the present mission on items i) ,ii), iii) of the above mentioned recommendations.

2. WORKS CARRIED OUT DURING THE PRESENT MISSION

The engine model converted for neat methanol operation during the first author's mission is of design which is rarely manufactured nowadays. Its peculiarity consists in a deflector on the piston crown which was thought to increase the tendency to abnormal combustion. Therefore, it was decided to change for the design which is more common at present using components of Bajaj Chetak model(piston with convex crown, cylinder head with squish area, cylinder).

The operation variables(mixture strength, ignition timing) of the engine with the new assembly were optimised and performances tested . At the similar compression ratio, performances of this engine as compared with those of the engine with Bajaj 150 assembly(piston with deflector) were as follows:

- engine power at WOT by 3-6% higher,
- energy consumption by 5-7% lower at the same air fuel ratio (minimum BSFC was below 290 g/HPh(petrol equivalent) which is considered to be very satisfactory for a scooter engine of such a design),
- unburnt fuel concentration(as propane equivalent) by 5% lower.

The compression ratio of the new engine was then increased to 8.5 by facing the head and profiling its squish area. The performances of the engine were further improved due to higher thermal efficiency. The power at WOT rose by 4-7% and BSFC was reduced by 4-10% depending on the load and speed as compared with lower compression ratio. The minimum BSFC was 275g/HPh(petrol equivalent) at part loads which was by 17% lower at the same air fuel ratio and 25% at the optimum ratio than that of petrol engines.

At the compression ratio 8.5 the abnormal combustion, whose symptons were a knock of different intensity depending upon load, speed, air fuel ratio and ignition timing, was observed. This abnormal combustion being a factor limiting the possibility of improvement of engine thermal efficiency by increasing the compression ratio, comprehensive studies of the phenomenon were initiated. They comprised :

- measurement of the characteristic frequency of the knock,
- determination of the effect of operating variables: load, speed air fuel ratio, ignition timing on the knock intensity,
- comparison of methanol and petrol engines with regard to knock intensity under different conditions,
- measurement of the octane requirements and actual octane number of both petrol and methanol fuel under different operating conditions.

The comparison of methanol fuel and petrol in respect of knock yielded some unexpected results. In the first place it is to note that the octane properties of methanol fuels measured by conventional CFR method are significantly higher than those of used petrol. Research and Motor octane numbers of both the fuels are respectively as follows:

- methanol fuel-about 107 and 88(calculated values),
- petrol-87 and 82.

However, if was found that the actual anti-knock properties of petrol in the two stroke engine as compared with those of methanol fuel depend on engine operating conditions mainly loads, speeds and igniniton timings, under some conditions methanol fuel properties were definitely inferior to those of ordinary petrol.

In the "Final Report" dated June, 1985 the author recommended to convert one more engine model for neat methanol operation in order to extend the experience. Either of the following models was suggested:

- 150 cc Vijai scooter engine manufactured by SIL, Lucknow,
- 50 cc M 50 Bajaj motorcycle engine manufactured by Bajaj Auto Ltd, Poona.

In the meantime the production of M50 Bajab was discontinued. The experience which was expected to be accumulated with Vijai scooter engine, was being gathered with Bajaj Chetak engine (convex piston crown). In this situation it was decided to select and convert another model. Different models in the market were analysed and 50 cc TVS moped engine was chosen for further studies. The experimental bench was set up and preliminary tests were started. Steps to be taken to convert the engine for methanol operation were discussed with IIP Scientists. Works on the modification of the carburettor were started.

Tests of the scooter with a Bajaj 150 engine converted for operation on neat methanol were resumed. The lean setting of the carburettor was optimised for evaluation of driveability, fuel economy and emissions. It was confirmed that the methanol scooter was characterised by excellent fuel economy. The energy consumption was by 20-30% lower than that of the average petrol engine with a comparable, very good driveability.
The only defect of the methanol engine was poor startability at lower ambient temperature. The following measures were tested in order to overcome this defect:

- opening of the starting device before parking the scooter (this technique improved the cold startability but not to the desired level),
- injection of light petrol in the intake pipe (the startability was improved to the fully satisfactory level),

- adding lighter petrol to increase the Reid vapour pressure of the methanol petrol belnd (works have not been completed yet).

3. DIRECTIONS OF FURTHER WORKS

The works carried out during the present mission contributed to further development of two-stroke methanol engines, better understanding of working processes and differences between petrol and methanol fuel. It was found that despite its better octane properties, methanol is more prone to the knock combustion under some conditions in particular at lower loads and higher speeds than petrol. These findings are of great importance. If confirmed on other engine model, they will prove that the conventional methods of measurement of anti-knock properties on CFR engines are not suitable for the correct rating of methanol fuel behaviour in two-stroke engines. The emphasis should be placed on this problem in further IIP works. The following is a list of problems recommended for further studies in the framework of the project to improve fuel economy and reduce emissions of methanol two-stroke engines:

i) 50 cc TVS moped engine:

- study of the effect of air fuel ratio on engine performances (fuel economy, power, emissions component temperatures), effect of air (or air fuel mixture) heating on performances optimization of the ignition timing, carburetter setting;
- abnormal combustion in the methanol TVS engine, factors effecting its occurance, increase of compression ratio; comparison of petrol and methanol fuel.
- evaluation of the converted TVS engine in the moped; final optimization of settings; driveability, fuel consumption, emissions,

ii) 150 cc Bajaj scooter engine:

- recording of the pressure time history in the cylinder at part and full loads under knocking conditions: cycle to cycle variation at part loads; maximum pressure and pressure rise; all the tests with petrol and methanol fuel;

- detailed studies of differences in engine performances (power, temperatures, delivery ratio, charging efficiency, trapping efficiency) with petrol and methanol fuels in order to explain differences in anti-knock properties under different operating conditions; calculation of combustion temperatures; measures to eliminate abnormal combustion in methanol engines (water adding, exhaust gas recirculation)
- evaluation of scooter performances with Bajaj Chetak assembly,
- continuation of works on the optimisation of engine setting (starting device jet size) and fuels (higher Reid vapour pressure) with regard to cold startability; modelling of starting process in two-stroke engines;
- exhaust odour; aldehydes content(continuation of the initiated work in cooperation with Roorkee University),

Moreover, it is recommended to carry out fundamental studies of hydrocarbons and methanol ignition in constant volume bombs according to the programme worked out by UNIDO expert, Dr. De Soete in order to better understand and explain the causes of abnormal combustion.

IV. REDUCTION OF FRESH CHARGE LOSSES

A considerable reduction of fresh charge losses into the exhaust to improve the fuel economy and decrease the emissions of unburnt fuel is a precondition for the acceptance of two-stroke engines, in particular their methanol versions. During the previous author's mission an original, new intake/scavenging system was devised, developed and tested. It was found that it improved the fuel consumption by 5-12% and reduced unburnt fuel emissions by 30-40% depending on the load and speed. The patent application was submitted to Indian Patents Office for the engine with the developed system through CSIR.

The detailed description of the system and results of the carried out works were given in author's "Final Report" dated June, 1985 in Chapter V and Annexes 6/ ,6/2. Further development works on the invented system were carried out during the present mission. Their objective was to further improve the efficiency of the system. It was found that the difference between expected improvement in fuel losses calculated on the basis of the scavenging model and actual improvement rose with the increased flow rate through the secondary circuit, though, in absolute figures the reduction was higher at higher flow rates. This relative drop in efficiency was attributed to the mixing of air and fresh charge on account of too small volume of transfer ports. Consequently it was decided to increase this volume. A simple way of its increasing was devised and the engine with bigger transfer ports fabricated. Preliminary tests carried out during the author's stay showed that the engine was working properly. Some further improvement in fuel economy and hydrocarbons emissions was achieved. More tests are required to confirm the achieved results. Parallely, works on flow controls for the developed system were carried out. Evaluation tests of the system with automatic flow controls are going to start in March.

Studies on another new concept of intake/scavenging system in two-stroke engine were initiated. It consists in a combination of selective exhaust gas extraction from the exhaust system points where unburnt full concentration is high and its introduction into the transfer ports through a secondary circuit similar in its design to the circuit used in the earlier developed and patented system. The system was called "Selective Exhaust Gas Recirculation"(SEGR). The functional model of the engine based on this concept was designed and fabricated. Tests carried out on the engine bench showed that the hydrocarbons concentration in the recirculated exhaust gas was upto three times higher than the average in the exhaust system which confirmed the rightness of the premise on which the concept of SEGR was based.

The new intake/scavenging system proved efficient. The fuel consumption was reduced by up to 10% and hydrocarbons emissions upto 35% (at higher loads)

It is recommended to concentrate further works on the following problems in order to optimise both the systems:

i) basic studies of the scavenging process in two-stroke engines:

- measurement of the instantaneous exhaust gas composition (hydrocarbons, oxygen, carbon monoxide, carbon dioxide) in the exhaust port versus crankangle (sample extraction by means of gas sampling equipment Sokken GSD-01 supplied by UNIDO),
- determination of the exhaust gas mass flow rate in the exhaust port and fresh charge flow rate in the transfer port, determination of the mass flow rate of the lost fresh charge in the exhaust port,

ii) system with the introduction of air into transfer ports:

- continuation of the works on the effect of transfer port volume on fuel economy and unburnt fuel emissions,
- mixing of the charge and air in the transfer port during the inlet process (measurement of hydrocarbons content in the charge comprised in the transfer ports and extracted by means of gas sampling equipment Sokken GSD-01) and optimization of the position of reed valves,
- continuation of the works on the flow controls,
- evaluation of an engine with the system on the scooter,

iii) System with selective exhaust gas recirculation(SEGR):

- mixing of the exhaust gas in the exhaust pipe; profile of hydrocarbons concentration along the exhaust pipe; optimization of the position, size and shape of the retracting probe;
- hydrocarbons content in the recirculated gas versus recirculation ratio, load, speed,
- continuation of the works on the cause of relatively low improvement at high recirculation ratio,

- application of the system in methanol two-stroke engines in order to suppress the abnormal combustion.

V. TRAINING OF IIP TECHNICAL PERSONNEL

The training of IIP technical personnel in the area of spark-ignition engines was continued during the present mission. As during the first mission, it took place in the form:

- consultancy on different works being carried out at IIP,
- informal discussions,
- on-the -job basis.

The main subjects of consultancies were as follows:

- conversion of a truck diesel engine into the neat methanol engine; carburetted methanol engine:

  selection and optimization of the carburettor, improvement of mixture distribution between the cylinders, measurement of maldistribution; methanol engine with fuel injection: advantages and defects as compared with carburetted one; methanol vapour spark-ignited engine: optimization of the fuel system and evaporator, mixture distribution, mixture strength and ignition timing setting,
- Indian driving cycle for emissions measurement.

The principal training took place as on-the- job training carried out during the works on the development of the methanol engines(ChapterIII) and the reduction of fuel losses(ChapterIV). The main subjects of the training were:

- Exhaust gas composition as a tool for studying the combustion process,
- validation of exhaust gas composition results,
- techniques/methods for evaluation of particular processes and octane requirements in two-stroke engines,

- evaluation of startability, road performances of two-wheelers ;road load simulation on the chassis dynamometer.

The attention of IIP technical personnel was drawn to unsatisfactory accuracy of many instruments (gas analysers, dynamometers, temperature indicators) and consequently poor accuracy and repeatability of test results.

VI. SUMMARY

During the present mission the works were continued on two following subjects:

- neat methanol two-stroke engines,
- reduction of fuel losses into the exhaust in two-stroke engines.

in keeping with the recommendations given in the author's "Final Report" dated June, 1985. These works resulted in further development of neat methanol engines, in particular improvement in fuel (energy) consumption. The minimum fuel consumption of the developed Bajaj methanol engine was reduced to 290 g/HPh(petrol equivalent) which is considered satisfactory for this category of power plants. One of the main findings was that actual anti-knock properties of methanol in two-stroke engines are not as high as it might be expected on the basis of its octane rating.

The works on a new system for the reduction of fuel losses consisting in selective exhaust gas extraction combined with its introduction into the transfer ports were initiated. This system proved efficient in reducing hydrocarbons emissions. The system invented and patented during the first author's mission was further developed and its efficiency improved. Altogehter IIP has got two new, original, efficient systems for the reduction of fuel losses.

The detailed and comprehensive recommendations with regard to the whole project " Application of Alternative Fuels for Internal Combustion Engines", priorities of particular applications of methanol, in particular in two-wheelers, upgradation of the standard of IIP Engines Laboratory and training of the technical personnel were given in the author's "Final Report" from the first mission. All these recommendation hold and therefore the author does not consider it to be necessary to repeat them in this report.

The author recommends to continue the works on heat methanol engines and on the reduction of fuel loss in accordance with the programmes worked out together with IIP Scientists (see Chapter III and IV of the present report), so that it would be possible to sum them up and draw final conclusions during the third phase of author's mission which is expected to start in November/December 1986.

The comprehensive technical reports will be prepared by IIP scientists after the completion of particular works.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Sudhir Singhal-Project Coordinator for the assistance received from Indian Institute of Petroleum during the present mission. Very satisfactory cooperation of scientists, project engineers and administrative personnel of Engines Laboratory is also acknowledged

Annex. 1

January 2, 1986.
ENGLISH.

PROJECT TITLE:

APPLICATION OF ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES. IND/82/001.

POST TITLE:

EXPERT IN COMBUSTION STUDIES IN SI ENGINES.
DP/IND/82/001/11-03/31.9.8.

PRELIMINARY REPORT

by

DR. STANISLAW RADZISZEWSKI
Assisting Indian Institute of Petroleum,
Dehradun, India.

INTRODUCTION

The title of the post is "Expert in Combustion Studies in S.I. Engines" DP/IND/82/001/11-03/31.9.B in the project IND/82/001 "Application of Alternative Fuels for Interna l combustion Engines", duration of the mission 3 months, beginning from 3rd December,1985, duty station - Dehra Dun/India/ assisted organisation - Indian Institute of Petroleum.

The duties of the expert outlined in job description DP/IND/82/001/11-03/31.9.B/revised 27.09.1985/ are as follows:

i) design and development of suitable systems for fuel introduction, modification of other engine systems and guidance with regard to combustion and emissions studies on two-stroke spark-ignition engines from the point of view of alcohol utilisation.

ii) development of techniques and methods to evaluate carburation requirements, delivery ratio, trapping efficiency etc.

iii) providing technical help in solving related problems from industry.

iv) training of IIP engineers on the above subject through lectures and group discussions.

The present mission as a continuation of the 6 month mission held by the writer in the first half of 1985. The main objective of the present mission is to get on with works started earlier in keeping with recommendations given in Final Report" dated June,1985 and with "Job descriptions". On the

basis of the writer's findings after the arrival in the field and IIP requests, the programme of works given below has been outlined. The emphasis is placed on two following subjects, which are considered to be important for the project:

i) further development of two-stroke engines for operation on neat methanol.

ii) reduction of fresh charge losses in two-stroke engines.

B. PROGRAMME OF WORKS

1. Development of two-stroke engines for operation on neat methanol.

- Conversion of another engine model for the operation of neat methanol.
- Optimisation of converted engine
- Improvement of fuel economy of methanol engines.
- Study of causes of abnormal combustion in methanol engines.
- Measures to reduce effects of abnormal combustion.
- Evaluation of a methanol scooter in the field under winter conditions.
- Improvement of cold startability of methanol engines.

2. Reduction of fresh charge losses.

- Study of the effect of exhaust gas recirculation in particular selective extraction (fabrication of the suitable extraction system, tests on benches, modelling of the system, if required).

- Optimisation of the engine design for the system developed earlier (Chapter V of Final Report), in particular the size of transfer ports, design and fabrication of an engine with increased volume of transfer ports, tests on benches).
- Design and fabrication of an automatic flow controls for the developed system, tests on benches.

3. Training of IIP project engineers in two-stroke engine design, testing and development, in particular on-the-job basis.

4. Consultancy for IIP and Indian industry in the area of two-stroke four stroke SI engines and alternative fuels (depending on the request).

The fulfilment of this programme, in particular with regard to the fabrication of components and experimental part, depends on many factors unpredictable at present. If any difficulties arise, UNDP Office in Delhi will be notified in due course.

S. Pawlowski
2.01.1986

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