PRACTICA
FOUNDATION

IDE Rural Prosperity Initiative Micro diesel development

The Lohmann experience

A concluding document about the development of a micro diesel engine based on the Lohmann homogeneous charge compression ignition engine

Jan Nederstigt
PRACTICA foundation
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Contents

1. Introduction

This report describes the development of the 'micro diesel' engine pumpset, an engine pumpset based on the Lohmann-diesel 18cc homogeneous charge compression ignition auxiliary bicycle engine that entered the market in 1950.
In this report, the efforts of PRACTICA foundation to improve, modify, test and market the micro diesel are summarized. Focus of this report is on the collaboration with IDE within the Rural Prosperity Initiative (RPI) program.

IDE's primary program objective is to enable farmers with very small landholdings to increase their annual net income. To do this IDE facilitates organization of affordable market systems so farmers can gain access to efficient, low-cost irrigation. Together with assistance for other strategic inputs this provides opportunity for smallholders to shift part of their production from rain fed, subsistence cereal crops to higher value crops for sale in markets. In many cases, developing an irrigation supply is the farmers' starting point for their road to success. IDE concentrates its development work on locations where surface water is available or can be economically developed at the farmstead level, or where groundwater can be accessed by digging or drilling a well and it is cost effective to pump water for irrigation.
Traditionally IDE has focused on the development and marketing of manually operated pumps—rower, treadle, and rope and washer pumps being the most suitable for small-plot irrigation. Millions of small-plot farmers have used treadle pumps to lift irrigation water and significantly boost their net annual income. While the treadle pump is an effective manual pump, it takes a relay of household members about 4 hours a day to successfully irrigate a quarter hectare of crops. Observation and interviews confirm that in order to reduce the arduous labor required for manual pumping, successful small-plot farmers search for alternative ways to access water as soon as they are financially able. Many purchase and operate an engine pumpset.

Figure 1; irrigation pumpset in Bihar, India

The objective of PRACTICA foundation is to develop and introduce pro-poor technologies. This is done against the background that the technologies available on the market are either not appropriate for the context or too expensive and that there is often considerable scope for improvement. To reach this, PRACTICA analyses the context and comes with solutions that can be sustained through for example setting up local production, local capacity building and involving the local private sector. Appropriate technical solutions are either copied from other locations and, if needed, modified to fit the local context, developed from scratch or developed by downsizing or simplifying 'high-end' solutions to make them affordable.

From the two different perspectives, both IDE and PRACTICA came to the same conclusion: the need for a small engine pumpset that could fill the gap for the Indian and Bangladeshi farmers irrigating with treadle pumps who wanted to make the shift to mechanized irrigation. Those farmers would require a small, low cost engine pump set that could run on diesel fuel, offering an alternative for the large, heavy and inefficient diesel irrigation pumpsets available on the market. This formed the basis for the joint effort of the micro diesel development.

2. Micro diesel application context / need for small engine pumpset

Applying additional water to crops is general farming practice in those areas where rain is not reliable throughout the growing season or in (tropical) areas where an additional (cash) crop can be grown in the dry seasons. The economical feasibility of this irrigation practice depends on the costs of acquiring and applying the water and the financial returns, which has a link with the scale of the farming practice. For smallholder farmers in developing countries, a first step away from rain fed agriculture only is small scale and manual irrigation which may include some sort of manual pumping device like a treadle pump. A next step, which is often seen by farmers as a leap forward, is mechanized irrigation by means of an engine pumpset. Especially for smallholder farmers, the available pumpsets on the market do not necessarily meet the requirements related to field size and water quantities. In practice, this means that for those smallholder farmers the available pumpsets are:

- Too big and too heavy;
- Unnecessarily fuel-inefficient;
- Using petrol instead of the cheaper and often preferred diesel fuel or kerosene fuel;
- Too expensive (resulting in non-affordability);


Figure 2; treadle pump

Those drawbacks often hamper the shift for those farmers to mechanized irrigation, withholding them the possibilities to improve their farm revenue and make the step out of extreme poverty.

It is for this specific reason that IDE initiated the search of a small, fuel efficient and affordable diesel irrigation pumpset that could enable those farmers to make the shift to mechanized irrigation.

3. PRACTICA / IDE micro diesel development history

The search for a small, fuel efficient and affordable diesel irrigation pumpset (further referred to as 'micro diesel pumpset') by IDE included initial contacts with Gert Jan Bom[1].

[1] Gert Jan Bom is the founder of PRACTICA foundation. Early work on the micro diesel was done by Bom's company Solartec. From 2001 onward, the work on the micro diesel has been incorporated in the activities of PRACTICA .

The start

Based on the extensive work in the field of both IDE and Bom (PRACTICA) in India and Bangladesh, assumption were made about the requirements of a small diesel engine pumpset. Although the requirements were never put on paper in a structural way, the common starting point included the following:

- Target customers are treadle pump farmers shifting to mechanized irrigation;
- The engine pumpset should enable for at least doubling the land the farmer has under cultivation;
- Engine pumpset can run up to 8 hours a day;
- When replacing a treadle pump, suction is usually in the range of 3-7m;
- Fuel efficiency should be optimized;
- Price of the engine should be considerably lower than the alternative diesel pumps on the market;
- Pump should be light weight and easy to transport;

Those findings were further pointed out in a document on improved fuel efficiency of diesel irrigation pumpsets in the West Bengal Terai (India) (TERI pump book[2]) that was published around the same time.

Based on those requirements, Bom was asked to design a suitable engine, however, it was considered not feasible to develop such an engine from scratch for the available budget, which put the project on a hold. The project was revived when Bom discovered the 1950's 18ccLohmann diesel auxiliary bicycle engine. It looked feasible to convert this engine to a stationary engine that would fit the micro diesel requirements. To decide whether this was an interesting path to follow, a proof of concept was made by Bom in 2002 based on an original Lohmann engine that was coupled to a centrifugal pump. This proof of concept was shipped to India and presented to IDE India. Based on this proof of concept, it was decided to continue the development of the micro diesel.

Figure 3; early proof-of-concept of the Lohmann micro diesel pump

The plan to continue with the development of the micro diesel based on the Lohmann auxiliary engine was also based on the expectation related to power output and fuel consumption (fuel efficiency); Most of the data on power and fuel consumption has been drawn from test reports from the 1950's that are used in different articles on the Lohmann, published in different locations and different magazines[3]. The test data mentioned in those reports is not traced back to a specific company or institution. Test data as found in the articles is presented below:

[2] Bom, Gert Jan; Ibrahim Hafeez Ur Rehman; David van Raalten; Rajeshwar Mishra; Frank van Steenbergen (2002); Technology innovation and promotion in practice; pumps, channels, and wells; TATA research institute (TERI).

[3] The articles found were published directly after the Lohmann was introduced on the market and are either in the German or Dutch language.

Table 1; Lohmann engine specifications

Lohmann assumptions (figures)	
Engine weight:	5kg
Cylinder capacity	18,5cc
Bore:	28mm
Stroke:	30mm
Maximum power output	0,82HP @ 8700 RPM
Optimum fuel efficiency:	420g/HPh @ 8000 RPM (=563g/kWh)
Maximum torque:	2,9Nm @ 3000 RPM
Compression ratio:	8,5:1 - 125:1 (variable); 13:1 - 17:1 for normal operation

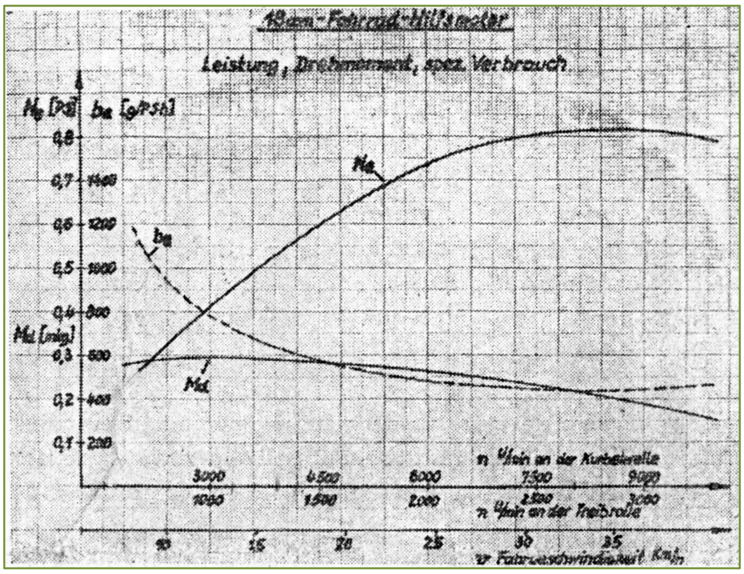


Figure 4; performance curve of the Lohamann engine from the 1950's

The early work 2000 - 2006)

Work on the micro diesel was continued by PRACTICA with small funds from different sources and major investments by Solartec and PRACTICA. Work done till the end of 2006 include:

- Preliminary testing done on an original Lohmann auxiliary bicycle engine, connected to a centrifugal pump in the Netherlands and in India (proof of concept);
- One prototype of micro diesel stationary engine produced based on parts from an original and new Lohmann auxiliary bicycle engine;
- Contacts established with the Hangzhou University where 1 prototype was being built at the time of the start of the RPI project;
- Contacts established with potential producers in India and part producers in China;

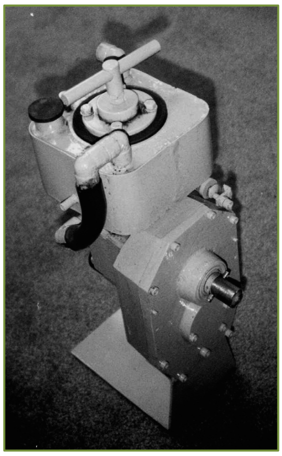


Figure 5; first 'micro diesel'

The prototype stationary prototype engine built in this period is the first engine that was considered as the ‘micro diesel’ has been

the foundation for further work. A full set of production drawings was available of this engine. Modifications made later on in the process relate to modifications of the design of this engine.
Although the philosophy of the design of the 'micro diesel' was to stay as close as possible to the original Lohmann design, some changes were made to convert the Lohmann in a stationary engine:

- A hand crank start with 1:16 gearing was added;
- Power takeoff shaft gearing was changed from 1:3 to 1:4 to enable use of lower RPM applications;
- Fuel tank was integrated in the design and combined with a water cooling around the cylinder;
- Compression adjuster handle was integrated in the cylinder head;
- A governor was added to regulate engine RPM independently from the engine load.

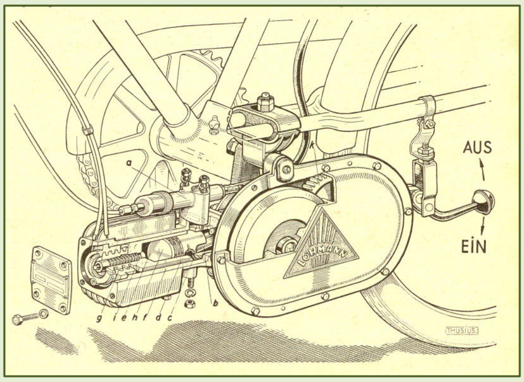
The continued work on both the proof-of-concept and the first micro diesel engine yielded important information that was the basis for continued work on the micro diesel development. The major findings and ideas based on this work include:

- Due to the engine working with compression ignition and variable compression, a 16:1 gearing is needed to start the engine using a hand crank. Rope pull start does not seem feasible;
- Starting of the prototype micro diesel has not been a problem, even in Dutch winter season;
- The engine runs best on kerosene, but running on diesel and pure vegetable oil has been achieved as well and appears to be feasible;
- The overall impression of the prototype micro diesel is that it runs surprisingly well;
- Addition of the governor on the micro diesel prototype solved the problem of two-handed operation, making it suitable as a stationary engine;
- Power output of the first engine (original Lohmann auxiliary engine) connected to a pump appeared to be less than expected: Although no power measurements have been done, the engine had insufficient power for the pump that was selected for the engine. A reduction of the impellor size solved this problem;
- The engine produces a considerable amount of smoke of which the cause was not clear;
- By displaying the engine developments on the PRACTICA website, a lot of different parties from over the world have approached PRACITCA for either a prototype, the drawings or a sort of cooperation. This interest has confirmed the idea that there was a market for such an engine;
- The producers approached in India were not very eager to pick up the concept and further developed to make it ready for production.
- In China, part suppliers and engine assemblers have been indicated that were more cooperative than their Indian colleagues, however, this had not resulted in concrete partnerships;
- The Hangzhou University of technology had proven to be capable of producing a prototype and had been responsive to questions;
- Another effort to produce a prototype based on the PRACTICA drawings was undertaken in Brazil.

TEXT BOX --- Lohmann history

The ‘Lohmann’ engine was invented by a German Engineer, Hermann Teegen (1899 – 1962) who worked on a series of engines all working with the ‘compression ignition’ principle and managed to get patents on three of the designs. This led to the development of the 18cc auxiliary bicycle engine known as the ‘Lohmann-diesel’, which was produced in the period 1949 till 1954 in the Lohmann Werke factory in Bielefeld, Germany.

The Lohmann engine was officially released on the market early 1950 after a year of testing and demonstrations with the engine. Although test reports of those days mentioned that the Lohmann was not a real diesel engine, the Lohamnn factory officially promoted the engine as the Lohmann-diesel, which helped to reach a large public.



During the time the engine was in production (1949 – 1954), the design of the engine was improved several times, resulting in different models entering the market. Those models are referred to by their year of introduction (e.g. the ’52 model), but consistent documentation of changes in the different models has not been found. Changes include:

- Improved muffler to reduce exhaust noise;
- Increased the size of the gudgeon pin from 10mm to 12mm;
- Increased the number of piston rings from 2 to 3.

Production of the different models in Bielefeld, Germany included an engine for the Spanish market under the name ‘Lohmann Hispania’ which only differed from the ’53 model on the gear cover with ‘Hispania’ logo. In 1954, a model was introduced that could run on both petrol and kerosene. The cylinder head design was slightly adapted to cope with the extra head generated. However, this model has never been a success. Till 1954, an estimated 51.000 units have been produced. It is not clear why production of the Lohmann-diesel was stopped in 1954.

Comparable compression ignition auxiliary bicycle engines have been produced in Japan, Austria (the Junior) and Sweden, all under license of Lohmann.

4. PRACTICA / RPI micro diesel development

With the cooperation between IDE and PRACTICA on the early micro diesel developments as a basis, IDE has put effort in finding opportunities to further develop the micro diesel concept as to come to large scale introduction.

RPI

An opportunity was found in the Rural Prosperity Initiative (RPI) that was funded by the Bill and Melinda Gates foundation. The purpose of this project is to develop efficient small-plot water technologies that are affordable for the rural poor earning $1 a day, and to implement value chains for high-value marketable agricultural products utilizing those technologies. This funding is used in the 2007-2010 timeframe to develop:

1) low-cost water control technologies that can be purchased without subsidy by the rural poor; that are simple, maintainable, divisible, and scalable; and that can be applied on small plots of land;

2) sustainable supply chains to manufacture and distribute the technologies and value chains to maximize the value of the agricultural outputs produced, thereby maximizing the incomes earned by the smallholders.[4]

Activities, outputs and outcomes for a number of technologies have been formulated. Based on the expected full market introduction of the micro diesel, the objectives were formulated as follows:

Table 2; proposed activities, outputs and outcomes of the micro diesel

Activities	Outputs	Outcomes (short and long term)
1. Fabricate and test five pumpset prototypes and prepare performance curves 2. Modify design to improve performance 3. Manufacture 500 pumpsets for testing 4. Field test pumpsets and monitor performance 5. Prepare business plans for supply chain establishment.	• Five prototype pumpsets built and tested • Improved pumpset design and workshop drawings prepared for production • 500 pumpsets tested • Field data collected on user acceptance and pumpset performance documented	• Proof of concept completed • Design ready for production • 500 pumpsets distributed for field testing in IDE country programs • Plans developed for mass production and dissemination of pumpsets

From the original work plan, focus has been on:

1. Fabricate and test prototypes and prepare performance curves and;
2. Modify design to improve performance;

To lesser extent, some work was executed on:

3. Manufacture 500 pumpsets for testing.

Design modifications (2)

The base model for further development of the micro diesel engine was the prototype built before the start of the RPI project (later referred to as 'prototype 1'). This design (and the technical drawings) has been optimized before building a second prototype for testing. Modifications in the design were done to simplify production of the prototype and to enable for use of other materials (e.g. use of aluminium instead of cast iron). The heart of the engine (crankshaft, cylinder, piston, etc.) has not been changed to match the characteristics of the Lohmann engine. The drawings of the improved design available as a 3D Solid Works model.

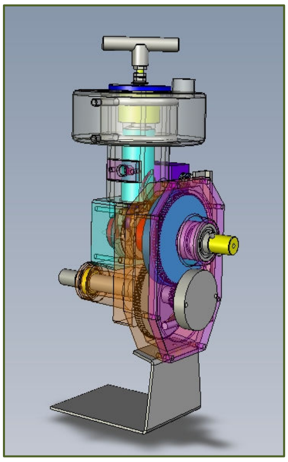


Figure 6; solid works model

Other design modifications refer to modifications of the design of prototype 1 rather than to modifications of the Lohmann engine. Modifications have been done based on test findings. Changes to the prototype engines were made to improve performance of the prototypes and results of these modifications are described under the 'prototype testing' section. As modifications made during testing have been temporary modifications as the desired performance improvements were not significant and

[4] IDE (2006); A Path Out of Poverty: Connecting Dollar-a-Day Farmers to Affordable Small-Plot Irrigation and Markets; An IDE Grant Proposal for the Bill and Melinda Gates foundation; PROPOSAL NARRATIVE; 18 August 2006

development of the micro diesel has not been continued after the prototype testing, the engine drawings have not been updated since the production of prototype 3.

Production of first series (3)

Early contacts with engine producers in India and China showed that production in China was likely to be cheaper and more feasible for engines in the range of the micro diesel. As manufacturing of the first series of 500 pumpsets in China was expected to be time consuming, contacts with Chinese manufactures that were established earlier were used in this phase of the project to start production of parts.
Within this process, a test series of pistons and crankshafts was produced. The production of the small series of parts was expected to result in:

- Experience with manufacturing in China and the quality issues related to that;
- Relationship with producers in China who could further assist with developing engine parts;
- A first series of essential engine parts that could be used for engine testing.

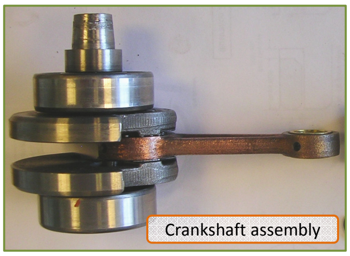


Figure 7; parts from China

The major conclusions from this effort are:

- Costs of production of parts in China are very low;
- Tolerances of the first series of pistons was not according to the drawings, indicating the importance of quality control on-site;
- Overall quality control is very difficult as direct contact with producers is not possible due to language problems;
- If production in China was to take place, local presence (or a good local agent) is essential to do quality control on the spot and to maintain a working relationship with the producers.

Further focus of the work have been on testing of the prototypes and not on production of other parts in China.

Prototype testing (1)

Overall focus of the micro diesel development project has been on performance testing of prototype engines, which has lead to the major conclusion that the Lohmann homogeneous charge compression ignition engine is not a suitable engine to drive a pump for smallholder farmer cash crop irrigation. This section describes the testing that was done on the prototype engines and the major test conclusions.

The prototypes

Prototype testing was started on three different prototypes:

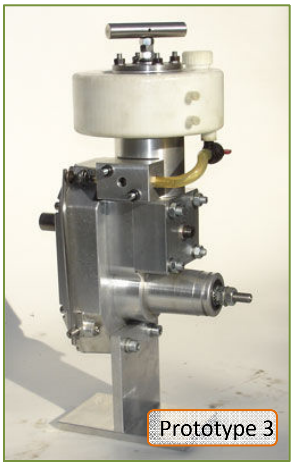


Figure 8; prototype engines

Prototype 1; the first prototype of the stationary engine built in 2003? with essential parts (piston, cylinder, crankshaft, flywheel, etc.) from an original Lohmann engine. This prototype had been used as a proof of concept and for initial testing without any output measurements.

Prototype 2; is one of the two prototypes built by the Hangzhou University of technology in Hangzhou, China. The university had plans to do testing on the prototype engines and collaborated for that with PRACTICA. This prototype engine was produced for PRACTICA for testing purpose too. The complete prototype has been produced by part suppliers in the neighbourhood of the university, except for the piston rings that were supplied by PRACTICA.

Prototype 3; was built in the Netherlands to further test and optimize the current design as on the design drawings. This prototype had to overcome problems with prototype 1 containing original Lohmann parts and prototype 2 showing poor tolerances on critical parts. Prior to production of the prototype, the set of drawings was updated, converted to a 3D model and minor changes to the design have been made (not affecting the hearth of the engine). The prototype body was machined out of aluminium solids and plastic parts were prototyped by using a 3D plastic printer. Within the prototype, the Chinese made crankshaft and piston were used.

The test equipment

The test bench was set up to measure engine torque, RPM of the outgoing shaft, fuel consumption and cooling water temperature. Initial setup was done using different sensors combined with a data

The components of the test bench include

- Hysteresis brake (compressed-air cooled): Magtrol AHB-5; rated maximum torque 5.00Nm; calibrated power supply.
- Torque sensor: Lorenz DR-2112-R; rated maximum torque 20Nm; integrated angle impulses (for RPM)
- Temperature sensor: PT100;

- Software: BMCM Nextview 4;
- USB interface: BMCM meM-ADfo;
- Measuring amplifiers: BMCM MA range and Dataforth frequency amplifier;
- Analogue volume measurement; burette with internal diameter of Ø11,6mm and stopwatch (not digitalized due to small volumes of fuel).

Initial testing with this equipment gave problems due to high vibrations of the engines, disturbing the readings of the torque sensor. As this problem was not easily solved, testing was continued without using the torque sensor and the Nextview system, but using the current readings of the calibrated power supply of the hysteresis brake. Improving the test bench was planned for continued testing activities.

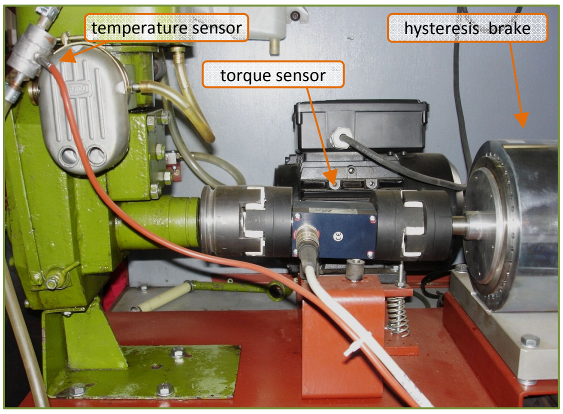
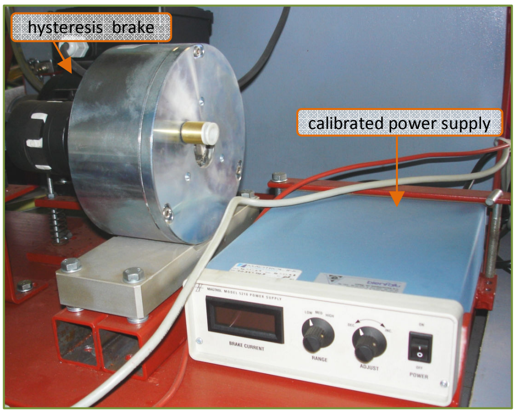


Figure 9; test setup



hysteresis brake setup

The prototype testing

Testing of the three prototypes is described in the report 'micro diesel prototype testing'. The main findings from the testing include:

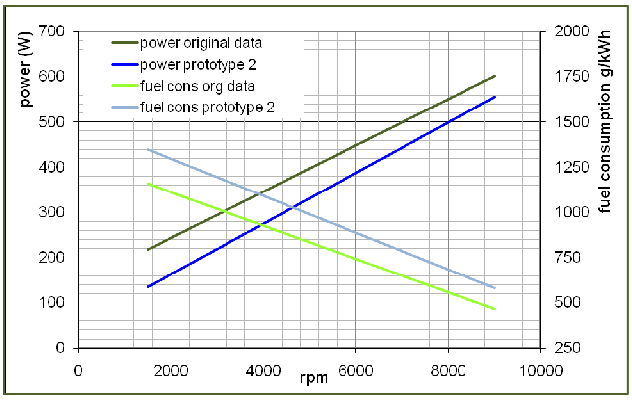


Figure 10; power and fuel consumption base test

1. **Lacking power**: the prototypes did not perform as expected, if compared to the 1950's data;
2. **Fuel consumption**: Higher than expected;
3. **Difference between prototype engines:** The three prototype engines were slightly different from each other (materials, tolerances, detailed design). Besides, the prototypes design differs from the original Lohmann design as the prototypes were modified for stationary running;
4. **Sensitivity to wear:** Reduction of compression was noticed during the testing period, which indicated wear of the piston rings and liner. Sensitivity to wear can be a major problem with small self-igniting engines, causing lower compression and thus starting problems. As feedback from Lohmann users also indicate wear

problems, wear of piston rings piston and cylinder need to be a focus point during further optimisation/testing;

5. **Stationary running:** Tests with running the engine for several hours under constant load showed problems as the engine needed regular adjustment on the compression;
6. **Emissions :** The information on the original Lohmann engine mentions that the first Lohmann auxiliary engines gave a lot of smoke when running; visually they were not very clean. During testing it was found that there was a constant blue smoke coming from the exhaust pipe. For present standards the engine is visibly unclean. Further testing and optimization of the engine need to include work on reduction of visible emissions. No quantitative emissions testing will be done until visible emissions have been brought down to visual emission levels of comparable 2-stroke petrol engines;
7. **Composition of the Fuel:** The main fuel mixture prescribed for the Lohmann engine was a mixture of kerosene and oil. Since the 1950's there is considerable doubt the composition of kerosene has changed in time. In one of the articles it was mentioned that the composition has changed in order to make it less toxic and safer for home use. The actual fuel used during the 1950 tests is unknown as the authors have not mentioned it;
8. **Data reliability:** The data found in literature was spread by the importer of the Lohmann engine (PON) and this data came from the factory producing the Lohmann engine. So far known, there has been no data check by an unbiased party.

Based on these finding, continuation of the micro diesel development was focussed around 4 themes:

1. **Wear:** To reduce or eliminate the loss of compression after prolonged running, attention has been paid to the fit of the piston and piston rings in the cylinder barrel. Major conclusion of the research around this theme is that loss of compression can be reduced by using a different piston ring slot design and different piston ring coating. Other ways to reduce wear is to study the cooling of the engine, which was not optimal. Overheating of the engine could have caused excessive wear;
2. **Emissions:** Reduction of visible emissions should be the first step before quantifying and further reducing the emissions of the micro diesel. Specific focus for reducing the emissions is on improved combustion of the fuel by better atomization in the crack case and better mixing of the fuel in the carburettor / mixer;
3. **Data reliability:** With the suspicion that the base data from the literature may not be realistic, further testing should be focused around validating the base data to quantify the performance of the prototypes;
4. **Stationary running:** With the basic difference between the Lohmann and the micro diesel being the application, it is essential that the micro diesel can run continuously without adjustment. With the hysteresis brake being a constant torque load, testing the engine with a pump load could give other results. Prolonged stationary running of the engine should be part of the testing.

Based on the results from the tests, work has taken place on all 4 themes. Within the process, major focus has shifted to the reliability of the base data.

Comparative testing of an original Lohmann bicycle engine

Based on the conclusions from the prototype testing that, even after repeated modifications, the prototypes were not performing as the Lohmann engine was said to perform in the 1950's the following assumptions were made:

1. The prototypes are all not conform the original design; that is, there is something crucial wrong with the engine that can explain the poor performance of the prototypes;
2. The performance data from the 1950's are unreliable and the actual performance of an original Lohmann engine differs from the claims.

Both assumptions seemed plausible, as:

1. The three prototypes had some variations in the accuracy of how they were built. Also some minor deviation from the original were included in the design:
    a. The inner surface of the crank case of the original engine used to have a rubbed structure, of which the function was not clear. The prototype engines did not have the same structure in the crank case, which could have influenced the performance of the engine;
    b. The carburetor / mixer of the prototype engines had been a critical part of which the design was changed due to the different setup of the engines;
    c. In the prototype engines, the cylinder is positioned vertically, whereas in the original Lohmann bicycle engine, the cylinder is positioned horizontally;
    d. In the prototype, the height of the fuel tank compared to the fuel inlet of the carburettor differs from the original Lohmann, which could affect the fuel flow to the engine.
2. Informal communication with people who worked or had worked with Lohmann engines expressed doubts about the performance of the original Lohmann engine (see also the boxed text 'What the Lohmann enthusiasts say'). Besides, it is said that in the years of industrial boost directly after the Second World War, there used to be a habit of exaggeration if it came to technical performance. In this light, actual performance of the Lohmann engine in the 1950's could easily have been less than what was claimed.

Instead of continuing the process of optimizing the prototype engines, it was chosen to acquire an original Lohmann auxiliary bicycle engine, to test this engine and to compare those test results to the claims from the 1950's.

TEXT BOX --- What the Lohmann enthusiasts say:

During the project, communication was initiated with a German Lohmann enthusiast and expert, Uwe Peters. He has shared his experiences with Lohmann engines from which he draws the conclusion that the Lohmann engine is not suitable to drive a pump and that the Lohmann has some intrinsic disadvantages that hamper further application of the concept. His arguments include:

1. The compression needs to be adjusted continuously when the engine is in operation and delivering power, which is a direct result of heating and cooling of the engine and ambient temperature. Even on the bicycle, it is not possible to drive a 10km straight stretch without adjusting the compression.;
2. Due to the high engine speed, the engine wear is too high. The cylinder lining and piston of a Lohmann engine need to be replaced every 1.500 – 2.000 km;
3. The engine is not a multi-fuel engine and does not work properly on different fuels;
4. From today's perspective, the engine's exhaust is too dirty, which is a combination of poor

combustion of the fuel and the use of two-stroke oil in the fuel.

He further concludes 'The Lohmann-Werke in Bielefeld spent 7 years working on development of this engine. The engine design was changed every year and in 1951 even three times. And although successful in producing bicycle parts, the company went bankrupt, which was the direct result of the Lohmann failure.'

Lohmann engine testing

For testing purpose, a second hand Lohmann engine was acquired (of the *Lohmann Hispania* type). The engine was opened and examined for excessive wear. The engine was in good shape and only the piston rings were replaced with new rings. The engine was cleaned and reassembled.

For testing, the engine was placed on the test stand and connected to the hysteresis brake, the electrical starting mechanism and the fuel system. Throttle and compression handles were mounted on the test stand and a forced air cooling was installed.

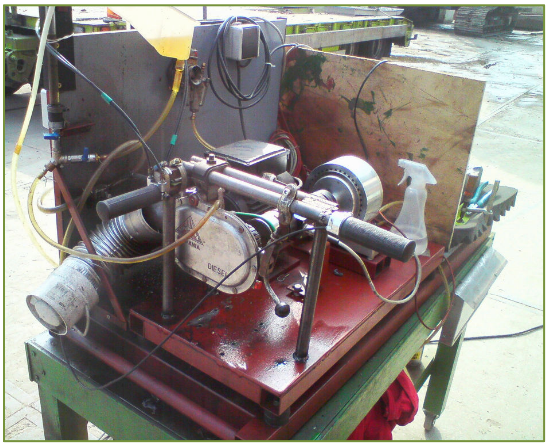


Figure 11; Lohmann diesel test setup

The objective of the test was to replicate the data as presented in the graphs in the articles that were published in the 1950's, where the same graphs for power and fuel consumption with maximum throttle related to the engine RPM are presented in different articles (see also figure 4).

Testing of the engine was troublesome as engine performance varied during the different testing sessions. This variation in performance could not be related to any specific factor, so the lower variations in the performance have not been considered in the performance curves and final results are based on the engine running at its best.
As first indicative measurement on the engine revealed a lower power output and higher fuel consumption, attempts have been made to better replicate testing conditions of the 1950's to improve both power and fuel consumption, which include:

- Varying exhaust backpressure to reduce short-circuiting of fuel;
- Adjusting the needle jet to adjust volumes of fuel and fuel air mixing ratio, also compensating for possible viscosity differences in the kerosene fuel;
- Under and overcooling of the engine to approach ideal running temperature;

Most of the mentioned adjustments did influence the running of the engine. Through indicative measurements, the optimum situation was approached, which was the basis for more extensive data collection. This test data is presented in the graphs below:

Maximum power is calculated by running the engine with full throttle under a fixed load (torque), using the compression setting to reach maximum RPM under the specific fixed load. RPM is measured. The curve is built up with a set of those data points.

Fuel consumption is calculated by stable running of the engine with full throttle at a fixed load (torque) and maximum RPM while measuring the time needed to consume a fixed volume of fuel.

From those graphs, it is clear that the maximum power is some 30% lower than claimed while fuel consumption is 50% higher (at 8500 RPM).

Based on the information collected during testing, it is not possible to explain the lack of performance and excessive fuel consumption compared to the 1950's results. Factors that might have influenced the performance of the engine include:

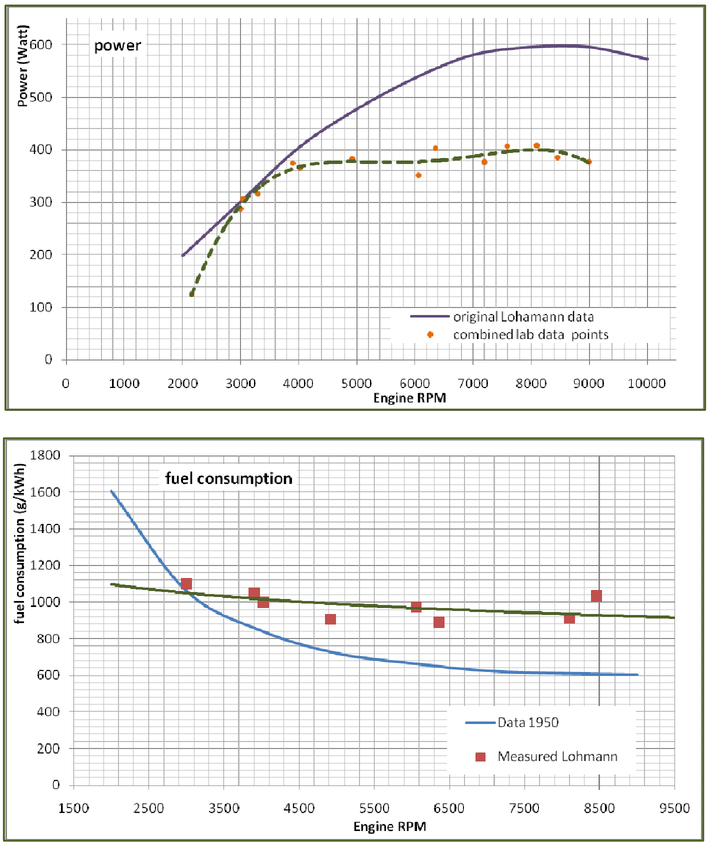


Figure 12; testing curves

- Ambient conditions: The engine was tested in outdoor conditions in Dutch spring with temperatures varying between 10 – 20 °C and humidity between 50 and 80%. Those conditions were considered as within the normal operating conditions of the engine.
- Composition of the fuel: Testing with different type of fuels was done at basic level, which included diesel and vegetable oil. Although the engine did run, there were no indications that the engine would perform significantly better with those fuels. There have been no recordings of the type of fuel used for testing in the 1950's, but there are sources that claim better engine performance by using a specific mix of fuels and oils for the Lohmann engine. Based on the assumption that use of exotic or expensive fuels or fuels with limited availability in developing countries is outside the scope of the micro diesel development, this has not been pursued.

Conclusions of Lohmann testing

The major conclusion of testing an original Lohmann Hispania engine with new piston rings and no visual indication of significant engine wear is that under normal ambient conditions and with using commercially available kerosene fuel, power output is significantly lower and fuel consumption is significantly higher than the claims made in the 1950's. Based on the test data, there is a strong presumption that the data from the 1950's is not representative for the Lohmann engine running under normal conditions and that for presentation of the data, actual figures may have been overstated.

5. Overall conclusions

The major conclusion based on the work done on the micro diesel is that further developing a micro diesel irrigation pumpset based on the 1950's Lohmann homogeneous charge compression ignition engine design is not feasible and as a result of this it has been stopped. The main reasons for this are:

1. The actual power output of both the 18cc micro diesel engine and the original Lohmann engine is lower than expected and lower than claimed in literature from the 1950's. With lower power output, the 18cc diesel engine is not the best choice for the purpose of powering a pump suitable for irrigating 0,5 – 1 ha land at static water levels up to 7m;
2. The fuel consumption of the 18cc diesel engine is higher than expected and higher than claimed in the literature from the 1950's. With the actual fuel consumption as measured in the range from 900 – 1100 g/kWh (compared to the claimed value of 563 g/kWh – see figure 12 and table 1) the engine is not an attractive alternative to other small engines with specific fuel consumption in the range of 500 g/kWh.
3. Visual emissions during the engine testing were higher than comparable small 2-stroke engines and it is expected to be very difficult to make the engine clean enough to meet the standards that apply;
4. Serious problems are expected with stationary running of the engine, due to the homogeneous charge compression ignition principle that needs constant adjustment of the compression with changing load, throttle, engine temperature or ambient temperature.

6. Recommendations

Based on the work with the Lohmann homogeneous charge compression ignition engine (pre-RPI and RPI), some recommendations can be made for further work on acquiring a small and fuel-efficient combustion engine suitable for smallholder irrigation:

The Lohmann 18cc 0,8hp HCCI engine concept

As the Lohmann engine is not suitable to be used as a stationary engine, continuing the development of a micro (diesel) engine pumpset should take advantage of the experiences with the Lohmann:

- **HCCI engines with variable compression** as the Lohmann are not suitable for stationary running when the engine compression is regulated manually. Although the variable compression should make the engine more fuel efficient at partial load, fluctuations in running conditions require adjustment of the compression. For continuation of the development of a small irrigation engine pumpset it is recommended not to use a variable compression;
- With the **engine size** of the Lohmann engine (18cc, 0,8hp) was judged to be sufficient for smallholder cash-crop irrigation at the start of the development of the micro diesel, more recent data indicate that a larger engine would better fit that purpose. The document on pumpset requirements prepared by IDE [5] elaborates on

[5] 'Small engine pumpset requirements document'; 2009; unpublished; IDE.

this. In case of further developing an engine pumpset for smallholders, the engine size should be re-considered based on the data available;

- **Clean sheet design** of a new (micro diesel) engine pumpset can be useful to overcome problems with existing engine pumpsets. However, there is currently no complete overview of existing engine pumpsets and it is possible that a suitable engine is already on the market.

Alternative engine pumpsets

It is recommended only to consider a clean sheet design after fully mapping and testing the existing alternative engine pumpsets. Alternative engine pumpsets that qualify as an fuel-efficient and low-cost pumpset for smallholder farmers can either be petrol or diesel engines. User feedback indicates that the diesel pumpsets are often preferred by famers due to lower fuel consumption and lower prices of diesel when compared to petrol, however, petrol engines are generally lighter and cheaper. Both PRACTICA and IDE have experience with small irrigation pumpsets, but the full market overview is missing. As a next step, mapping the alternatives should yield valuable information. Additional testing of a selection of engine pumpsets should indicate how those engines perform under lab and field conditions, which is essential to collect representative and comparable data.

Figure 13; field testing of diesel engine in Bihar, India

Within the scope of the micro diesel development project, field data collection on small and medium size diesel and petrol irrigation pumpsets has been done in India and Nepal. This data could be used as basis for further study.

8. Discussion

Although the Lohmann 18cc homogeneous charge compression ignition engine concept does not seem feasible as a micro diesel irrigation pump, there is still a considerable market for a small, low-cost and fuel efficient engine irrigation pumpset that can enable smallholder farmers to make the shift to mechanized irrigation. Within the IDE RPI project, alternatives have to be found for the Lohmann micro diesel.

Historically, producers of engine pumpsets aim for a higher segment of the market, that is, farmers with more land under irrigation than the 0,5 – 1 ha smallholder farmers the micro diesel is meant for. Development of products for 'the bottom of the pyramid' or 'the other 90%' is not automatically done by the market.

With all options open again, a start has been made with better describing the market and the requirements of a small engine irrigation pumpset[6], leaving the two options open of either finding a suitable engine pumpset on the market or re-starting an engine development process (clean sheet design). Continuation of the development of a small, low

[6] 'Small engine pumpset requirements document'; 2009; published by IDE.

cost and fuel efficient engine irrigation pumpset can be followed through the website of IDE[7] or PRACTICA foundation[8].

9. Other outputs available

Apart from this report, the following output documents are available as outputs of the Lohmann micro diesel development project:

- Micro diesel prototype 3D Solid Works model;
- Micro diesel prototype production drawings in pdf format;
- Test data (as far as digital data is available) in excel format;

Those outputs are open source and can be used freely according to the disclaimers attached to those documents. Outputs will be available through the PRACTICA website[9] or upon request.

[7] www.ideorg.org
[8] www.practicafoundation.nl
[9] www.practicafoundation.nl