HGCA

PROJECT REPORT No. OS6

RAPESEED OIL FOR COMBUSTION - PRACTICAL TRIALS

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RAPESEED OIL FOR COMBUSTION - PRACTICAL TRIALS

by

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Final report of a six month project carried out by Peakdale Engineering Limited. The work commenced in December 1992 and was funded by a grant of £9,230 from the Home-Grown Cereals Authority (HGCA Project No. OS16/1/92).

Contents

1 Summary

Peakdale Engineering was asked by the Home-Grown Cereals Authority to carry out practical trials of the combustion of rapeseed oil in heating burners.

Following a feasibility study completed in December 1992, the practical questions left unanswered by the feasibility study were:

a) Is it possible to fire crude rapeseed oil in conventional domestic and industrial burners?

b) What modifications must be made to such burners to permit successful combustion?

c) What are the differences, if any, between the combustion properties of rapeseed oil produced from farm-scale, medium-sized and full scale commercial extraction plants?

The aim of the work reported here was to answer these points.

The conclusions are:

Rapeseed oil can be fired successfully in conventional heating burners of about 200KW capacity and above. This is the type of burner used in industrial steam boilers and water heaters for large commercial buildings.

Rapeseed oil has been fired successfully in specialised domestic heating burners but only when blended 40:60 with class D fuels such as gas-oil or diesel.

Preliminary trials indicate that a 50:50 mixture of rapeseed oil with a class C fuel such as kerosene (which is more volatile than a class D fuel) should burn successfully in conventional domestic heating burners. The disadvantage is that kerosene is more expensive than class D fuels.

All rapeseed oil burners encounter problems with deposition of unburned oil in on-off cycling trials.

Rapeseed oil will be most successful as a combustion fuel when used in high temperature apparatus such as steam boilers.

There are no significant differences in combustion properties between the samples of rapeseed oil obtained from the three possible sources identified at (c) above.

The scope of work as established at the start of the project is attached in appendix 1.

2 Background

In December 1992 Peakdale Engineering completed a study on behalf of the Home-Grown Cereals Authority which investigated the feasibility of localised production of rapeseed oil for combustion.

The feasibility study concluded that (subject to developments in the Common Agricultural Policy) it is feasible for individual farmers to extract oil from their own rapeseed on a small scale. The cost of extraction is low enough for the rapeseed oil to be marketed as an alternative to class D heating fuels such as gas-oil or diesel.

The use of rapeseed oil in this way would provide an interesting new industrial market for rapeseed growers.

If rapeseed oil could be substituted directly for gas-oil or diesel in industrial heating applications the demand would easily consume the entire UK rape crop.

The positive environmental qualities of the fuel, in particular its low sulphur content, high biodegradeability and renewable nature mean that, even if burner modifications are required there are still likely to be significant niche customers who are prepared to spend a little more on capital cost for their burners in order to use a 'green' fuel.

The feasibility study predicted that some modifications would be required for conventional burners to burn crude rapeseed oil and concluded that practical burner trials were needed to assess the viability of this potential new market for rapeseed oil.

3 Fuel Characteristics

3.1 Oil samples

Three oils were tested in the study as follows:

Sample A

Four drums of solvent-extracted, water-degummed oil of the type normally produced as final product by a large-scale crushing plant were purchased from Unitrition at Selby.

Sample B

A drum of hot-expelled oil taken direct from the expeller and filtered with no further treatment was also procured from Selby.

This oil simulates the product which would be obtained from a medium-sized oilseed crushing unit of 300-500Kg/hr capacity, the type of unit which might be located at a centralised cooperative crop store.

Sample C

A sample of cold-expelled oil was obtained by sending 1.5 tonnes of double-low rapeseed from Sentry Farming Group to the test facility of the expeller manufacturers IBG Monforts at Monchengladbach in Germany.

Monforts processed the seed through an expeller of the type which could be used on an individual farm (model DD85G, capacity 35Kg/hr of seed).

Two drums of oil were returned to the UK. One filtered and one unfiltered. The unfiltered material was clarified at Nu-Way by settling.

3.2 Test results

Laboratory tests were carried out on the samples by City Analytical Services at Coventry and Bretby Analytical Consultants Ltd at Burton on Trent. The following results were obtained:

Test		Units	Sample A	Sample B	Sample C	Diesel
Net Calorific Value		MJ/Kg	39.1	39.2	39.3	42.5
		MJ/litre	35.6	35.7	35.8	35.3
Flashpoint		°C	326	320	322	60
Density	@15°C	g/l	910	910	910	830
Viscosity	@-10°C	cSt	410			
	@20°C	cSt	74.2			4.0
	@40°C	cSt	34.0	34.1	34.0	3.0
	@60°C	cSt	18.9			2.2
	@100°C	cSt	8.0			1.0
Sulphur content		%	<0.02			0.15 (max)

Note:

(i) The figures quoted above for diesel are standard literature values. They were not re-measured in the course of this study.

(ii) cSt is short for centistoke, a measure of viscosity. As a guide, water has a viscosity of about 1 cSt at room temperature.

3.3 Interpretation

The results demonstrate that rapeseed oil has a heating value which is 8% less than diesel per kilo but is almost exactly the same per litre (due to the difference in density between the two fuels).

The viscosity of rapeseed oil is significantly higher than diesel. Rapeseed oil viscosity also varies more with temperature than diesel.

One advantage of rapeseed oil is that it does not 'wax up' at low temperatures as diesel does. It freezes suddenly at about -15°C over a temperature range of about 1 centigrade. A sharp freezing point means that blockages due to freezing will clear much more readily than waxed-up diesel.

Rapeseed oil has a much higher flash-point than diesel.

The flash point is the minimum temperature at which a flammable vapour mixture is present above the surface of the liquid fuel. It was anticipated that this could lead to ignition problems.

4 Combustion Trial Results

Combustion trials were carried out in the development laboratories of Nu-Way Burners Limited at Droitwich. Nu-Way are the UK market leaders in medium sized oil burners.

Trials were carried out on a 400kW industrial burner suitable for use in a small boiler and on a 60kW domestic heating burner. Results are reported in detail in appendix 2.

Laboratory measurements indicated that in most respects rapeseed oil should be similar in its combustion characteristics to class D fuels such as diesel or gas-oil. However its viscosity profile is similar to heavier class E fuels. For this reason preheated burners were used for the trials. Class D fuels do not normally require preheat.

Preheated burners are more expensive to purchase and operate than non-preheated burners.

4.1 Industrial Burner

Nu-Way built one of their preheated burners (model NOH 13-23) specifically for this trial, see technical data overleaf.

The burner was mounted in a test rig consisting of a large water-cooled combustion chamber, 4 m long, 0.6m internal diameter, with a vertical stack.

Oil was fed direct to the burner from the drums in which it was delivered. The burner has its own internal oil feed pump.

Measurements were taken of:

% carbon dioxide
% carbon monoxide
% oxygen
ppm nitrogen oxides
smoke number
combustion chamber pressure
burner fan supply pressure
oil preheat temperature
oil supply pressure.

4.1.1 Combustion properties

Rapeseed oil requires a slightly different geometry of atomising nozzle (45 degree) to the type of nozzle usually specified for diesel (60 degree).

Optimum preheat temperature is about 65°C

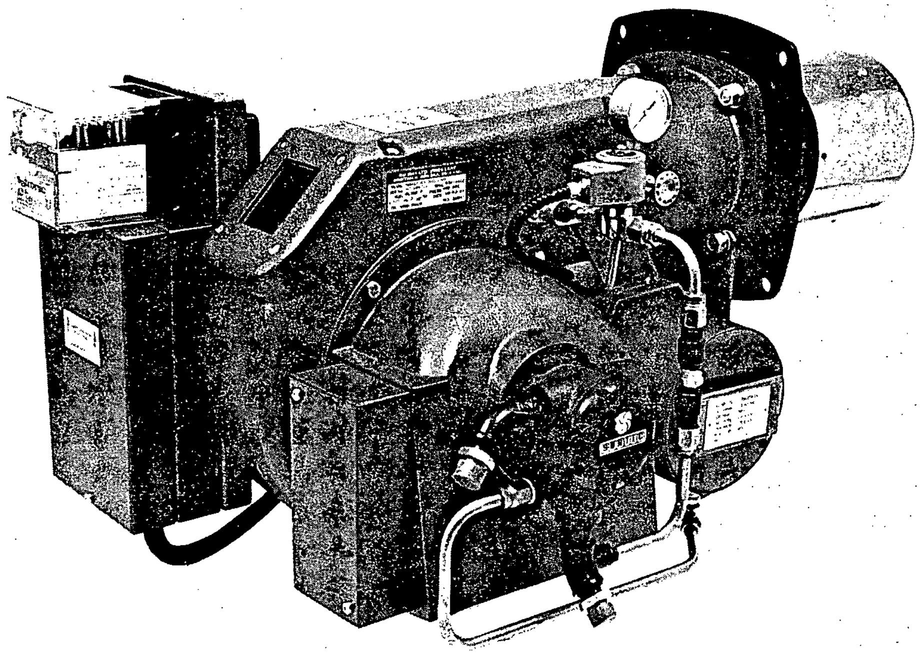
Oil pressure required for the test burner was 320 psi.

When fired continuously rapeseed oil burns cleanly, with similar flame shape and general combustion characteristics to class D fuels such as diesel.

Leaders in Burner Technology

TECHNICAL DATA

Series NOH fully automatic oil burners Models NOH 13 & 18-23



CAPACITY

The Nu-way NOH 13 and 18-23 pressure jet burner is designed for automatic operation with burner outputs from 147-542 kW (126,000 – 462,000 kcal/h): 500,000 – 1,850,000 Btu/h). Available for on/off operation only, it is designed to meet the requirements of all international markets. The burners will fire pressurised systems having resistances as listed under burner selection and also systems having a maximum draught of 0.125 kPa (13mm wg: 0.5 in wg), at full appliance rating.

CONSTRUCTION (C4)

Monobloc design, using fasteners to ISO standards. Suitable for flange mounting. Burners with hinged mounting are available as an optional extra (projection 190 only). The fan and inner assembly are accessible by removal of the top cover plate.

AIR CONTROL

Air control is by (letter box) damper. A silencer, and/or fully closing damper, can be fitted as an optional extra.

FUEL

NOH Nu-way burners are suitable for residual fuels listed below. Burner model numbers include a reference letter in them to define the fuel they have been set up for.

CLASS F. Residual Max. 20cSt at 100°C – Models NOH.

For fuel storage and handling requirements please refer to relevant Burner Manual.

FUEL SYSTEM

Use a single pipe gravity feed or oil ring main system. An edge filtration filter is supplied with recleanable element.

Fuel connection. Filter inlet connection:-
Residual oil - 1" BSP. (Fuel line to be correctly sized to suit application.)
Burners incorporate a factory set oil pre-heater unit.
Minimum oil temperature at burner inlet:
(Max. 20 cSt at 100°C) 54°C for CLASS F FUEL

CONTROLS

The burner may be controlled by suitable thermostats, time switches, frost-stats etc.
Burners are supplied complete with a pre-wired control pack. An additional separate panel is also supplied on steam-boiler applications, this containing relays, feed pump starter (direct-on-line up to 4kW with star delta above), etc., to steam boiler requirements.

SAFETY FEATURES

Flame supervision is by photo electric with sequence control.

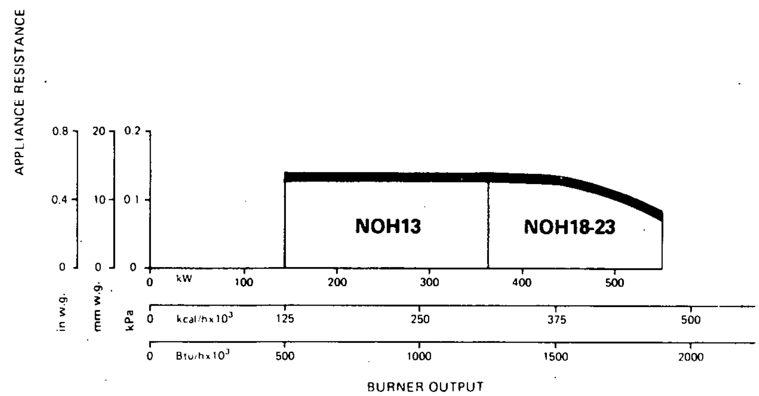
APPROX. WEIGHT

77 kg.

MODELS

NOH 13 & 18-23

BURNER SELECTION



ORDERING INFORMATION

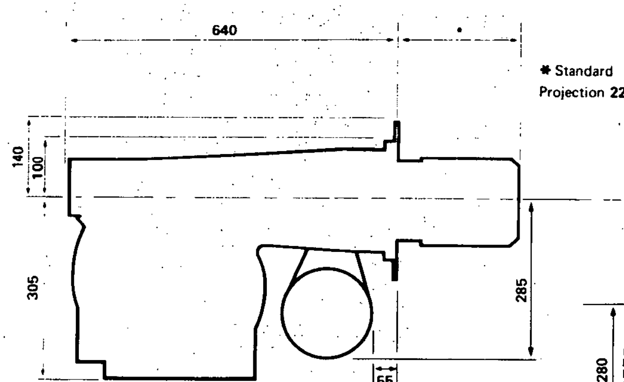
When ordering a Nu-way model NOH13 and 18-23 burner please specify the following information in order to expedite your order:
Type of appliance with which the burner is to be used.
Appliance rating and resistance.
Specification of electricity supply locally available, i.e. voltage, frequency, and whether single or three phase.
type of oil fuel

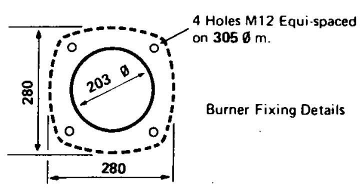
ELECTRICAL DATA

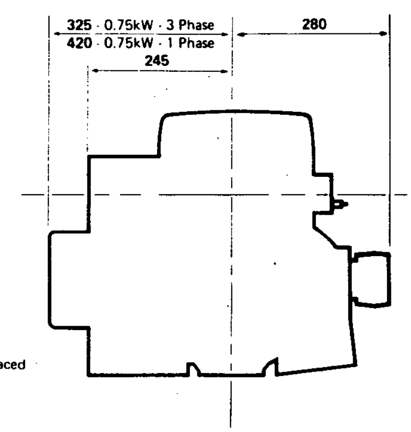
BURNER MODEL	VOLTAGE	MOTOR		PRE-HEATER K.W.	START CURRENT A/PHASE	RUN CURRENT A/PHASE	CABLE SIZE (mm^2)	H.R.C. FUSE (A)
		K.W.	H.P.					
NOH 13	1 PHASE	0.75	1.0	2.0	52.5	18.7	2.5	25
NOH 13	3 PHASE	0.75	1.0	2.0	15.2	6.3	1.5	20
NOH 18-23	1 PHASE	0.75	1.0	3.0	52.5	18.7	2.5	25
NOH 18-23	3 PHASE	0.75	1.0	3.0	15.2	6.3	1.5	20

DIMENSIONS

All dimensions are in mms.







NU-WAY Leaders in Burner Technology

NU-WAY LIMITED, P.O. Box 1, Vines Lane, Droitwich,
Worcs. WR9 8NA, England.
Tel: Droitwich (0905) 794331 & 794242
Telex: 338551 Nuway G
Facsimile: (0905) 794017

Nu-way policy is one of continuous improvement. The right to change prices and specifications without notice is reserved.

BS 5750 PART 1
CERT No. FM921
ISO 9001
EN 29001

Issue 9/90

4.1.2 Emissions

It was easy to adjust the burner to produce very low smoke and carbon monoxide levels in the discharge stack. Smoke numbers of zero were measured consistently.

Sulphur dioxide levels were not measured but the fuel has a very low sulphur content which means that it will not release significant quantities of sulphur compounds when burned.

Nitrogen oxide levels in the stack were lower than for class D fuels in the same burner. Levels measured were 45-55 ppm. Levels of 60-70 ppm would be expected for a typical class D fuel.

4.1.3 On-off cycling performance

Once the initial burner settings (preheat temperature, oil pressure, nozzle choice and air flow) had been optimised the light-up performance was tested by setting the automatic timer to switch the burner on and off in 10 minute cycles of 5 minutes on and 5 minutes off.

Although the burner appeared to light up crisply and evenly during the initial burner optimisation runs it became apparent in the cycling trials that it was taking about 1 to 1.5 seconds for the flame to develop around the burner from the igniter spark.

During this time a mist of oil drops could be seen passing out of the flame envelope and impinging on the walls of the combustion chamber.

If the combustion chamber had been hot enough these droplets would have evaporated and either burned or disappeared up the stack as vapour. However because the walls were cold the droplets collected in the base of the chamber.

After about 30 starts (5 hours) sufficient oil had collected for it to start dripping from the door of the chamber.

Several modifications were attempted in order to overcome the on-off cycling problem:

Two igniters were fitted. One on either side of the burner. This produced only a marginal improvement.

A 50:50 mixture of rapeseed oil with gas-oil was tried. Oil pressure was reduced to compensate for the higher calorific value, lower density and lower viscosity of gas-oil. The mixture burned successfully, with particularly low nitrogen oxide emissions. Preheat was still required and although the cycling performance was better some deposition of droplets in the chamber was still observed.

Finally a new oil feed system was designed to allow the burner to start-up on diesel for a few seconds then switch to rapeseed oil. This control system would cost about £150 to install on a burner of the type used in the test. The modification reduced oil impingement during the cycling trial but did not eliminate it.

The reason for the slow light-up is undoubtedly the high flash point of the fuel. More heat than is normal for a class D fuel is required before the fuel vaporises and ignites.

Once the burner is fully lit there is sufficient heat in the flame to vaporise all droplets leaving the atomiser before they can impinge on the chamber walls.

Droplet impingement should be less of a problem in applications requiring few start-ups or where the oil is fired into a chamber in which the walls are kept at a temperature above about 100-150°C.

4.1.4 Extended firing trial

It was decided not to carry out an extended firing trial due to constraints on the quantity of oil and the number of test days available after the on-off cycling problems had been tackled.

Several 4 hour combustion trials were carried out in the course of optimising the burner settings. These indicated that continuous firing of rapeseed oil should not be a problem.

4.1.5 Performance with different grades of rapeseed oil

There was no detectable difference in the combustion characteristics of the three types of rapeseed oil used in the trial.

4.2 Domestic Heating Burner

Trials were carried out using a preheated 60kW domestic heating burner fitted in the same type of test rig as described for the industrial burner.

It was not possible to achieve a satisfactory light-up despite many attempts with different burner configurations.

Several different nozzle types and a range of oil supply pressures were tried. Preheat was used up to 70°C.

Combustion of a 50/50 rapeseed oil/gas-oil mixture was also attempted, with similar results to 100% rapeseed oil.

Adjustment margins on small atomising burners are tighter than for larger units. The combination of high flashpoint and relatively high viscosity was too much for the smaller unit.

A short trial by Nu-Way at the end of the main testing programme indicated that a 50/50 mixture of rapeseed oil with kerosene should burn successfully in a conventional, unpreheated domestic heating burner.

No detailed test results on gas composition etc were taken but the mixture lit successfully and the flame was stable. The flame shape was conventional but longer than a gas-oil flame in the same burner.

In a domestic heating application the burner would have to be mounted on an extension piece to provide sufficient space in the boiler cavity to accommodate the longer flame. If the burner was operated in dual fuel mode (rapeseed/kerosene or gas-oil) the extension piece would not be likely to alter the performance when firing gas-oil.

It must be emphasised that the kerosene/rapeseed oil trial results are only preliminary. A practical demonstration in a domestic heating unit would be essential before any firm conclusions could be drawn.

5 Experience of Others

In the course of preparing for the practical trials three other organisations with experience of burning crude rapeseed oil were contacted.

5.1 MAN Brennerbau

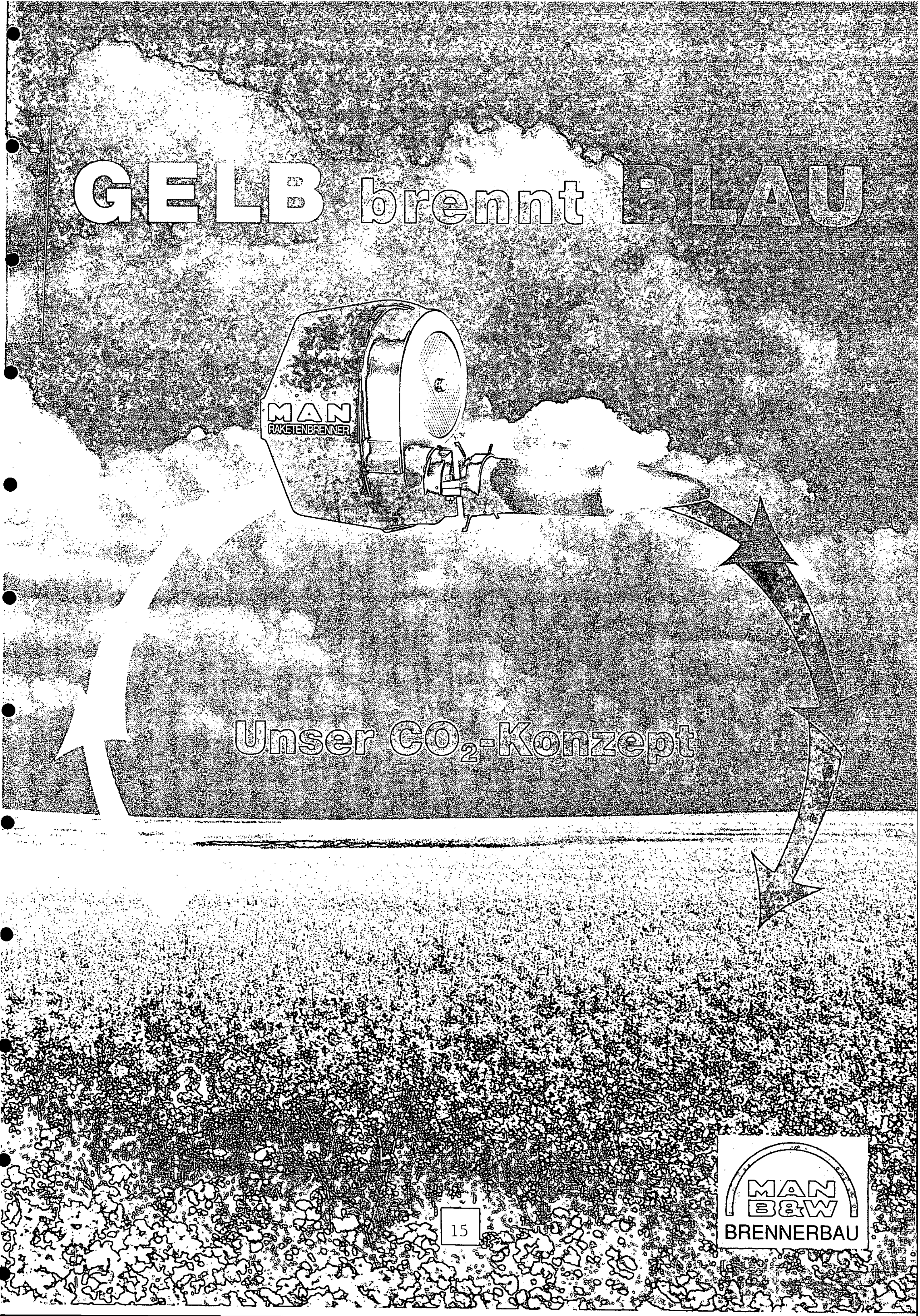
MAN Brennerbau of Hamburg market a series of 'blue flame' burners designed to run on rapeseed oil. A description is attached. These units are available in the domestic size range (15-60kW).

The burner draught tube and air supply are designed to recirculate part of the hot gases from the flame back to the base of the atomising nozzle. This helps to vaporise the fuel droplets before they ignite.

The 'blue flame' system was originally designed to produce low nitrogen oxide emissions but it provides a practical solution for fuels like rapeseed oil which are difficult to vaporise.

Further enquiries with MAN established that they do not recommend their burners for use with 100% rapeseed oil. They specify rapeseed oil/diesel mixtures up to a maximum rapeseed oil content of 40%.

MAN stated that they also observe oil deposition in rapid cycling trials, even with 40% rapeseed oil mixtures. However they do not see this to be a major problem in most practical applications.


GELB brennt BLAU
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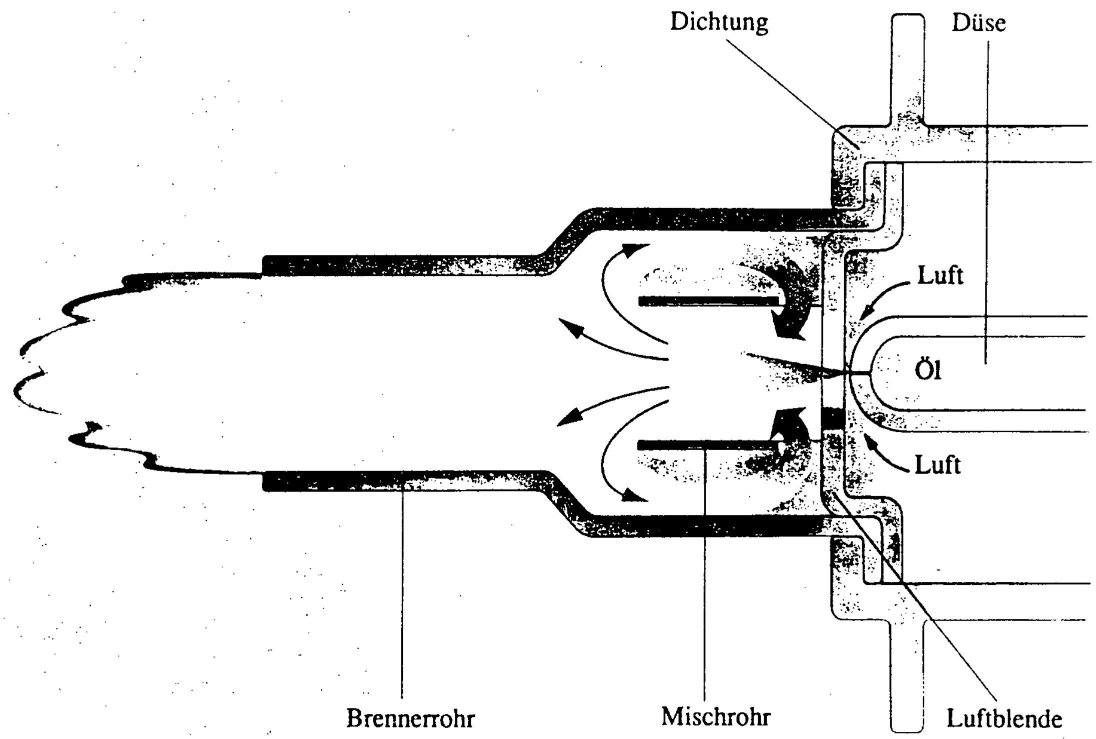

Verbrennungsablauf

1. Zerstäubung des Öles in der Düse
2. Verdampfen durch rezirkulierende Heißgase
3. Vermischen mit der Verbrennungsluft
4. Verbrennen in eigener Keramik-Brennkammer

= rußfreie Verbrennung
= optimale Energieausbeute
= niedrigste Schadstoffwerte
bei CO, NO_x und C_xH_y

5.2 Dunphy Burners

Dunphy Burners of Rochdale (Tel Mr Bob Moss, 0706 49217) have burned 100% rapeseed oil but only in burners fitted with a permanent gas pilot flame to maintain combustion.

Burners of this type are much more expensive than the units used in this trial. They are not a practical alternative for light industrial applications.

5.3 Danish Farm Advisory Service

Mr Jens Hoy of the Danish Farm Advisory Service (tel 010-45-86-10-90-88, fax 010-45-86-10-97-00) reported verbally the experience of his organisation.

They asked a Danish agricultural college to carry out combustion trials using pure rapeseed oil in a domestic heating burner.

The college was able to ignite the fuel in a domestic burner but heavy deposition was observed in cycling trials and the experiment was abandoned.

The Danish Farm Advisory Service are not planning to publish or circulate their report on these trials.

6 Fuel Handling Requirements

Rapeseed oil is relatively simple to handle as a fuel.

Its high flashpoint means that no special precautions need to be taken in the design of storage tanks to control escapes of flammable vapour.

Tank heating is not required for installations in the UK because rapeseed oil has no tendency to wax up. It has a low freezing point at about -15°C.

Store tanks should be enclosed, with minimum access for air and sunlight to prevent degradation of the fuel in storage.

Fuel transfer pipes between store tanks and burners should be of larger diameter than conventional fuel pipes to allow for the higher viscosity of rapeseed oil.

The fuel is biodegradable so spillages are not a major issue.

7 Burner Costs

7.1 Operating Costs

Rapeseed oil burners cost slightly more to run than burners for conventional class D fuels because of the requirement for electrical preheat.

The power requirement is approximately 0.04KWhr per litre of oil (assuming 25% heat losses), adding 0.25 pence per litre to the cost of using the oil.

7.2 Capital Cost

Budgeted capital costs for preheated and conventional versions of the 400kW Nu-Way burner used in these trials are as follows:

Preheated	£1760
Conventional	£ 810

A budget price for a 60kW domestic scale 'blue flame' burner from MAN to run on 40:60 rapeseed-diesel mixture is £500.

A conventional 60kW burner from Nu-Way costs approximately £140.

8 Conclusions

Rapeseed oil can be burned successfully as an alternative to gas-oil or diesel in medium scale industrial oil burners.

Minor modifications to burner settings and the addition of an oil preheater are required.

Deposition of unburned oil is likely to be a problem in applications where:

- Frequent start-ups of the burners are required
- The burner is fired into a low temperature combustion chamber.

Storage of rapeseed oil is straightforward.

Capital cost for preheated burners capable of burning rapeseed oil is significantly greater than for conventional oil burners.

Additional operating costs are about 0.25p per litre.

Combustion of 100% rapeseed oil in conventional domestic burners has not been carried out successfully. However MAN Brennerbau in Germany offer domestic 'blue flame' burners capable of burning 40/60 mixtures of rapeseed oil with diesel. A preliminary trial by Nu-Way Burners indicated that it should be possible to burn a kerosene/rapeseed oil mixture in a conventional domestic heating boiler with only minor modifications.

There are no significant differences in combustion properties between rapeseed oil samples extracted by different methods.

For further details please contact:

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9 Acknowledgement

Peakdale Engineering would like to thank the following companies for their help and advice in carrying out this study:

Nu-Way Burners Ltd, Droitwich. In particular Mr David Cadwell, Research and Development Manager and Mr Trevor Goodhall, Research Engineer.

IBG Monforts, Monchengladbach, Germany. In particular Herr Dimpker, General Manager.

Appendix 1 - Scope of Study

The following terms of reference were established at the start of the study:

The combustion trial will use rapeseed oil produced by three different extraction methods.

Fuel handling problems and combustion efficiency will be investigated for rapeseed oil produced from the following sources:

1. Cold-expelled oil from a small (35Kg/hr) expeller of the type which could be used on a farm. The oil will be clarified by settling and decanted before use without filtration.

2. Hot-expelled oil from a large commercial expeller of the type operated by one of the large UK seed crushers. The oil will be taken direct from the expeller and filtered before use. No further purification or treatment methods will be used.

3. Solvent-extracted, water-degummed oil of the type supplied as final product by one of the three large UK seed crushers.

The aim of the study is to establish the combustion performance of these oils in both industrial scale burners and domestic heating burners.

The project is to be organised in three phases:

a) Analysis of the oils
b) First order combustion trials
c) Longer firing studies

a) Analysis

A detailed fuel oil analysis will be carried out to establish chemical and physical properties for each of the oils.

b) First Order Combustion Trials

The same procedure will be used for each of the three oils described above:

A 400kW preheated burner will be built specially for the trial by Nu-Way. The aim will be to establish ignition/light-up characteristics and optimised burner settings including preheat temperature, excess air and feed pressure.

During each run the following parameters will be measured:

- carbon dioxide
- oxygen
- carbon monoxide
- nitrogen oxides
- smoke

Trials will also be carried out on a 50/50 mixture of the cold-expelled rapeseed oil with conventional gas-oil.

c) Extended Firing Study

If the first order trials are successful an extended firing study will be carried out.

The aim will be to observe any tendency for the preheater, burner head or atomiser to foul up.

Appendix 2 - Detailed Results

DETAILS OF BURNER

A standard Nu-Way NOH13-23 oil burner, specification no. S32-410Z, serial no. 40-2265 was constructed for the trial. This unit has a maximum firing rate of 400kW but was set to run at 300kW for the trial.

The burner was fitted to a 0.6m diameter water cooled test tank.

Oil sample descriptions are as defined in section 3.1 of the main report.

METHOD

Sample A

The burner was fired using sample A rapeseed oil. Ignition occurred cleanly. Excess air fed to the burner was varied using the inlet damper for a range of oil preheat temperatures. The same procedure was used for each of the oil samples tested. The following results were recorded:

Nozzle: Monarch 4.5 USG x 60 degree PLP
Oil pressure: 320psi

Preheat 68-76°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
5.5	12.3	8	55	0	+1.3	35.0
5.5	12.5	6	56	0	+0.7	33.5
5.2	13.5	8	48	0	+0.4	31.5
4.5	13.9	8	51	0	0.0	27.5
3.4	14.6	7	56	0	-0.2	25.5
2.9	14.9	9	54	1	-0.4	24.0
2.3	15.1	300	41	4	-0.8	22.0

The amount of preheat was then reduced and the tests repeated.

Preheat 55-67°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
5.7	11.8	7	42	0	+1.6	41.5
4.8	13.7	8	50	trace	+0.9	35.0
4.0	14.3	8	46	0-1	+0.8	34.0
3.0	14.6	8	43	1	+0.5	30.5
2.5	15.0	18	50	3	0.0	28.5

Start-up cycle

A start-up cycle was started, 5 mins on, 5 mins off. After 36 starts (6 hours) oil was observed dripping from the combustion chamber door. The test was abandoned.

An inspection revealed free oil lying in the bottom of the combustion chamber and that flame impingement on the edge of the blast tube had occurred. Various nozzles were tried in an attempt to overcome this problem. The best results were obtained with a Monarch 45 degree PLP.

Sample B

The initial combustion tests were repeated for oil sample B.

Nozzle: Monarch 45 USG x 45 degree PLP
Oil pressure: 320 psi

Preheat 73-83°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
7.5	10.9	8	54	0	+2.2	44.0
6.0	12.2	8	41	0	+1.1	37.0
5.0	12.8	8	52	0	+0.8	33.0
3.8	14.4	9	50	0	-0.2	26.0
2.9	15.0	10	45	1	-0.5	24.8
2.1	15+	400	45	2-3	-0.7	21.0

The amount of preheat was reduced and the tests repeated.

Preheat 64-73°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
6.8	11.4	8	43	0	+2.0	42.5
5.3	12.8	9	47	0	+0.7	33.5
3.8	14.3	9	43	0	-0.2	25.5
2.8	15+	10	49	1	-0.5	23.5

No significant differences were observed between the combustion properties of samples A and B.

Blast tube impingement and combustion tube wetting were still observed in the on-off cycling trial.

Further attempts were made to rectify the cycling problem.

The problem seemed to be rectified by substituting the standard blast tube with a shorter tube (part no L04-096X), closing the diffuser slots to 1.5mm and closing the primary air band to minimum. After a few light-ups the combustion tube and blast tube were inspected. No droplet impingement was observed in the chamber although the combustion tube was still wet.

Observations of the light-up revealed that, during ignition, oil mist was passing out of the flame before the flame was fully established and hitting the walls of the chamber. The operating temperature of the walls was insufficient to vaporise or burn the free oil.

Temperature appears to be important, both for lighting the oil and to prevent the combustion chamber from fouling.

It was not possible to shut off the combustion chamber cooling water supply during the burner 'off' periods in order to keep it warm. The wetting problem could probably have been resolved with a warmer chamber.

Sample C

Sample C oil was connected to the test burner with modified combustion head. The previous tests were repeated.

Nozzle: Monarch 45 USG x 45 degree PLP
Oil pressure: 320 psi

Preheat 73-81°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
5.8	11.8	12	46	0-1	+1.2	49.0
5.4	12.9	10	37	0-1	+0.7	42.0
4.5	13.3	10	39	0	+0.2	38.0
3.4	14.0	10	39	0	0.0	34.0
3.0	14.9	12	42	2	-0.4	29.5

An inspection after the test revealed that the blast tube was clear of impingement but the chamber was still damp.

Again there was no significant difference between the combustion properties of this oil and the other two sample oils tested.

50/50 mixture Sample C with 35SRI grade gas-oil

The tests were repeated with a 50/50 rapeseed oil/gas-oil mixture to check whether it could be burned without preheat. The burner proved difficult to ignite but the following test was taken.

Nozzle: Monarch 45 USG x 45 degree PLP
Oil pressure: 295 psi
(oil pressure was reduced to compensate for the calorific value, viscosity and density of the gas-oil)

Preheat - none

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
5.8	12.0	12	41	0-1	+2.2	60.0
5.3	12.8	11	42	0-1	+1.6	52.5
4.5	13.4	11	38	0-1	+1.1	48.0
3.8	14.0	11	38	1-2	+0.6	43.0
3.2	14.5	11	39	2	+0.4	40.0

Oil was observed dripping from the tank door throughout the test. On inspection oil impingement on the blast tube was found. The preheater was reinstated and the test repeated.

Nozzle: Monarch 45 USG x 45 degree PLP
Oil pressure: 295 psi

Preheat 62-74°C

%O2	%CO2	CO ppm	NOx ppm	Smoke No	Combustion Chamber P mm WG	Fan Static P mmWG
5.5	12.2	9	46	0-1	+0.4	40.0
5.1	12.7	9	46	0-1	+0.1	36.5
4.2	13.4	9	40	1	-0.2	33.5
3.6	14.1	10	44	2	-0.5	30.0
	14.7	35		off chart		

At the conclusion of the test the blast tube was found to be clear but the chamber was still damp.

A final attempt was made to resolve the cycling problem by designing a new fuel supply system which allowed the burner to start up on gas-oil then switch to rapeseed oil.

A secondary fuel pump was placed next to the burner. By using two additional oil valves the burner could be made to light and run on gas-oil until the flame was established, then switch to rapeseed oil after a predetermined time.

The unit was fired and adjusted as follows:

	gas-oil	rapeseed oil
Preheat temperature	ambient	82-92C
Oil pressure	210psi	320psi
%CO2	11.9	14.3
%O2	6	4
ppm NOx	45	49
Smoke No	3	0-1

The combustion head configuration required to burn rapeseed oil is different to that required for gas-oil. The head was optimised for rapeseed oil, hence the high smoke number of 3 observed for the gas-oil during start-up.

The timers were adjusted to give approx ten minute cycle time as follows:

Purge time	0 min	40 sec
Gas-oil	2 min	3 sec
Rapeseed oil	2 min	22 sec
Off time	5 min	1 sec
TOTAL	10 min	6 sec

An on-off cycling test was started. After about 20 starts (3 hours 20 min) oil began to drip from the test tank door, which was an improvement over the previous tests.

Appendix 3 - Fuel Categories

Combustion fuels are classified into groups for ease of identification. The categories are related to both combustion and physical properties. The formal definitions are complex but generalised features of the fuel classes of interest in this study are as follows:

Class C fuels	Relatively volatile and low viscosity examples are kerosene and aviation fuel
Class D fuels	Less volatile, more viscous and less expensive than class C fuels examples are gas-oil and automotive diesel
Class E fuels	Low volatility, viscous (require preheating in most burners), less expensive than class D fuels an example is heavy fuel oil